

Testing of Early Applied LTE-Advanced Technologies on Current LTE Service to overcome Real Network Problem and to increase Data Capacity

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Abstract—LTE service that has advantage of high data rate and speed is successful launched in the world wide with 57 service provider in 32 countries as of Mar 2012. But data throughput gap between peak data rate and average data rate is more increased than legacy wireless application, and it brings big problem on the current high rate data service. Although LTE supports high peak data rate, its average is 35% lower than peak data rate. But 2G service, GSM/GPRS is almost same rate with peak data rate. So Frequency efficiency is became important factor for high data throughput service. Especially, Korea Service providers, SKT, KT, LGU+, try to apply early engaged LTE-Advanced technologies to increase frequency efficiency and to cover data traffic using complementary wireless application like Carrier-Aggregation, Multi-Frequency band, Heterogeneous Network. First of all, briefly introduce LTE-Advanced technologies and problem of current LTE service and finally, we are finding design and test challenges of early applied LTE-Advanced technologies, Carrier-Aggregation, Multi-standard Radio and Multi-frequency band LTE.

Keywords— LTE, LTE-Advanced, Heterogeneous Network, Carrier Aggregation, Multi-Frequency band

I. INTRODUCTION

Wireless communication technologies have been enhanced from 1st generation with analogue modulation, through 2nd generation with digital modulated communications, 3rd generations with faster data communications and now we are moving to 4th generations for much higher data communications. However, Huge amounts of data traffic on limited resources like frequency spectrum brings significant issues with wireless data communications. For example, 1 video streaming can cost up to 500 thousands text messages' traffic, and if multiple users at the busy street simultaneously access to wireless data streaming, the overall wireless data rates of that area will go very slow or even hard to access to networks. In real world, it's hard to see more than 10 to 20 Mbps wireless data rate even with LTE network. That's why wireless service providers are working hard and making huge investments to improve wireless data communication quality,

but the demands are growing faster now. Given the situation, we see that many service providers stepped back from unlimited wireless data plans. And LTE service providers try to early apply part of LTE-Advanced technologies like carrier aggregation and multi-frequency band as well as heterogeneous network on current LTE service to overcome real network problems. So I will show the LTE-Advanced technologies to improve wireless data throughput and also suggest method to overcome difficulty of testing and verification of early engaged LTE-Advanced technologies in this paper.

II. CURRENT LTE SERVICE

A. LTE(Long Term Evolution)

The Long Term Evolution project was initiated in 2004. The motivation for LTE included the desire for a reduction in the cost per bit, the addition of lower cost services with better user experience, the flexible use of new and existing frequency bands, a simplified and lower cost network with open interfaces, and a reduction in terminal complexity with an allowance for reasonable power consumption.

These high level goals led to further expectations for LTE, including reduced latency for packets, and spectral efficiency improvements above Release 6 high speed packet access (HSPA) of three to four times in the downlink and two to three times in the uplink. Flexible channel bandwidths—a key feature of LTE—are specified at 1.4, 3, 5, 10, 15, and 20 MHz in both the uplink and the downlink. This allows LTE to be flexibly deployed where other systems exist today, including narrowband systems such as GSM and some systems in the U.S. based on 1.25 MHz

B. Gap between Peak and Average Data Rate

Most big problem of LTE service is gap of data throughput between peak data rate and average data rate. It will bring big influence to service quality, and this problem is mostly caused

by cell edge when many subscribers try to access LTE service simultaneously.

We can plot the projected gains in spectrum and efficiency over the next ten years alongside the planned increases in peak data rate capability. What we see is a big concern since the 10x gap that exists today between peak and average data rates looks likely to grow to 90 times by 2015. This is clear evidence that the growth in spectrum and average efficiency cannot keep pace with the growth in peak data rates which in the ITU's IMT-Advanced 4G proposals have reached a staggering 1Gbps to a single device. If we were to deploy such a system, and migrate all legacy networks and users onto it, the average performance for our 83 users per cell would be around 11 Mbps, just over 1% of the designed peak.

