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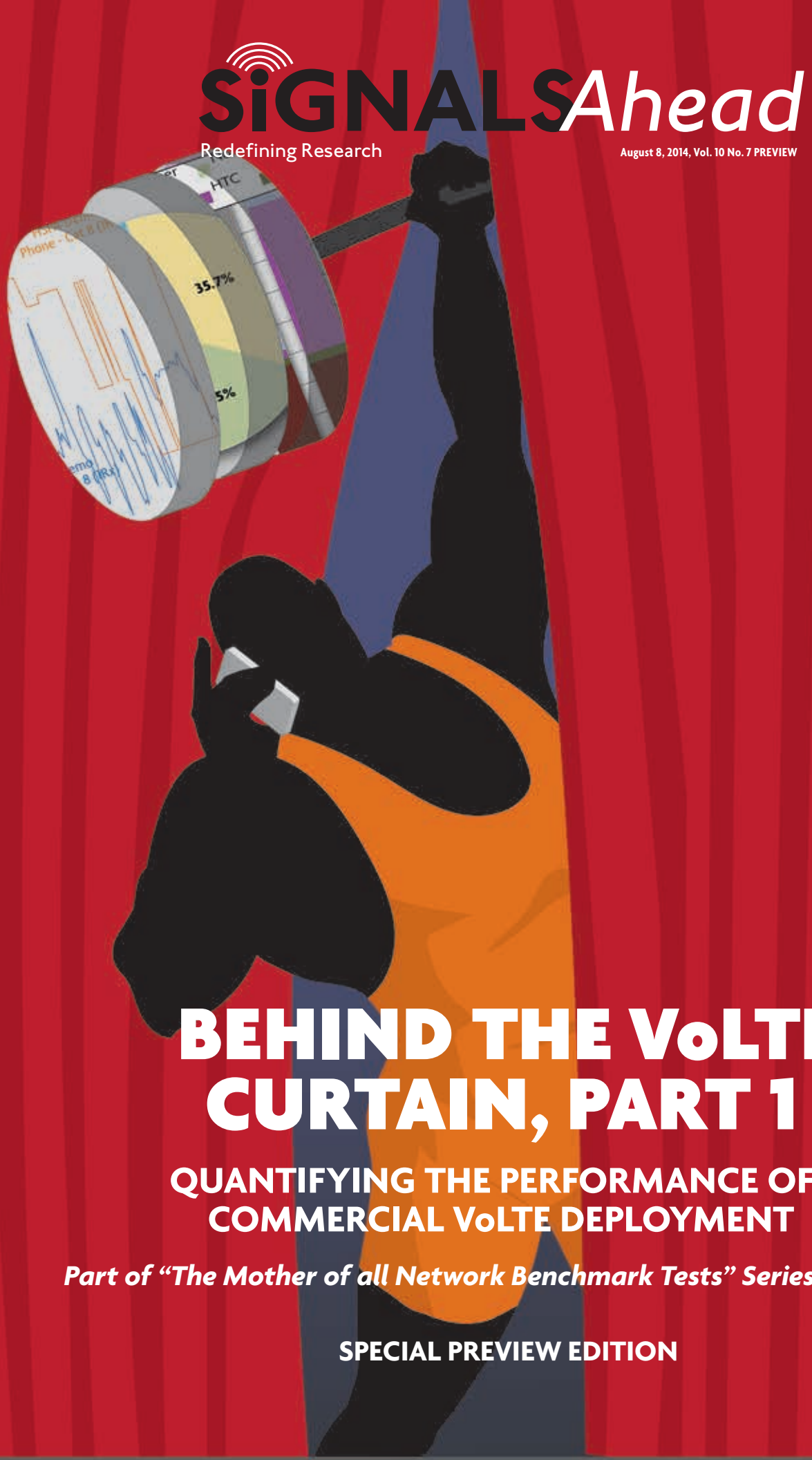


