Carrier Aggregation Turbocharges Mobile Apps

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This white paper describes the benefits that carrier aggregation will provide for operators and users of LTE-Advanced wireless networks. Carrier aggregation enables downlink and uplink in multiple frequency bands to increase connection speed and network capacity over single-carrier LTE systems. These improvements enable higher performance in mobile devices, but require SoC designs that take full advantage of the faster data rates. Users will benefit from new and enhanced applications that exploit the capabilities that carrier aggregation will provide. The Linley Group prepared this paper, which Qualcomm sponsored, but the opinions and analysis are those of the author.

The availability of wireless broadband networks and affordable mobile devices has caused a transition in how the world accesses the Internet. Google has found that users in ten countries, including the U.S. and Japan, perform more searches from smartphones and tablets than from personal computers. In 2014, the China Internet Network Information Center (CNNIC) reported that 86% of that country’s 649 million Internet users connected via their mobile phones. This exceeds the proportion of Chinese Internet users connecting with a desktop PC, which was only 71%. Smaller numbers used laptops, tablets, or smart TVs to surf the Internet.

The shift to a mobile Internet is driving greater demand for wireless bandwidth. Figure 1 shows how faster mobile networks have shaped usage patterns in China. The three most popular applications are music streaming, online video, and gaming. More than 50% of Chinese cell-phone users watch video on their mobile device. This trend is increasing the load on cellular downlink capacity. There are 500 million WeChat users in China, and that social-networking app’s new video calling feature will increase uplink data traffic as well.

To keep pace with increasing demand, wireless operators worldwide are increasing deployments of 4G LTE networks. In 1Q15, according to data from the Global Mobile Suppliers Association, operators had commercially deployed LTE networks in 138 countries. Operator investments are underway that will likely bring that number to more than 180 countries in 2016. The LTE ramp has been particularly rapid in China, where in 1Q15 the number of 4G users grew to 160 million, increasing by more than 60 million subscribers in just three months.

Next-generation LTE-Advanced systems with carrier aggregation (CA) promise an even greater increase in mobile broadband speed. In 2Q15, operators have commercially deployed 64 CA networks. The current CA standard allows aggregation of up to five separate channels in a mobile device, for up to 100 MHz of total bandwidth. We expect the number of CA networks to grow to 100 by the end of the year.

Initial LTE-Advanced deployments use two carriers to boost downlink data rates, with single-carrier uplink. Category 4 LTE-Advanced uses two 10MHz carriers, which can theoretically downlink at a 150Mbps maximum data rate. Category 6 supports aggregating two or three carriers for up to 40MHz total bandwidth, and theoretical
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maximum 300Mbps downlink with 50Mbps on the uplink. Category 9 boosts the maximum speed for a trio of 20MHz channels to 450Mbps. The theoretical peaks rarely occur under real-world conditions, but each additional carrier will proportionally increase the speeds that users experience.

![Image of bar chart showing mobile app users in China (2014)].

**Figure 1. Top mobile app categories in China (2014).**

The deployment of CA networks is driving demand for OEMs to produce more LTE-Advanced smartphones. Manufacturers have launched more than 70 CA-capable devices, which require a new generation of application processors. Mobile-processor vendors are integrating carrier aggregation into these new SoCs across multiple price tiers, so smartphone users won’t need to purchase the most expensive flagship device to experience these performance gains. In 2H15, we expect midrange devices will be available that provide Category 6 performance, and entry-level phones will support Category 4. Many new high-end smartphones use Qualcomm’s Snapdragon 810, which enables LTE-Advanced Category 9.

New chips with LTE-Advanced modems will deliver 2-3x the data rates of LTE, but to provide the full benefit they must also include upgrades to other key processing blocks, including the CPU, GPU, video codec, and display driver. Application developers will also need to upgrade their software to take advantage of LTE-Advanced performance. The increased data rates enable higher-resolution 3D games, high-definition video, and larger file downloads and uploads, as well as opening up the potential for a new generation of mobile apps.
Benefits of LTE-Advanced With Carrier Aggregation

The deployment of carrier aggregation in LTE-Advanced networks will benefit both operators and users. For operators, the most obvious benefit of higher data rates is the ability to support enhanced services such as high-definition (HD) video streaming. Single-carrier LTE is capable of transmitting 1080p HD video to users within midrange or closer to a cell tower, but speeds at the cell edge decline by 4-5x. Carrier aggregation will extend the range for HD services, and the 2-3x increase in downlink speeds will support 4K streaming under nominal conditions.

Wireless spectrum is a limited resource, but aggregation enables operators to use their licensed frequencies more efficiently. The majority of LTE networks use paired spectrum in frequency-domain duplex (FDD) mode, which dedicates one channel within a frequency band to downlink and another to uplink. In time-division duplexing (TDD), used by China Mobile and a few other operators, a single channel supplies both downlink and uplink. LTE-Advanced allows operators of both systems to repurpose fragmented spectrum by combining channels in non-contiguous bands. The component carriers can also have different bandwidths, from a minimum of 1.4MHz to 3, 5, 10, 15 or 20MHz. Operators can dedicate a greater number of channels for downlink, which must typically sustain a higher volume of data traffic than uplink.