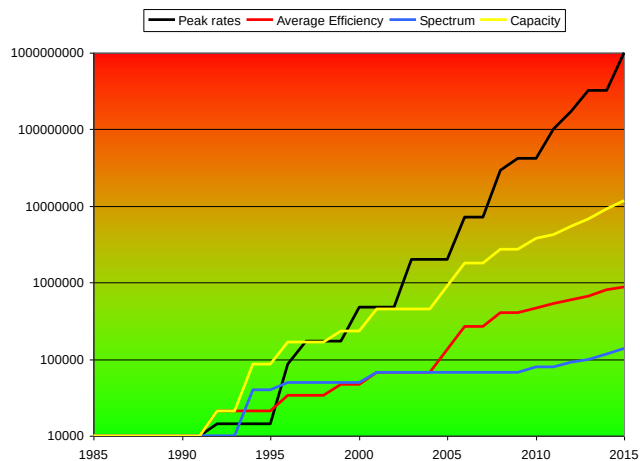


Figure 1. Projecting ahead shows the gap between average and peak rates in a loaded cell will grow to 90 times

C. Performance varies across the cell based on SINR

We can see the variation of wireless application throughput depend on number of user and cell condition and position. The ratio between peak (single user) and cell edge performance has increased.

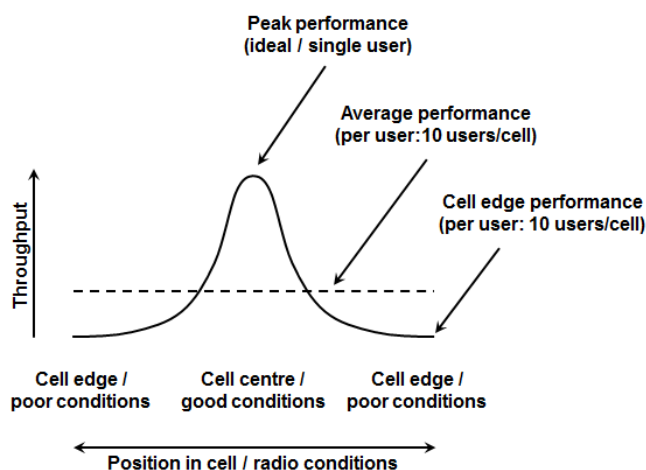


Figure 2. Performance varies across the cell based on SINR

D. The difference of data throughput between Cell edge and single user peaks

The difference of each Wireless application between Peak throughput, Average throughput and Data throughput at cell edge is max 250 times like below table.

TABLE 1. CELL EDGE NOT KEEPING UP WITH SINGLE USER PEAKS

Format	Throughput				
	Occupied Bandwidth	Peak (Single user)	Average (10 users/cell)	Cell Edge (10 users/cell)	Peak/edge ratio
GSM (1 slot)	1 MHz	9.6 kbps	9.6 kbps	9.6 kbps	1
GPRS (4 slot)	4 MHz	81.6 kbps	50 kbps	36.2 kbps	2.3
EDGE (4 slot)	4 MHz	236.8 kbps	70 kbps	36.2 kbps	6.5
UMTS (Rel-99)	5 MHz	384 kbps	100 kbps	30 kbps	12.8
HSDPA (Rel-5)	5 MHz	3.6 Mbps	250 kbps	80 kbps	45
HSDPA (Rel-7)	5 MHz	42 Mbps	350 kbps	120 kbps	350
HSDPA (Rel-8)	10 MHz	84 Mbps	800 kbps	240 kbps	350
LTE (Rel-8) 4x4	20 MHz	300 Mbps	5.34 Mbps	1.6 Mbps	187
LTE-A (Rel-10) 4x4	20 MHz	600 Mbps	7.4 Mbps	2.4 Mbps	250

The Ratio can be reduced at expense of cell capacity with proportional fair scheduling and fractional frequency reuse and a high ratio is bed for application consistency and end user experience.

III. LTE-ADVANCED TECHNOLOGIES TO OVERCOME PROBLEM OF LTE SERVICE

Simple method to increase average throughput and to reduce performance ratio between cell edge and peak performance is to use more spectrum like Figure 3 but it is really expensive to use many frequency band and hard to find available spectrum to cover wide bandwidth. LTE-Advanced proposes similar method using multi-frequency and band that is carrier-aggregation and multi-band service. And another method is to use simultaneously complementary another wireless application like WLAN. LTE-Advanced defines this technology as Heterogeneous Network.