BEHIND THE VoLTE CURTAIN, PART 1

QUANTIFYING THE PERFORMANCE OF A COMMERCIAL VoLTE DEPLOYMENT

Part of "The Mother of all Network Benchmark Tests" Series of Reports

SPECIAL PREVIEW EDITION

YOUR ATTENTION PLEASE

This document provides a preview of a separately published 67-page report that provides detailed analysis and insight into VoLTE performance, based on a multi-day evaluation of the AT&T deployment in Minneapolis-St. Paul, MN. This report is a must read for any organization that wants to understand how VoLTE performs and how it compares and contrasts to 3G CS Voice and an OTT voice application, specifically Skype Voice. This study was done in collaboration with Spirent Communications who provided us with its Nomad User Experience Analytics System to measure the call quality (MOS) and its Quantum Battery Life Measurement System to measure current drain and power consumption. We also used other tools to capture and analyze chipset diagnostic messages in order to determine the network impact of these voice applications.

This report is included as part of a subscription to *Signals Ahead* or it can be separately purchased for $1,750. We are currently preparing to do part two of the study, which will include extensive lab-based testing of these applications and various VoLTE clients with Spirent. This companion report is available for $1,295 (pre-order) or it can be bundled with this report for $2,500.

In addition to the Executive Summary and Test Methodology, we include a complete Table of Contents and List of Figures (74), a summary of past reports, and a list of topics that we are currently considering for the upcoming year.

Executive Summary

KEY HIGHLIGHTS FROM THIS STUDY

We conducted an extensive benchmark study of AT&T's VoLTE service offering in the Minneapolis-St. Paul area that we did in collaboration with Spirent Communications, who provided us with its test equipment and engineering support to collect much of the data. Based on our analysis of the data, we conclude that VoLTE is pretty much everything that we hoped it would be.

For starters, the call quality (MOS), based on the POLQA algorithm, greatly exceeded that of 3G CS voice and it was measurably higher than Skype Voice. With network loading, and in particular with background applications running on the mobile phone and transferring data with the network, the VoLTE results were considerably better than Skype (over Wi-Fi and LTE) – the former showed no impact while the latter frequently failed to deliver the voice packets. Relative to 3G CS voice, VoLTE's other big advantage was the call setup time. A CSFB call took nearly twice as long to establish as a VoLTE call.

Lastly, VoLTE required substantially fewer network resources (DL/UL RBs, TTIs, PDCCH downlink scheduling grants (i.e., signaling traffic) etc.) than Skype and presumably other OTT voice applications, which in turn resulted in a longer estimated battery life – we separately measured both attributes. In large part these two advantages were achieved with several LTE features (RoHC, TTI bundling, and DTX/DRX) which are either not supported by an OTT application that isn't assigned QCI=1 or which are supported less efficiently. Additional positive network and user experience implications are likely once SPS and short DRX are launched.

Continued improvements in LTE network coverage will give VoLTE an even greater advantage in the future, including an even longer battery life and fewer eSRVCC handovers to the 3G CS network.

When operators first launched LTE in late 2009 and into 2010 the focus was entirely on the high bandwidth capabilities of the network and its ability to dramatically improve the user experience. Operators also leveraged the new air interface and spectrum that frequently came with it to offload data traffic from their legacy 3G networks. Since the networks were all-IP it was relatively easy to get the networks up and running while "problems" were easily masked due to the best effort applications that took advantage of LTE's potential.

This luxury goes away when the networks are required to support a real-time application, such as voice over LTE (VoLTE). The network needs to be intelligent enough to schedule and deliver the real time voice packets along with the best effort data packets so that the quality of the voice call is never degraded, regardless of how much best effort data traffic exists. Interworking with the legacy 3G network is also critical, in particular in the early days when not all devices support VoLTE and LTE coverage isn't ubiquitous.

Offering a VoLTE service sounds easy, but it isn't.