Carrier aggregation can also increase network capacity compared to the same frequency bands deployed separately. For short-burst mobile traffic, such as downloading a file or accessing a web page, applications complete more quickly, freeing the network to service more users in the same amount of time. According to simulations performed by Qualcomm, pairing 10MHz channels on a network carrying an average 20Mbps load enables users to download files in half the time, compared to those users downloading the same files with separate carriers. Aggregating three carriers provides a nearly proportional increase in throughput, resulting in 2.8x faster average download with a 30Mbps network load.

Operators can also deploy carrier aggregation on the uplink. LTE-Advanced Category 7 and Category 10 provide for aggregation of two 10MHz or 20MHz uplink channels to deliver up to 100Mbps data rates. Uploading photos and videos can benefit from this added speed. Applications such as Meerkat and Periscope are encouraging users to stream live video to Twitter, and Facebook has become primarily a picture-sharing website. The need for greater uplink bandwidth is especially acute at concerts and sporting events, where thousands of Instagram users clog the cellular networks as they instantaneously share the experience with their friends through social media.

For smartphone OEMs, the cost of supporting carrier aggregation is coming down as chip vendors integrate this capability into their new RF front-end chips and application processors. As Figure 2 shows, Qualcomm’s WTR3925 transceiver enables smartphone manufacturers to implement Category 6 downlink-CA without increasing parts count over standard LTE designs. The WTR3925 integrates two 20MHz LTE transceivers along with a global navigation satellite system (GNSS) core for BEIDOU, GLONASS, and GPS location satellites. To achieve the full downlink rate, the Snapdragon 620 modem can aggregate two 20MHz-wide carriers. This feature is also useful for other carrier
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combinations, such as 20+10 and 10+10, giving the operator additional flexibility. The Snapdragon 620 also supports LTE Category 7 uplink-CA with the addition of a second RF chip, such as the WTR4905.

![Block diagram of the RF front-end and application processor for LTE-Advanced carrier aggregation.](image)

**LTE-Advanced Requires Turbocharged SoCs**

To deliver the benefits of LTE-Advanced carrier aggregation, mobile processor vendors must boost the performance of their SoCs, starting with the cellular baseband. Qualcomm is the first chip supplier to add CA-equipped devices throughout its processor lineup. The Snapdragon 210 brings dual 10MHz carrier Category 4 performance to entry-level smartphones, with peak downlink rates up to 150Mbps. The mid-range 425, 618, and 620 support Category 6/7 for up to 300Mbps downlink and 100Mbps uplink. The company’s Snapdragon 810 supports three-carrier Category 9 for downlink.

To process data at such high rates, most LTE-Advanced SoCs will employ ARM’s 64-bit CPUs, which deliver a 30%-40% boost in performance over previous generation 32-bit cores. High-end processors will use Cortex-A72 or A57 as the big CPUs, combined with Cortex-A53 to save power for less compute-intensive applications. Midrange and low-cost processors will employ quad or octal Cortex-A53s.

The size of smartphone displays has been steadily increasing, and so have their resolutions. Five-inch four-megapixel quad-HD (2,560x1,440) screens are now common in high-end phones, and six-inch or larger phablets are also popular. These displays provide nearly 10x the number of pixels as standard-definition (800x480) devices. LTE-Advanced with carrier aggregation provides the bandwidth necessary to meet user
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demand for viewing HD video content on these devices. Ultra-HD 4K content is just beginning to proliferate, but such material demands more of an SoC’s display controller, GPU, and video codec. Even with the built-in high-resolution displays, processors must include HDMI 1.4 outputs capable of sending full-resolution video to an external UltraHD monitor.

Because games are some of the most popular mobile applications, high-end processors will integrate at least quad-core GPUs that support the latest Khronos OpenGL ES 3.1 APIs, as well as Microsoft’s Direct X 11. To encode and decode HD and 4K content, the chip’s video codec will employ High Efficiency Video Coding (HEVC or H.265) compression algorithms, which run on dedicated hardware accelerators. Processing 4K video also requires greater memory bandwidth. Some high-end processors support dual 64-bit LPDDR3 channels, but doubling DRAM ports can also reduce battery life. The new generation of LTE-Advanced devices will upgrade DRAM support for lower power LPDDR4 memory.

Smartphone cameras and video recorders are the major sources of increased uplink traffic on mobile networks. Greater use of uplink carrier aggregation will relieve some of this traffic load, but SoCs must include more advanced DSPs and image-signal processors (ISP) to satisfy user demand for these applications.

A mobile processor’s DSP and ISP offload the CPU for tasks such as high-dynamic-range photography, panoramic stitching, and multi-camera input. Almost all smartphones now include front- and rear-facing cameras, but manufacturers are beginning to add depth-sensing capabilities that use dual (stereoscopic) cameras to enable 3D imaging. These new camera features will require dedicated engines to perform advanced image processing tasks such as facial and object recognition.