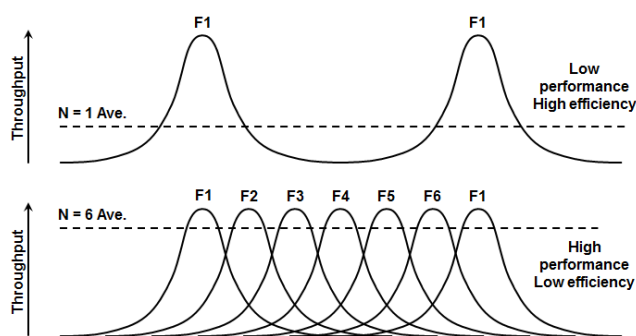


Figure 3. Solving the cell problem with more spectrum

A. What is new in LTE-Advanced

In the feasibility study for LTE-Advanced, 3GPP determined that LTE-Advanced would meet the ITU-R requirements for 4G. The results of the study are published in 3GPP Technical Report (TR) 36.912. Further, it was determined that 3GPP Release 8 LTE could meet most of the 4G requirements apart from downlink spectral efficiency and the peak data rates. These higher requirements are addressed with the addition of the following LTE-Advanced features:

- Wider bandwidths enabled by Carrier Aggregation
- Higher efficiency, enabled by enhanced uplink multiple access and enhanced multiple antenna transmission (advanced MIMO techniques)

Other performance enhancements are under consideration for Release 10 and beyond, even though they are not critical to meeting 4G requirements:

- Coordinated multipoint transmission and reception (CoMP)
- Relaying
- Support for heterogeneous networks
- LTE self-optimizing network (SON) enhancements
- Home enhanced-node-B (HeNB) mobility enhancements
- Fixed wireless customer premises equipment (CPE) RF requirements

B. Carrier Aggregation

Achieving the 4G target downlink peak data rate of 1 Gbps will require wider channel bandwidths than are currently specified in LTE Release 8. At the moment, LTE supports channel bandwidths up to 20 MHz, and it is unlikely that spectral efficiency can be improved much beyond current LTE performance targets. Therefore the only way to achieve significantly higher data rates is to increase the channel bandwidth. IMT-Advanced sets the upper limit at 100 MHz, with 40 MHz the expectation for minimum performance.

Because most spectrum is occupied and 100 MHz of contiguous spectrum is not available to most operators, the ITU has allowed the creation of wider bandwidths through the aggregation of contiguous and non-contiguous component carriers. Thus spectrum from one band can be added to

spectrum from another band in a UE that supports multiple transceivers. Figure 4 shows an example of contiguous aggregation in which two 20 MHz channels are located side by side. In this case the aggregated bandwidth covers the 40 MHz minimum requirement and could be supported with a single transceiver.

However, if the channels in this example were non-contiguous—that is, not adjacent, or located in different frequency bands—then multiple transceivers in the UE would be required. The term component carrier used in this context refers to any of the bandwidths defined in Release 8/9 LTE. To meet ITU 4G requirements, LTE-Advanced will support three component carrier aggregation scenarios: intra-band contiguous, intra-band non-contiguous, and inter-band non-contiguous aggregation. The spacing between center frequencies of contiguously aggregated component carriers will be a multiple of 300 kHz to be compatible with the 100 kHz frequency raster of Release 8/9 and at the same time preserve orthogonality of the subcarriers, which have 15 kHz spacing. Depending on the aggregation scenario, the $n \times 300$ kHz spacing can be facilitated by inserting a low number of unused subcarriers between contiguous component carriers. In the case of contiguous aggregation, more use of the gap between component carriers could be made, but this would require defining new, slightly wider component carriers.

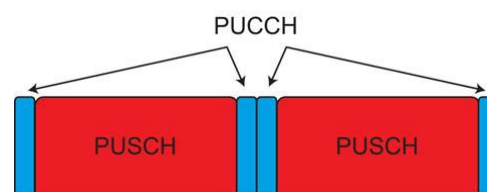


Figure 4. Contiguous aggregation of two uplink component carriers

An LTE-Advanced UE with capabilities for receive and/or transmit carrier aggregation will be able to simultaneously receive and/or transmit on multiple component carriers. A Release 8 or 9 UE, however, can receive and transmit on a single component carrier only. Component carriers must be compatible with LTE Release 8 and 9. In Release 10, the maximum size of a single component carrier is limited to 110 resource blocks, although for reasons of simplicity and backwards compatibility it is unlikely that anything beyond the current 100 RB will be specified. Up to 5 component carriers may be aggregated. An LTE-Advanced UE cannot be configured with more uplink component carriers than downlink component carriers, and in typical TDD deployments the number of uplink and downlink component carriers, as well as the bandwidth of each, must be the same.