Further, the use of the IP protocol to deliver the voice packets creates additional challenges since the protocol can create inefficiencies that do not exist with a circuit switched connection and a dedicated radio bearer. In a wireline network, operators can simply throw more bandwidth at the problem. In a wireless network this strategy isn't possible since the associated CapEx is high and spectrum is limited. Lastly, one needs to consider the tradeoffs between the improved voice quality that VoLTE can [hopefully] deliver and the [potential] "higher cost" associated with delivering it. After all, conventional wisdom suggests that higher bandwidth applications generally use additional

network resources, limit the effective coverage area of the service, and can have a bigger impact on the battery life of the mobile device. Offering a VoLTE service sounds easy, but it isn't.

We included VoLTE, 3G CS voice, and Skype Voice/Video in the study.

Signals Research Group (SRG) conducted a drive test of AT&T's VoLTE deployment in Minneapolis-St. Paul in mid-June with some subsequent tests taking place in mid-July. As part of this test campaign, we evaluated several attributes of the VoLTE service, including VoLTE and CSFB (Circuit Switched Fallback) call setup times, call reliability and call quality (MOS), network resource requirements, and the impact on battery life. We tested VoLTE, 3G CS voice and Skype Voice/Video from stationary locations and while mobile, including Skype over Wi-Fi in the study. In this market, Alcatel-Lucent is the infrastructure supplier, supporting the radio access network, the core network and IMS, including the primary VoLTE functionality. AT&T loaned us two Samsung Galaxy S4 mini smartphones but otherwise had no involvement in the study. As a courtesy, we provided AT&T and Alcatel-Lucent with a pre-brief just prior to publishing this report. These pre-briefs also gave us the opportunity to get answers to some questions that we had and to ensure that our analysis of the data was correct.

We worked closely with Spirent Communications who provided us with its test equipment and engineering resources to help collect some of the data.

Throughout this study we worked closely with Spirent Communications who provided us with its test equipment and engineering resources to help collect much of the data. We used the Spirent Nomad User Experience Analytics System to measure the call quality (MOS) of the three voice applications and to control and capture performance data during the call setup and reliability tests. We used the Spirent Quantum Battery Life Measurement System to measure the power consumption, current drain and the implied battery life for the three applications, plus Skype Video. We relied on Qualcomm's QXDM to measure the impact that these applications had on the network as well as to capture the RF parameters that existed when we were doing the tests. For post-processing and analysis of the QXDM logs we used a combination of Accuver's XCAP software and Xceed Technologies' WindCatcher software. SRG takes full responsibility for the analysis and opinions expressed in this report.

As long-time *Signals Ahead* readers are aware, we have worked with Spirent on numerous occasions over the years. More recently, we have been combining the data that we have captured with them in live networks and bringing it into a lab setting for further analysis in a controlled environment. We plan to leverage this capability in this two-part series of VoLTE reports. In a forthcoming report we will use their test equipment to replicate many of the test scenarios that we conducted in AT&T's network. The advantage of the lab setting is that it will allow us to repeat the tests under identical conditions as well as to introduce subtle and not-to-subtle changes, including different RF conditions and VoLTE clients, to name a few. Since we know that Spirent is working closely with several operators and vendors who are in the process of rolling out VoLTE, we will be able to leverage their expertise and insight that they have gained in the process. Look for this report sometime this fall.

VoLTE generally lived up to our high expectations.

Whenever we do these types of studies we are always fearful that the results will fall short of our expectations and we will be in the precarious position of telling proud parents that their baby is less than beautiful. Fortunately, we were not faced with this situation after completing the first part of the VoLTE study. VoLTE generally lived up to our high expectations.

Although the wideband AMR codec that enables HD Voice can be used with legacy 3G voice services, it is an inherent feature of VoLTE. According to the MOS (mean opinion score) results, VoLTE achieved a substantially higher call quality than 3G CS voice and a measurably higher call quality than the HD voice service offered by Skype. And while other network traffic or background traffic downloading on a smartphone could bring Skype Voice to its knees, there was no indication that it impacted the VoLTE call. This result stems from VoLTE using QoS Class Identifier 1 (QCI=1), a guaranteed bearer that isn't supported by OTT (over-the-top) applications.

