QUALCOMM

Qualcomm, Inc.

LTE Advanced

An evolution built for the long-haul

October 2013

Disclaimer

QUALCOMM is a registered trademark of QUALCOMM Incorporated in the United States and may be registered in other countries. Other product and brand names may be trademarks or registered trademarks of their respective owners. This technical data may be subject to U.S. and international export, re-export or transfer ("export") laws. Diversion contrary to U.S. and international law is strictly prohibited.

Qualcomm Incorporated

5775 Morehouse Drive

San Diego, CA 92121

U.S.A.

Table of Contents

1 Executive summary

With the critical milestone of 100 Million connections[1] reached and more than 200 networks deployed[2], LTE is on a strong growth path. Being a common global standard for paired and unpaired spectrum (LTE FDD and TDD) resulting in a common ecosystem, LTE has had a unifying effect and is lining up the whole industry behind one common goal.

On the heels of the tremendous success of LTE, Industry leaders have already gotten a head start in LTE's next step—LTE Advanced. The first step of LTE Advanced—carrier aggregation—was launched in June 2013, powered by third-generation Qualcomm Gobi™ modems integrated into Qualcomm Snapdragon™ 800 chipsets, from Qualcomm Technologies, Inc.

LTE Advanced, true to its name, packs an impressive collection of advanced features, that can meaningfully grouped in to three categories: 1) Carrier aggregation that bonds multiple carriers together to provide extremely high data rates across the cell coverage age; 2) Advanced antenna techniques to improve spectral efficiency; 3) Above all, HetNet optimizations to bring more out of small cells. Carrier aggregation from its humble beginning of two 10 MHz that was launched in June 2013, will evolve in to many directions, many bands, many types so that operators can utilize all spectrum assets they have access to. Advanced antenna techniques leverage more antennas on the device to offer higher data rates and capacity. HetNet optimizations such as "Range expansion" made possible through advanced interference coordination and cancellation ensure that increase in capacity scales with the densification of small cells.

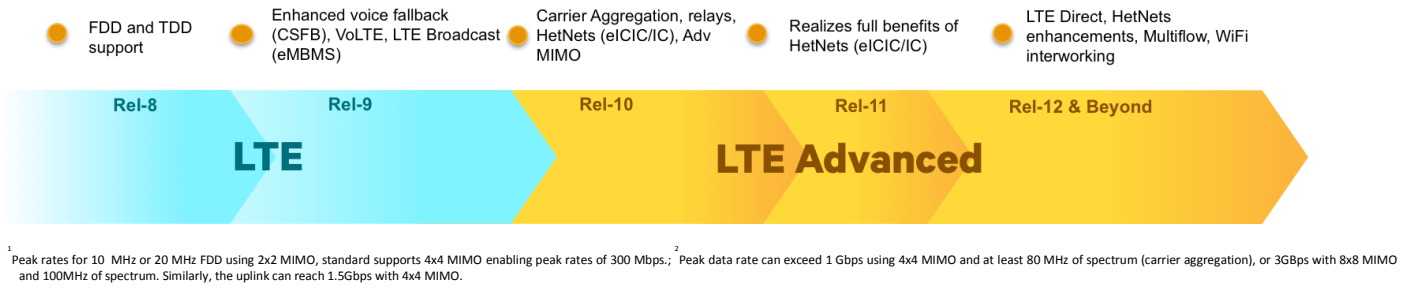
LTE Advanced is shaping up to be a pervasive technology with solutions that not only meet the ever-increasing data demand of traditional mobile broadband services, but also open up opportunities to transform new industries. Direct device-to-device proximity based services, addressing unconventional spectrum, are some such early examples. This paper discusses the many dimensions of benefits LTE Advanced brings in, the new horizons it is poised to explore, and how it is an evolution for the long-haul.

Qualcomm, with its demonstrated ability to foresee and solve seemingly impossible wireless challenges, is at the forefront of LTE evolution, not only envisioning, but also inventing, developing and commercializing technologies that bring our vision to fruition. Our quest to develop solutions to increase the data capacity of today's networks by 1000-times (what we call "the 1000x mobile data challenge"), and being first to commercialize LTE/3G multimode and now LTE Advanced (carrier aggregation) are vivid and recent proof-points of such thought leadership. Qualcomm is one of the main contributors to LTE Advanced standards development and was among the first to prototype and demonstrate the benefits of LTE Advanced HetNets using our state-of-the-art over-the-air small cell test network at San Diego

2 LTE Advanced is here

LTE Advanced is the next milestone in the evolution of LTE, starting from 3GPP Rel. 10, as shown in Fig. 2.1

[1]LTE/3G connections reached 100 Million in May 2013, source – Wireless Intelligence; [2] as of Aug, 2013, source www.gsacom.com



[1] Peak rates for 10 MHz or 20 MHz FDD using 2x2 MIMO, standard supports 4x4 MIMO enabling peak rates of 300 Mbps.; [2] Peak data rate can exceed 1 Gbps using 4x4 MIMO and at least 80 MHz of spectrum (carrier aggregation), or 3GBps with 8x8 MIMO and 100MHz of spectrum. Similarly, the uplink can reach 1.5Gbps with 4x4 MIMO.