For mapping at the physical layer (PHY) to medium access control (MAC) layer interface, there will be one transport block (in the absence of spatial multiplexing) and one hybrid-ARQ entity for each scheduled component carrier. (Hybrid ARQ is the control mechanism for retransmission.) Each transport block will be mapped to a single component carrier only. A UE may be scheduled over multiple component carriers simultaneously. The details of how the control

signalling will be handled across the multiple carriers are still being developed.

Aggregation techniques are not new to 4G; aggregation is also used in HSPA and 1xEV-DO Release B. However, the 4G proposal to extend aggregation to 100 MHz in multiple bands raises considerable technical challenges owing to the cost and complexity that will be added to the UE. Moreover, operators will have to deal with the challenge of deciding what bands to pick for aggregation and it may be some time before consensus is reached allowing sufficient scale to drive the vendor community. 3GPP initially identified 12 likely deployment scenarios for study with the intention of identifying requirements for spurious emissions, maximum power, and other factors associated with combining different radio frequencies in a single device.

However, because of the number of the scenarios and limited time, the study for Release 10 LTE-Advanced was initially limited to two scenarios, one intra-band TDD example and one inter-band FDD example. In June 2010 a third scenario was added for bands 3 and 7. This scenario is an important combination for Europe, where re-farming of the underused 1800 MHz band currently allocated to GSM is a significant possibility.

The physical layer definition for CA is considered 80% complete and although the CA concept is simple, the details of the physical layer changes to support the signalling are complex and involve changes to the PCFICH, PHICH, PDCCH, PUCCH, UL power control, PUSCH resource allocation, and the UCI on the PUSCH. The radio performance aspects are only at 30% completion. To get some idea of the number of combinations requested by operators, refer to Annex A of TR 36.807. Every combination introduced into the specifications has to be assessed for aspects such as required guard bands, spurious emissions, power back off, and so forth. One of the new challenges that CA introduces to the radio specifications is the concept of variable TX/RX frequency separation. This attribute impacts specifications for reference sensitivity and receiver blocking, among others. In Release 8 and Release 9, the TX and RX separation for each of the 19 defined FDD bands is fixed. The introduction of CA changes that, since asymmetric uplink and downlink allocations will be commonplace. The asymmetry is driven by three scenarios; different numbers of CCs in the uplink and downlink, different bandwidths of CC in the uplink and downlink, and finally a combination of different bandwidths and numbers of CCs. How to limit the allowed allocations in order to minimize the number of test scenarios is still under study

C. Multi-Carrier LTE Service

Multi-carrier service is little different with Carrier Aggregation technology of LTE-Advanced because it is not use multi-carrier to transfer data simultaneously, and only use selected one frequency band between assigned available frequency bands. one of the major benefits of the technology is that, by allowing the use of additional spectrum bands it ensures effective and efficient use of frequencies it is

understood that by using the new technology the multi-carrier system optimally distributes mobile data traffic to each frequency band, helping to ensure that the network remains as congestion-free as possible.

D. Heterogeneous Networks

Release 10 intends to address the support needs of heterogeneous networks that combine low power nodes (such as picocells, femtocells, repeaters, and RNs) within a macrocell. Deployment scenarios under evaluation are detailed in TR 36.814 Annex A. [20] As the network becomes more complex, the subject of radio resource management is growing in importance. Work is ongoing to develop more advanced methods of radio resource management including new self-optimizing network (SON) features. The Release 10 specifications also continue to develop the use of femtocells and home base stations (HeNBs) introduced in Release 9 as a means of improving network efficiencies and reducing infrastructure costs.