The CSFB call setup time was nearly two times longer than the VoLTE call setup time.

Voice call quality is arguably a bit subjective in nature, even when the results are based on the industry-accepted POLQA algorithm, but VoLTE also did quite well when it came to more objective criteria. For example, the CSFB call setup time was nearly two times longer than the VoLTE

call setup time. Further, in a number of cases once the 3G CS call finished the phone remained camped on the HSPA+ network instead of returning to the higher bandwidth LTE network. The VoLTE call reliability, or the ability to establish and sustain a voice call, was comparable to 3G CS voice, although the latter came out slightly ahead due to its relative maturity as a technology, not to mention the better coverage that the 3G network offered.

VoLTE really shined when it came to its network resource requirements. Unlike OTT applications, VoLTE was able to take advantage of important features, including TTI (Transmission Time Interval) bundling and RoHC (Robust Header Compression), while it took greater advantage of DTX/DRX (discontinuous transmit/receive). All of these features were present in the Minneapolis-St. Paul market and their combined capabilities resulted in a VoLTE call consuming far less network resources than a Skype Voice call for a given amount of voice activity. This advantage also translated into a meaningfully longer battery life for a smartphone sustaining a VoLTE call versus an OTT voice application. Once AT&T has commercialized SPS (Semi-Persistent Scheduling) and short DRX in the Minneapolis-St. Paul network the differentiation with OTT voice applications will be even more pronounced. 3G CS voice still came out on top when it came to power consumption but the advantage wasn't overwhelming while we expect VoLTE to catch up and likely surpass 3G CS battery life in a relatively short period of time.

VoLTE features, such as RoHC, TTI bundling and DTX/DRX, significantly limited the amount of network resources that were required.

We did observe some measurable differences in the LTE network coverage compared with the 3G network coverage. The less dense LTE network was evident in the receive signal strength and we know that the lighter coverage impacted the battery life of the smartphone during a VoLTE or Skype call while it also resulted in a few unintended eSRVCC handovers from LTE to the 3G network during a voice call. This observation speaks more to the LTE network coverage than it does to the maturity of the VoLTE solution. Nonetheless, this issue is important and it will have a greater impact on operators that are deploying VoLTE in higher frequency bands.

The real competition for VoLTE is the numerous OTT voice applications that are available and which consumers may elect to use instead of an operator's VoLTE service. Depending on how the operator offers its VoLTE service these choices could limit the near-term consumer adoption of VoLTE. In the case of an operator that bundles its voice and data services, the clear choice for the consumer should be a no brainer. VoLTE delivers a consistently higher call quality than OTT voice applications, in particular when network loading is present, and it offers a far longer battery life. Some operators may elect, or at least try, to sell VoLTE as a service. The value proposition remains the better overall user experience (better call quality and longer battery life) compared with OTT voice applications, although in some markets nothing competes with something that is perceived by consumers to be free, even though the data usage from the OTT VoIP application is still charged to the subscriber's data plan. Operators should also strongly consider the long-term network cost savings associated with VoLTE, given that it is far more efficient when it comes to supporting a voice call compared with OTT voice applications. Lastly, it never hurts to "keep up with the Joneses," meaning that operators will need to support VoLTE in order to remain competitive. All this and more in this issue of *Signals Ahead*.

Operators should strongly consider the long-term network cost savings associated with VoLTE.

Test Methodology

We worked closely with Spirent Communications to conduct the evaluation of AT&T's VoLTE deployment. In addition to providing various test equipment that we mention in a moment, Spirent also provided us with engineering support to collect some of the data and post-process some of the results. Since Spirent is currently working with a number of operators and vendors on VoLTE it was a natural fit to work with them. Further, we can leverage the observations that we made from the field testing and apply it to lab testing in Spirent's facilities. Look for this report later this fall. SRG takes full responsibility for the analysis of the data and the commentary that appears in this report.