Fig. 2.1: Strong LTE evolution

As can be seen, the evolution of LTE is a well thought-out roadmap with releases providing successively improving capabilities that result in higher and more consistent data rates for users, higher capacity, and a better overall user experience. The first step of LTE Advanced—carrier aggregation— was commercially launched in June 2013. It was powered by third-generation Qualcomm Gobi™ modems, integrated into Qualcomm Snapdragon™ 800 solutions. From standards perspective, the first phase of Rel. 12 is already complete and the second phase is in full swing and expected to be completed by end of 2013. So, indeed LTE Advanced is already here! And also has a long way to go on the evolution path.

3 The three dimensions of improvements of LTE Advanced

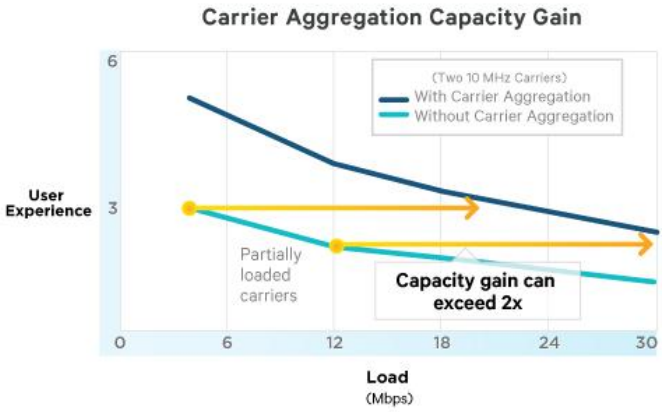
True to its name, LTE Advanced incorporates multiple dimensions of enhancements which can be grouped into three major categories:

1) Carrier aggregation to leverage more spectrum and increase data rates (bps)
2) Advanced antenna techniques to increase spectral efficiency (bps/Hz)
3) HetNets to bring most benefit out of small cells and increase capacity on per coverage area basis (bps/Hz/km^2)

Although, each of these enhancements has its role to play to increase capacity and improve the user experience, the most gain comes from optimizing HetNets.

3.1 Carrier aggregation and its evolution

Carrier aggregation, as the name suggests, combines multiple carriers (a.k.a. channels) at the device to provide a bigger data pipe to the user. A bigger data pipe means higher data rates, both peak (as high as over 1 Gbps) and, more importantly, higher user data rates across the cell coverage area. The higher data rates can be traded off to get increased capacity for bursty applications such as browsing, social media apps, smartphone usage and more.



Source: Qualcomm simulations, 3GPP simulation framework, FTP traffic model with 1MB file size, 57 macro cells wrap-around, 500m ISD (D1), 2x2 MIMO, TU3, NLOS, 15 degree downtilt 2GHz spectrum.,

Fig. 3.2: Carrier aggregation capacity and user experience (data rates) tradeoff

As a first step, the commercial launch supported aggregation of two 10 MHz carriers, enabling a 150 Mbps peak data rate (Cat 4 terminals). This doubles the user data rates across the cell, whether the user is close to the cell or at the cell edge. These higher data rates can also be traded off to provide twice (or more) the capacity for bursty apps, while keeping the same user experience, under typical loading conditions, as illustrated in Fig 3.2. Thanks to trunking efficiency, when you keep the user experience same (i.e. same burst rate), the cell can instead support more users for partially loaded carriers. The gain depends on the load and can exceed 100% for less loaded carriers.

From today's two 10 MHz configuration, carrier aggregation will evolve in many directions enabling operators to use utilize all spectrum resources, be it lower bands, higher bands, paired or unpaired. This becomes very apparent when ones looks at the variety of spectrum bands being targeted for LTE across the globe. In the near term, there could be aggregation across more carriers—up to five defined in LTE Advanced—and more band combinations—more than 45 being defined in 3GPP; aggregation in the uplink etc. There is currently work going on to facilitate aggregation across cells on the same carrier for load balancing, called MultiFlow; aggregation across paired and unpaired spectrum (LTE FDD and TDD) and many more.