IV. DESIGN AND TEST CHALLENGES OF CARRIER AGGREGATION AND MULTI-CARRIER SERVICE

As an evolution of LTE, LTE-Advanced and Release 10 will pose many challenges to engineers. The LTE standard is new and quite complex, with multiple channel bandwidths, different transmission schemes for the downlink and uplink, both frequency and time domain duplexing (FDD and TDD) transmission modes, and use of MIMO antenna techniques. LTE and LTE-Advanced will have to co-exist with 2G and 3G cellular systems for some time, so interworking necessities and potential interference remain important issues. In typical difficult radio environments, LTE sets the bar for performance targets very high, and LTE-Advanced raises it even higher. Although not considered a problem for the base station, carrier aggregation will undoubtedly pose major difficulties for the UE, which must handle multiple simultaneous transceivers. The addition of simultaneous non-contiguous transmitters creates a highly challenging radio environment in terms of spurious management and self-blocking. Simultaneous transmit or receive with mandatory MIMO support will add significantly to the challenge of antenna design. The exact impact of carrier aggregation on the specifications depends on the reference UE architecture, and several are still under discussion. Until this discussion is concluded, the performance requirements for carrier aggregation remain to be decided.

A. Creating Carrier Aggregation and Multi-Carrier Signals

To illustrate the concepts of carrier aggregation some examples are provided here using Agilent's SystemVue design software, which can be used for high level system design and verification. Various options exist for implementing carrier aggregation in the transmitter architecture depending primarily upon the frequency separation, which heavily influences where the component carriers are combined:

- at digital baseband
- in analog waveforms before the RF mixer
- after the RF mixer but before the power amplifier (PA)
- after the PA

All of the transmitter architectures illustrated in Figure 5 can be implemented easily in Agilent SystemVue software. Figure 4 shows a quick implementation of LTE Advanced sources with carrier aggregation.

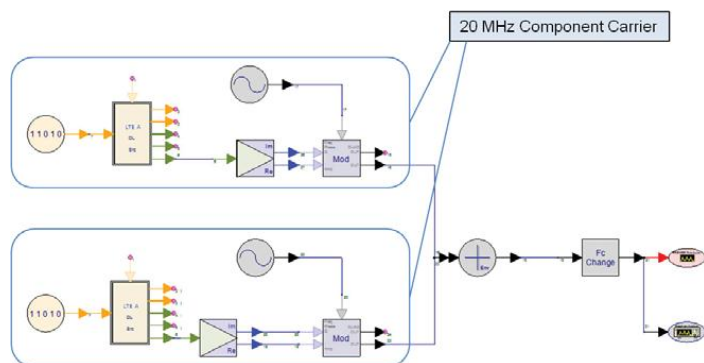


Figure 5. Example of intra-band carrier aggregation in Agilent SystemVue

Figure 5 is an example of intra-band contiguous carrier aggregation. The structure assumes that each component carrier is processed by an independent signal chain. This structure could also be applied to non-contiguous carrier aggregation for both intra-band and inter-band.

Figure 6 shows the spectrum of two 20 MHz component carriers chosen from Band 7 (2600 MHz) are aggregated with the center frequency spacing set to 20.1 MHz (a multiple of the required 300 kHz). Figure 7 shows the constellation of the physical channels and physical signals in the first component carrier (2630 MHz).