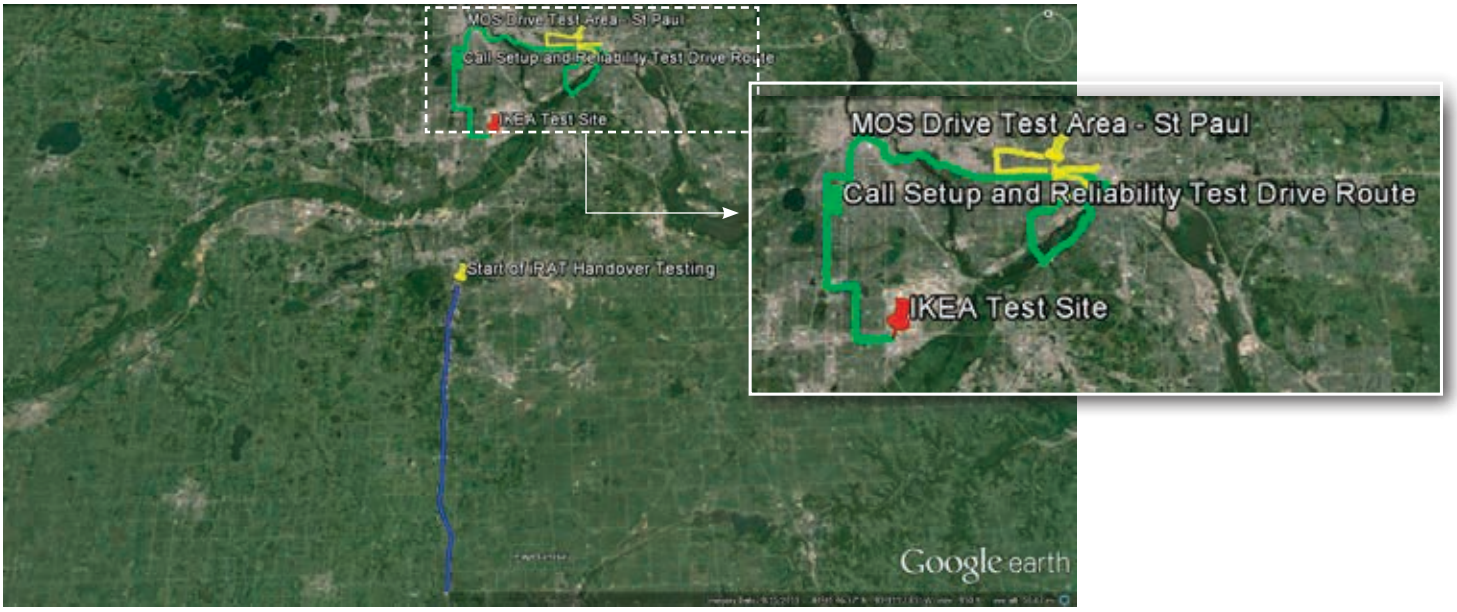
We worked closely with Spirent Communications to conduct the evaluation of AT&T's VoLTE deployment.

We used the Spirent Nomad User Experience Analytics System to measure the call quality (MOS) of the three voice applications and to control and capture performance data during the call setup and reliability tests. We used the Spirent Quantum Battery Life Measurement System to measure the power consumption, current drain and the implied battery life for the three applications, plus Skype Video. We relied on Qualcomm's QXDM to measure the impact that these applications had on the network as well as to capture the RF parameters that existed when we were doing the tests. For post-processing and analysis of the QXDM logs we used a combination of Accuver's XCAP software and Xceed Technologies' WindCatcher software. SRG takes full responsibility for the analysis and opinions expressed in this report.

The initial testing took place over a three day period in mid-July. During this visit, we conducted all of the call reliability, call setup, and call quality tests and a limited number of battery life tests. We returned in mid-July on our own to conduct some additional tests with the Quantum tool.

We did MOS testing at a fixed location in the IKEA parking lot near the Minneapolis-St. Paul airport and adjacent to the Mall of America. We also did some testing in a hotel room since it gave us the opportunity to leverage the hotel's Wi-Fi service. In addition to the stationary testing, we did MOS testing in a mobile environment and over a relatively large geographic area. We also measured MOS when we evaluated eSRVCC handovers. Figure 64 provides an indication of where we conducted the various tests that we performed.