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According to a global study performed by Ericsson, approximately two-thirds of most countries’ mobile traffic volume comes from just the five most popular apps. Social networking apps such as Facebook top the list in many regions, owing to the popularity of sharing photos and videos and its integration of live chat functions. In China, Tencent’s WeChat app is the most popular, and it has recently added features that rival Facebook, including group chat, social gaming, and video calling.

When these applications first rolled out, developers had to design for the limitations of 3G networks that provided a maximum of only a few megabits per second downlink. The proliferation of LTE has made downlink speeds of 10-20Mbps commonly available, and LTE-Advanced carrier aggregation will double and triple those typical speeds. This will enable app programmers to upgrade from single-player games such as Angry Birds and Candy Crush that use relatively simple 2D graphics. New multi-player social games will require greater network bandwidth, and provide 3D graphics that rival PC and console platforms.

Also high among the top sources of mobile data traffic are video-streaming applications like YouTube and Netflix. Broadcast, cable, and satellite TV providers have recognized
the growth in consumer desire for on-demand access to programs, both in the home and on mobile devices. To retain subscribers, these companies will take advantage of the greater bandwidth provided by LTE-Advanced to support high-definition streaming to smartphones and tablets. To upgrade to 4K streaming, however, service providers recommend a minimum 25Mbps connection. Carrier aggregation can support the 4K bandwidth requirement, at least for short-format programming, but users will need high-limit data plans to accommodate such services.

LTE-Advanced will drive greater adoption of cloud-based applications and services. File-storage applications such as Dropbox and Google Drive are popular for archiving and sharing files, but accessing large files from a mobile device requires either long wait times or connecting to a LAN via Wi-Fi. With carrier aggregation, most mobile users will experience downlink speeds from 20-60Mbps, exceeding the bandwidth of many broadband Internet services. This will enable real-time sharing of large files, such as multimedia presentations.

Carrier aggregation will also enable new types of mobile applications that are infeasible on previous-generation mobile networks. One such application category is augmented reality (AR). The combination of more powerful SoCs, higher-resolution cameras, and faster wireless connections will make AR practical.

Opportunities for AR include location-based advertising, games, navigation and search. With LTE-Advanced and high-speed video downlinks, smartphone users will be able to overlay real-time maps and personalized directions on their device’s display as they scan their surroundings with the built-in camera. This will aid in navigation, but also enable visual 3D searches. A scan for local restaurants and shops would provide opportunities for business owners to present graphical advertisements and discount offers based on a user’s preferences, along with directions to their location. AR and geolocation can enable individuals to find each other in a crowded venue, or point emergency responders to people in need of help.

**Conclusion**

LTE-Advanced technology with carrier aggregation enables network operators to increase the speed of mobile data transmission for both downlink and uplink. The higher data rates allow operators to offer enhanced services, such as 4K video streaming. Carrier aggregation makes better use of fragmented spectrum by enabling operators to link non-contiguous frequency bands with unequal channel bandwidth. Capacity of a cell site also increases, since users that generate short bursts of data traffic can get on and off the network more quickly.

To deliver the performance enhancements that LTE-Advanced promises, smartphone manufacturers must employ new SoCs that can keep up with the 2x-3x increase in data rates. New mobile processors use the latest generation of 64-bit CPUs to increase compute capabilities, along with multicore GPUs that support PC-like 3D graphics and high-definition displays. These chips include H.265 video codecs to enable encode and decode of 4K video. Specialized DSPs and image processors support higher resolution
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still and video cameras, and provide advanced features such as high-dynamic range photography and 3D depth perception.

Users of LTE-Advanced equipped devices will benefit from new and enhanced applications. Carrier aggregation enables downloading large files in half to a third the time of single-carrier LTE networks. Video chat will support full-HD resolution. Mobile games will provide more immersive experiences with 3D graphics and console-type social games. Augmented reality and high-bandwidth mobile connections will foster a new class of applications that allow users to interact with their surroundings for entertainment, information, search, and navigation.

The cost of implementing LTE-Advanced is falling. Processors that implement carrier aggregation are now available at all price tiers, including very low cost devices such as the Snapdragon 210. Carrier aggregation also requires extra RF components to support simultaneous operation in multiple bands. Semiconductor vendors are developing more highly integrated RF devices that integrate multiple transceivers, enabling OEMs to add LTE-Advanced capabilities with minimal increases in BOM cost.

The worldwide deployment of 3G and then 4G LTE networks has provided many people with their first broadband connection to the Internet. LTE-Advanced and carrier aggregation enable operators and mobile device manufacturers to deliver experiences that previously required fixed broadband connections and desktop PCs. Chipsets that support this next generation of mobile applications are now available, and the greater integration enabled by Moore’s Law means that the cost of adding these features will continue to decline.

Mike Demler is a senior analyst at The Linley Group and a senior editor of Mobile Chip Report. The Linley Group offers the most comprehensive analysis of the mobile semiconductor industry. We analyze not only the business strategy but also the internal technology. Our in-depth reports also cover topics including embedded processors, network processors, base-station processors, and Ethernet chips. For more information, see our web site at www.linleygroup.com.