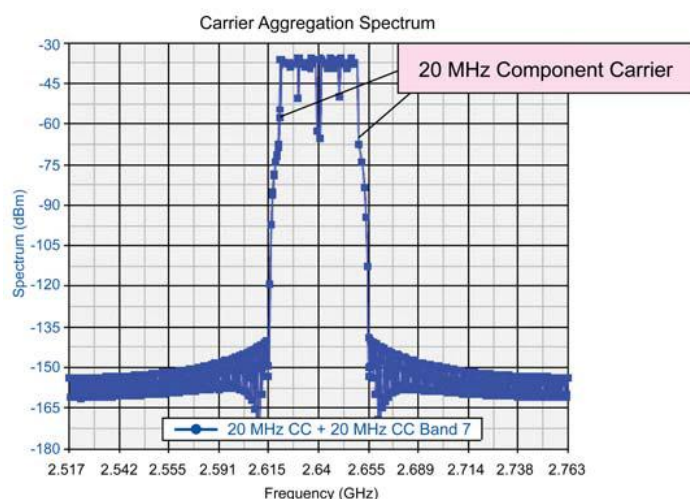


Figure 6. Carrier Aggregation Spectrum of two adjacent component carrier

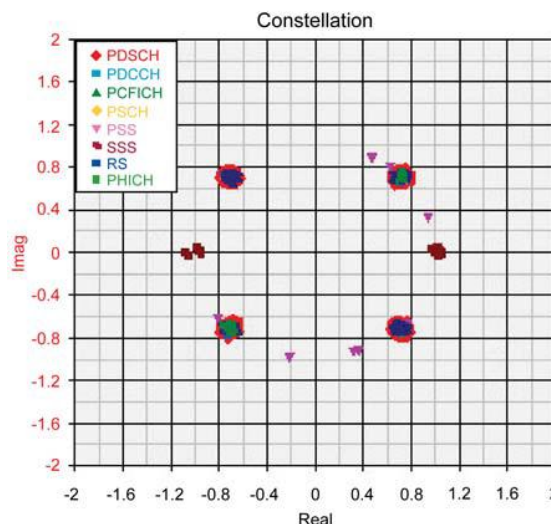


Figure 7. Constellation of the first component carrier

In Figure 8, four adjacent 20MHz component carriers chosen from 3.5 GHz are aggregated with the adjacent center frequency spacing set to 20.1 MHz.

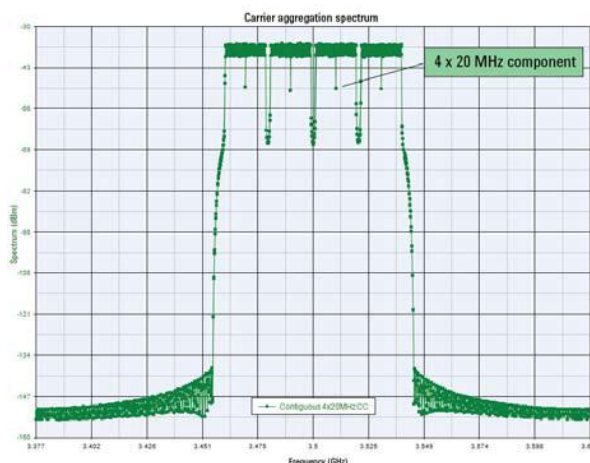


Figure 8. Carrier Aggregation Spectrum of Four Carriers

B. Analysing Carrier Aggregation and Multi-Carrier Signals

The other test challenge is to analyze the multiple transmit and receive chains simultaneously. When an eNB transmits multiple component carriers to a UE, the multiple component carriers must arrive at the receiver at the same time, time alignment error of 1.3 μ s for inter-band and 130 ns for intra-band are specified for downlink. This requires simultaneous demodulation of the multiple component carriers. Using existing LTE tools will only allow to analyze one component carrier at a time, but analyzing multiple component carriers simultaneously requires advanced tools to capture all component carriers, regardless of inter-band or intra-band, and does the analysis simultaneously. The Agilent 89600 VSA software and X-Series signal analyzers or the N7109A multi-

channel signal analyzer can be used to overcome this test challenge.

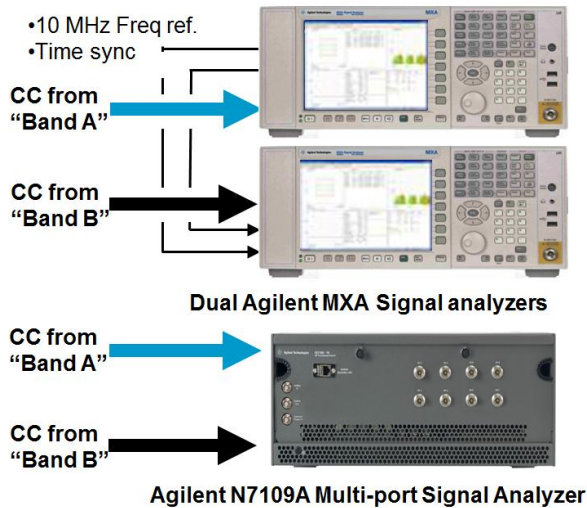


Figure 9. Configuration of Analyzing Carrier Aggregation Signal and Multi-Carrier Spectrum

The other test challenge is specific to inter-band carrier aggregation. Demodulating of inter-band carrier aggregated signal simultaneously since it requires signal analyzer with bandwidth that spans multiple frequency bands (ex. 800 MHz and 2100 MHz). So we need to address this challenge with a solution by using two synchronized signal analyzers that are dual MXA or dual EXA, each tuned to a relevant frequency band along with 89600 VSA software running on a PC, or embedded in one of the X-Series analyzers. The N7109A multi-channel signal analyzer is also another alternative to the X-Series analyzers. The analyzers are controlled with 89600 VSA software with its LTE-Advanced option. The 89600 VSA has the ability to acquire all the component carriers simultaneously from the two synchronized analyzers or multi-channel N7109A signal analyzer, demodulate the captured signals, and analyze them all simultaneously.