Figure 1. VoLTE Test Area



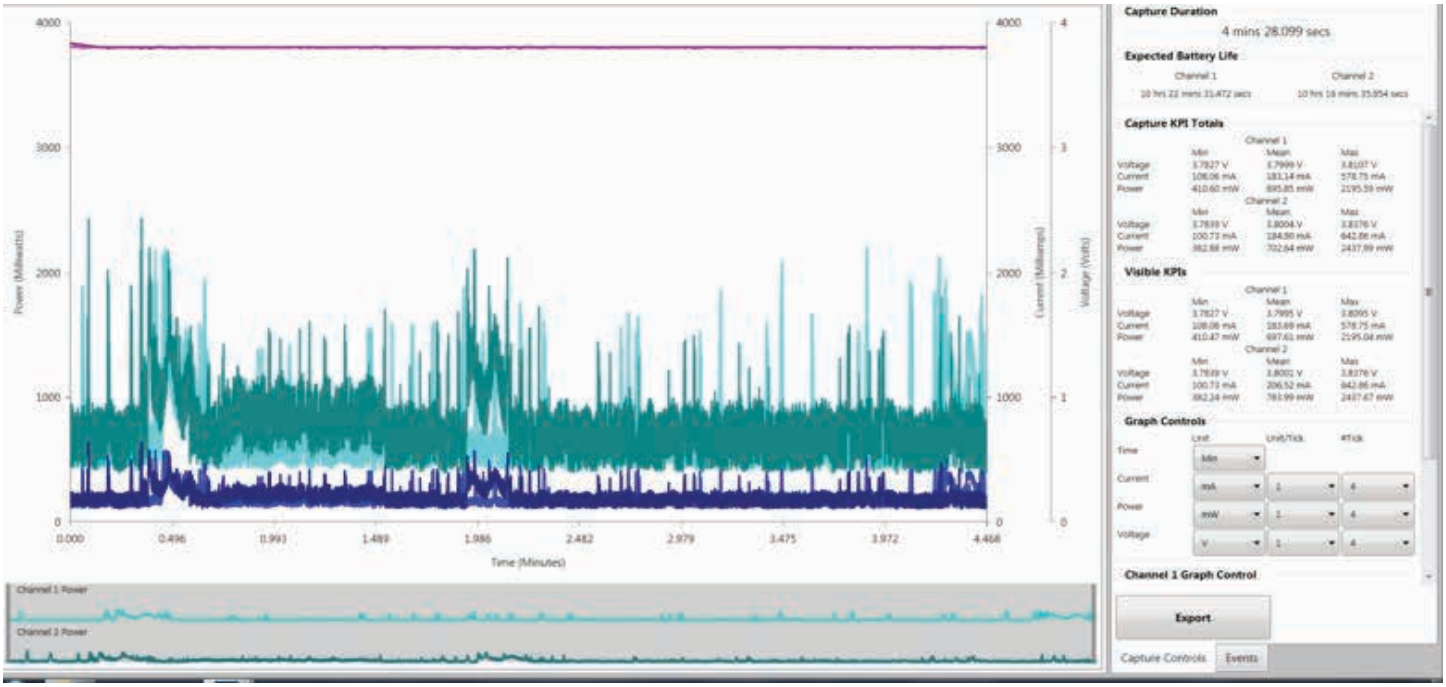
Source: Signals Research Group

All of the MOS results presented in this report stem from mobile to mobile testing although Nomad supports testing to a VoLTE or cloud-based server. In the case of the mobility MOS drive test that we did in St. Paul the second device was stationary in a hotel room and always using VoLTE even though the mobile device rotated between VoLTE, Skype Voice and 3G CS voice as appropriate. For the stationary testing the two Galaxy S4 mini smartphones were collocated in our test vehicle. Each MOS value that we recorded stemmed from two short recorded sentences – one spoken by a man and one spoken by a female with the measurement taking place on the receiving end. Since the recording bypassed the microphone and speakers there wasn't any impact due to external noise.