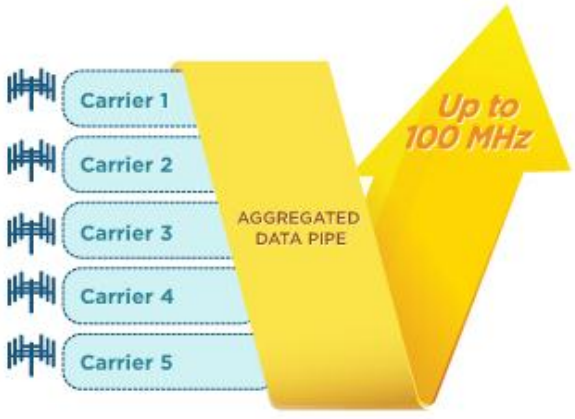


Fig. 3.3: LTE Advanced supports carrier aggregation of up to 5 carriers (100 MHz)

The proliferation of small cells and their dense deployment envisioned will add a new dimension to carrier aggregation. For example, higher spectrum bands that provide smaller coverage footprint will prove highly beneficial in enabling extremely dense small cell deployments. Carrier aggregation will be a glue to bind the lower band marco carriers with higher band small cell carriers, many of which are also unpaired. With all these possibilities, It is safe to say that the current aggregation across two 10 MHz carriers is only the beginning.

3.2 Advanced antenna techniques for higher spectral efficiency

A popular axiom is "the more antennas, the better it is." But the challenge is to fit all of those antennas for all the technologies, in a small device form factor. We believe that the natural next step from today's commercial 2x2 MIMO configuration is to go to four antennas, specifically, four-way receive diversity (standard supports up to 8x8 MIMO). As shown in Fig. 3.4, four-way receive diversity provides most of the gains that can be achieved with four antennas. What makes four-way receive diversity

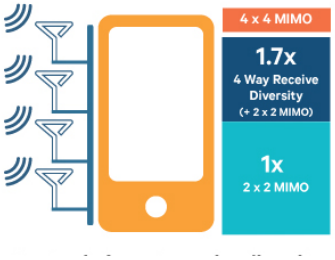


Fig. 3.4: four-way diversity provides most gains

worthwhile is that it's a device-only feature that does not require any standard change or change in network infrastructure. This makes it much easier for operators to deploy and reap the benefits. Of course, the capacity gains scale with the penetration of such devices in the system.

Another interesting technique called CoMP (Coordinated MultiPoint) is also available for fiber installations with a centralized processing and scheduling facility. What CoMP essentially does is to coordinate the scheduling and transmission of resources between various cells (or Remote Radio Heads) so that the interference is minimized, thereby increasing capacity and improving the user experience. Since all the processing and scheduling is centralized, it indeed needs low-latency fiber connections between the processing/scheduling facility and the cells

3.3 HetNets – bringing more out of small cells

As mentioned before, optimizing HetNets is the most important component of LTE Advanced. It is becoming increasingly more evident to most of the industry; small cells are the future—all different kinds, shapes, and technologies—deployed everywhere, wherever people and machines use broadband. Small cells are simply a convenient way to add capacity wherever and whenever needed.

Adding small cells to the network seems like a simple thing to do. But each cell added has a profound effect on the overall network, both with the increased capacity it brings as well as the interference it generates. This effect is even larger when you consider the hyper-dense small networks being envisaged for the future.

LTE Advanced brings a robust suit of interference management tools to address the interference; resulting in what we call "Range Expansion." Range Expansion is essentially a way to extend the reach of small cells so that they cover more and more users in their vicinity. It is critical for two equally important reasons: 1) more users who can be better served by small cells (than the macro) are being connected to them; 2) more users can be offloaded from macro network (to small cells) freeing up resources for the users on the macro.

Consequently, these actions increase the data rates for users on both small cells and the macro network, thereby improving their experience as well as increasing overall network capacity. Range Expansion can double the capacity of HetNets without any additional spectrum or infrastructure, as shown in Fig. 3.5.