V. CONCLUSIONS

These are just a few of the challenges that LTE-Advanced and Release 10 will present wireless design and test engineers. As the 4G specifications are published and the certification process moves ahead, so too will test vendors have to increase the capability of their products and invent ingenious new ways to verify the performance of the evolving 4G systems. Industry-supported field trials are already demonstrating the viability of many of the technical concepts in LTE-Advanced, and 3GPP's submission to the ITU included a self-evaluation of its proposals concluding that LTE-Advanced meets all 4G requirements for being officially certified as 4G. Nevertheless, the timing of LTE-Advanced deployment is difficult to predict and will be dependent on industry demand and the success of today's Release 8 and 9 LTE rollouts. From a standardization perspective LTE-Advanced is about two years behind LTE. However, the deployment of LTE-Advanced may be more

than two years behind LTE for many reasons. These include the fact that LTE itself will have a slow rollout due to limited spectrum availability and the continued development and success of 2G and 3G systems. In addition, LTE-Advanced represents a big increase in system and device complexity, and it will take time for the industry to respond.

Carrier Aggregation and Multi-Carrier is one of the most important and priority features of LTE-Advanced enabling higher data rates as well as add flexibility for efficient use of fragmented spectrum. In Release 10, the implementation will be limited to two component carriers and will be extended with Release 11 and beyond. It introduces various design and test challenges covering both inter-band and intra-band carrier aggregation.

ACKNOWLEDGMENT

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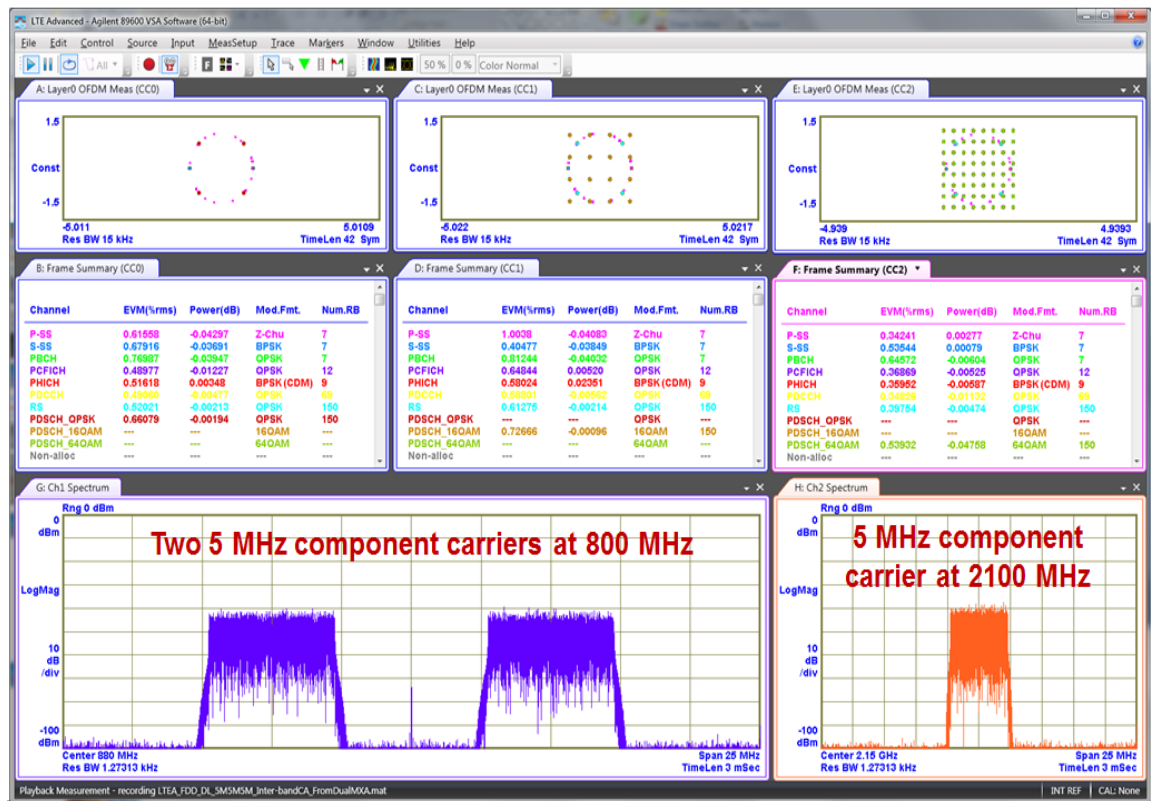