We used Quantum to measure the current drain, power consumption and to calculate the estimated battery life based on these two parameters as well as the battery's voltage and milliamp-hour rating. Figure 65 provides a screen shot of the Quantum GUI, which was displayed on a Dell PC that was used to control the Quantum box.

In order to simulate voice activity on the call we used a recording that we made with our personal smartphone and then played this recording into the phones' microphones. Some of the Quantum results also reflect measurements that we made with the same voice activity patterns that we used for the MOS testing. In fact, for VoLTE the voice activity patterns are evident in the Quantum results, as shown in Figure 63. For the Quantum testing the measurement period was 2-6 minutes and in several locations we repeated the tests more than once to get more consistency in the data.

Figure 2. Quantum Display



Source: Spirent Communications

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IN CASE YOU MISSED IT: *SIGNALS AHEAD* BACK ISSUES

- **7/8/14 "By the Light of the Silvery Moon - 4x2 Closed Loop MIMO Drive Test Study"** With the continued support of Accuver, we leveraged its XCAL drive test solution and its XCAP post-processing software to evaluate the performance of Closed Loop MIMO (CL-MIMO) with a 4x2 antenna configuration - 4 transmit/receive antennas at the cell site and 2 receive antennas in the mobile device. We compared 4x2 CL-MIMO and 2x2 OL-MIMO, 4x2 CL-MIMO and 4x2 transmit diversity (by getting T- Mobile to "turn off MIMO" in its network), and the benefits of 4 receive antennas at the cell site. In addition to presenting an analysis of overall DL/UL network performance we also quantify the downlink and uplink performance gains associated with 4x2 over 2x2. These gains include higher data rates for a given RSRP/downlink pathloss, more efficient use of network resources, and an improved battery life.

- **5/29/14 "LTE and the Public Safety Paradigm Shift"** Although forecasts vary dramatically, Public Safety LTE is a multi- billion dollar market opportunity for infrastructure vendors, chipset suppliers and device manufacturers. Unfortunately, it is approaching 20 years in the making and it still seems as if not very much has happened since the initiatives first began - in some cases in the previous Century. In this report, we provide a history lesson of where the Public Safety Communications sector has been; we discuss where the industry is going on a global basis; we identify the Public Safety Communications requirements and how the industry standards' bodies are [or are not] addressing these needs; and we look to the future and discuss how we believe the market will evolve, the vendors that are helping in the effort, and the innumerable challenges that remain.

- **5/7/14 "Chips and Salsa XVIII – LTE Chipset Performance Benchmark Results: The Cat 4 is out of the bag"** In our tenth benchmark study that we have done with Spirent Communications, we provide results from LTE FDD Category 4 chipset testing. We benchmarked six LTE chipsets from Ericsson (pre-commercial), HiSilicon (commercial), Intel (commercial), MediaTek (pre-commercial), Qualcomm (commercial) and Samsung (pre-commercial). We tested each chipset against 29 test scenarios involving five ITU channel models, two transmission modes, and three MIMO correlation factors. Results are based primarily on achievable throughput, although we also analyzed the distributions of reported CQI values, ACK/NACK/DTX percentages for both codewords and MIMO utilization rates. The Samsung pre-commercial chipset was the top-performing chipset and it distinguished itself from its peers, in particular with some of the more challenging test scenarios.

- **4/3/14 "Deep in the Bowels of LTE Network Performance"** With the support of Sanjole, who provided us with its WaveJudge 4900A LTE Analyzer and IntelliJudge test platform, we conducted a deep dive analysis of LTE network performance. The study included the 4 largest US operators and all of the major infrastructure suppliers. The results of the study provide insight into the use of MIMO, the performance traits of the eNB schedulers, network loading, downlink/uplink spectral efficiency, and end user data rates. Bottom line – while video traffic may represent 70% or more of total data traffic, one should not ignore all of the remaining data traffic which frequently uses a disproportionate amount of network resources.