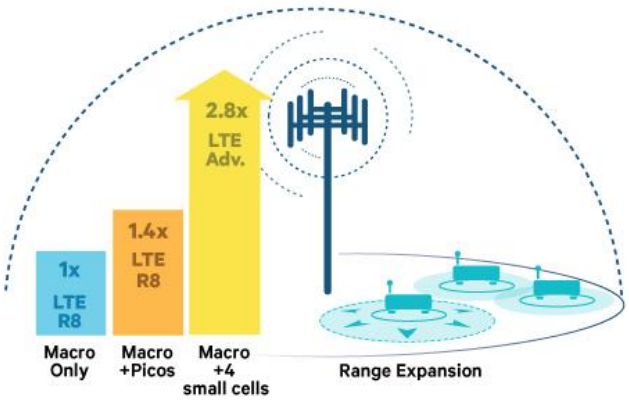


Fig. 3.5: Range Expansion can double capacity of HetNets

Range Expansion is enabled by two key features—eICIC (enhanced Inter Cell Interference Coordination)[3] from the network side, and IC (Interference Cancellation) from the device side. The former is, essentially, cells coordinating resources among themselves to minimize interference and the latter is devices with advanced receivers cancelling overhead/signaling channels so that devices can discover small cells even at very low

[3]In 3GPP Rel 11, this feature is called as FeICIC (Further enhanced ICIC)

signal level (low signal to noise ratio). Together these two make sure that every added cell brings in more capacity, while minimizing the interference. In essence, LTE Advanced ensures that the overall network capacity scales with the densification of small cells.

Qualcomm has an established leadership in the HetNets space. We envisioned the key role that HetNets will play in the future of wireless and have been steadfastly developing, prototyping and demonstrating innovative technologies since 2011, the time when the industry was still buzzing around the promise of 1 Gbps peak rates that LTE Advanced imparts. We have used our state-of-art over-the-air LTE Advanced small cell network in our San Diego campus to show the benefits of HetNets at many global events through live demonstrations. Qualcomm is also a main contributor to the LTE Advanced standards and, of course, as evidenced many times, is usually the first to bring these technologies to commercial reality

4 Role of LTE Advanced in addressing the 1000x mobile data challenge

The meteoric rise of mobile data traffic in the last few years has forced the industry to seek effective solutions to address the growing demand. Qualcomm is leading the charge through its compelling technologies and path breaking innovations in preparing the industry to meet what we call the *1000x mobile data challenge*— the challenge to increase data capacity of today's networks by 1000-times. As illustrated in Fig. 3.6, our vision to solve the 1000x challenge has three major components, and LTE Advanced plays a key role in all of them.

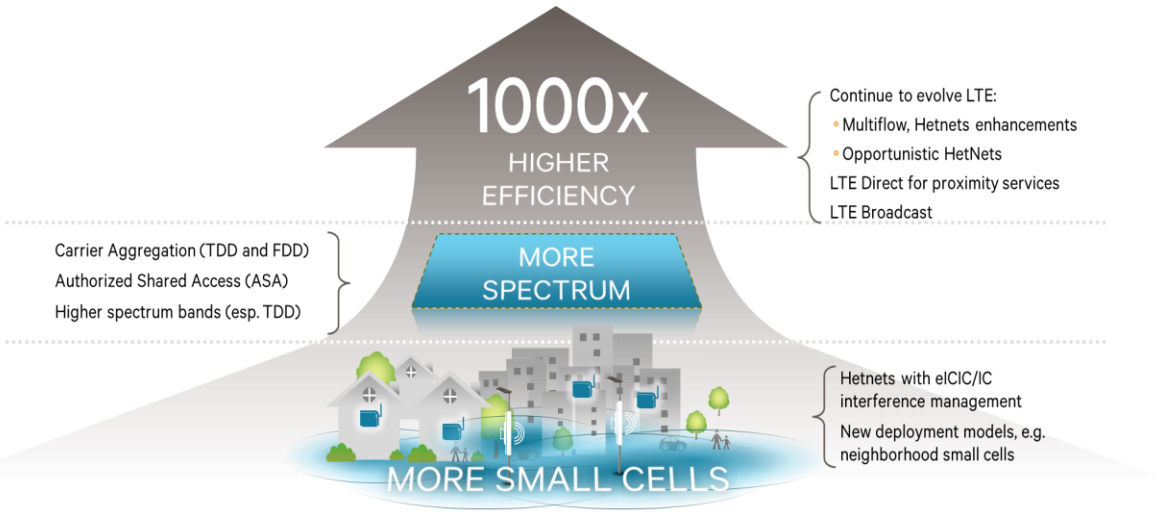


Fig. 3.6: LTE Advanced plays a key role in addressing the 1000x mobile data challenge

Additionally, LTE Advanced enables many new and innovative approaches and new deployment models which are crucial to solve the challenge that is of the magnitude as 1000x. Small cells are at the heart of the solutions to the 1000x challenge. Specifically, hyper-dense deployments of small cells. LTE Advanced makes this possible through its advanced interference management techniques (eICIC/IC). As illustrated in Fig. 3.7, LTE

Advanced ensures that capacity scales with the densification of small cells. LTE Advanced interference management techniques along with other enhancements that Qualcomm develops enable a new ad-hoc deployment model called “Neighborhood small cells.”