Figure 10. Inter-Band Carrier Aggregation (Simultaneous analysis of CCs from different bands)

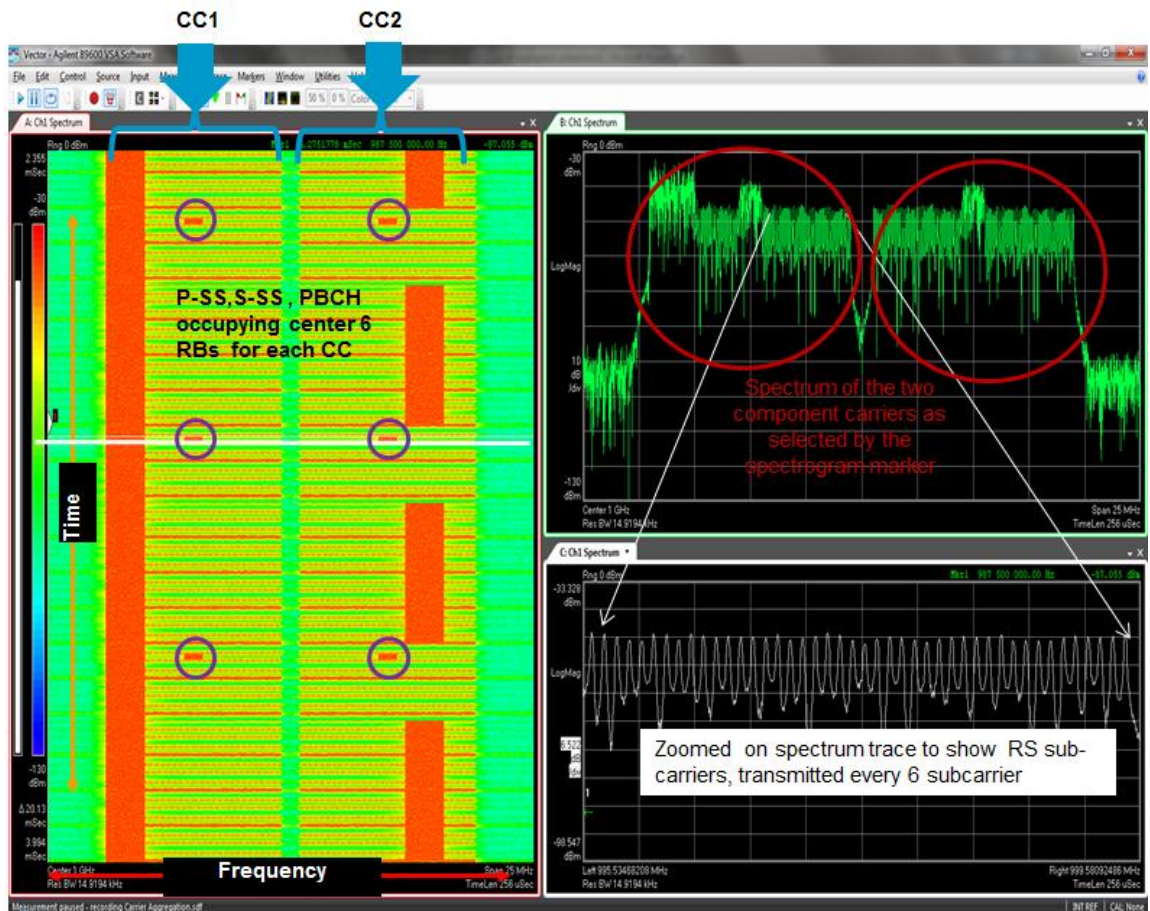


Figure 11. Spectrogram of Inter-Band Carrier Aggregation