- **2/12/14 "eMBMS/LTE Broadcast - once bitten, twice shy?"** We examine the market opportunity for eMBMS. Specific topics include looking at what went wrong the first time MBMS and related technologies were proposed. We also provide a technology primer that looks at how eMBMS impacts the network architecture and the air interface. The primer also includes a look at the functionality by 3GPP release. We then examine the use cases with a particular focus on why we like some use cases versus other use cases. Next, we present the all-important challenges that operators will face before being able to offer LTE Broadcast services. Lastly, we provide our market outlook for eMBMS, including the catalysts that could drive wider spread adoption, including more operators and larger MBSFN Areas.

- **1/15/14 "Chips and Salsa XVII - When Iconic meets Anechoic"** For this study we continued our multi-year collaboration with Spirent Communications, who provided us with a full suite of test equipment and engineering support to conduct the tests. ETS-Lindgren joined us in the collaborative effort by providing its anechoic chamber as well as providing access to the company's facilities in Austin, Texas. We benchmarked five commercially procured smartphone – the LG G2, the Samsung Galaxy S4, the Samsung Galaxy Note II, the HTC One, and the Motorola Moto X. The top performing smartphone won by a country mile, outperforming the second best performing smartphone by more than 35% across all tests. We include results from some sensitivity studies that look at the incremental impact of MIMO (TM3) versus transmit diversity (TM2) as well as the performance impact of introducing a protective cover.

- **11/27/13 "SDN and NFV - It's not a single network anymore"** In this issue we look at Software Defined Networking (SDN) and Network Function Virtualization (NFV), which are two intertwined initiatives that operators and vendors are pursuing to address challenges and inevitable changes to the operator's traditional business model, not to mention the inherent shortcomings of the current core network architecture. We examine the numerous advantages and objectives associated with them as well as some of the pitfalls that will exist if they are not successfully implemented. We also look at likely operator rollout strategies and the likely network functions from the radio access network through the core and backhauls where they will first be used. Finally, we take a quick look at what some of the vendors are doing in the space and the work that is taking place in the various standards bodies and specific associations that are trying to introduce important standards.

- **10/23/13 "LTE Advanced Network Drive Test – Gangnam Style (As the Carrier Aggregation World Turns)"** Based on testing in South Korea we provide the industry with its first independent assessment of LTE Advanced carrier aggregation. In addition to providing detailed analysis of the downlink throughput for the two radio carriers as well as other important KPIs which have an impact on performance, we also analyze the uplink performance and quantify the incremental benefits of a Category 4 device. Additionally, we present the results from several user experience tests involving web browsing, VoLTE, downloading applications from Google Play, 1080P video streaming and Skype video/Video telephony. Ultimately, we conclude that carrier aggregation has real benefits that extend beyond increasing the peak data rates.

ON THE HORIZON: POTENTIAL *SIGNALS AHEAD/SIGNALS FLASH!* TOPICS

We have identified a list of pending research topics that we are currently considering or presently working on completing. The topics at the top of the list are definitive with many of them already in the works. The topics toward the bottom of the page are a bit more speculative. Obviously, this list is subject to change based on various factors and market trends. As always, we welcome suggestions from our readers.

- VoLTE versus OTT benchmark study (part II)
- Over-the-air Smartphone user experience benchmark study
- Small cell market update, potentially including network economic analysis
- Content Caching and its impact on the user experience
- LTE Advanced 10 MHz + 20 MHz Carrier Aggregation Drive Test (including other LTE Advanced features as they become available)
- Over-the air Smartphone RF performance benchmark study
- CTIA Wireless Week Key Takeaways (Signals Flash)
- Video delivery and LTE benchmark study
- LTE TDD and LTE Advanced Carrier Aggregation chipset study
- Cloud RAN
- Smartphone signaling implications across operating systems
- A-GNSS platform benchmark study (Round II)

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