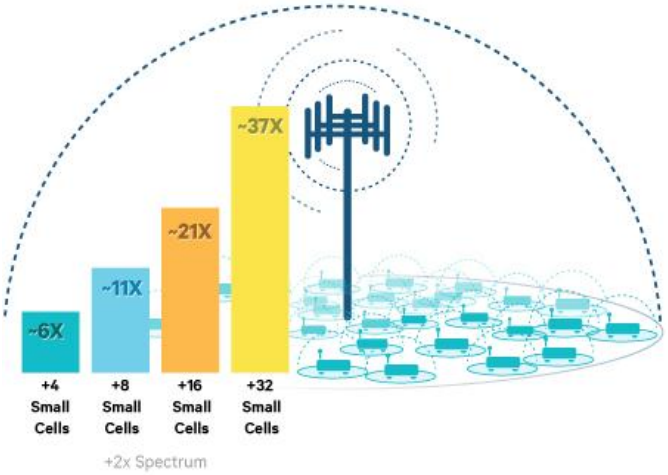


Fig. 3.7: LTE Advanced ensures capacity scales with small cell densification

As discussed in section 3.1, LTE Advanced carrier aggregation enables utilization of many new spectrum bands, including higher and unpaired bands. It is also a part of a new complementary licensing approach to access underutilized spectrum called “Authorized Shared Access (ASA).” ASA is a framework for 3G/4G operators and incumbent spectrum holders to share underutilized spectrum (e.g. naval radar) in terms of location or time on an exclusive and licensed basis.

LTE continues to evolve to successively increase efficiency across the network. It is introducing new as well as improving many existing features that make LTE Advanced suitable for various applications. Section 5 discusses this evolution in detail.

To learn more details about the 1000x mobile data challenge, Neighborhood small cells and ASA, please visit our webpage www.qualcomm.com/1000x.

5 LTE Advanced evolution – Rel. 12 and beyond

LTE Advanced is continuing to evolve. From the standards perspective, 3GPP Rel. 12 development is in full swing and expected to be completed by end of 2013. The evolution includes many organic, evolutionary components as well as revolutionary approaches that can potentially transform industries not yet touched by LTE.

HetNets continue to be one of the main focus areas. There are features allowing combining carriers across cells, called MultiFlow, and even combing across LTE (as well as HSPA+) and Wi-Fi; features such as opportunistic small cells that dynamically switches small cells ON and OFF to reduce interference; features to further improve device interference cancellation and more. Seamless interworking with Wi-Fi is another focus area. There are also enhancements to address the burgeoning machine-to-machine market.

Above all, LTE technology is poised to extend its influence into many new horizons beyond mobile broadband, be it new industries, new applications/services or new, unexplored spectrum bands. LTE technology is versatile and robust enough to morph itself to suit the needs of these areas, while still maintaining its basic tenets of high efficiency and excellent user experience. Early indicative examples of such upcoming transformations are LTE Direct, a new proximity-based device-to-device technology, and LTE Broadcast enhancements for more efficient mass media distribution.

So, LTE Advanced is not a mere collection of 3GPP releases, but a well-planned technology evolution that will continue to play a pivotal role in the future of wireless for years to come and indeed an evolution for the long-haul.

6 Conclusion

LTE's successful run and its growth continue unabated. On the heels of a successful LTE launch, LTE Advanced is making its foray. Its first step—carrier aggregation—was launched in Jun 2013 using Qualcomm Snapdragon chipsets, integrated with third-generation Qualcomm Gobi LTE modems, from Qualcomm Technologies. Apart from carrier aggregation, which helps to leverage wider bandwidths, and utilize fragmented spectrum, LTE Advanced brings multiple dimensions of improvements, including advanced antenna techniques, and HetNet optimizations that bring the most out of small cells. LTE Advanced continues to evolve, ensuring that it is a preferred wireless technology for years to come.

Qualcomm is the leader in LTE and LTE Advanced on multiple fronts. Right from the beginning with the Qualcomm Gobi world-first LTE/3G multimode modems to the most recent carrier aggregation support, Qualcomm (together with its subsidiaries) is a main contributor to LTE Advanced standards and has developed, prototyped and demonstrated many HetNet optimizations at global events. To sum it up, building on our heritage, Qualcomm is in the forefront of LTE development, with a clear vision, robust roadmap and a proven track record.

To get most updated information about LTE Advanced, please visit *www.qualcomm.com/lte_advanced*