White Paper 122

Testing CDMA and EV-DO Mobile Terminal Devices: Beyond Conformance

September 2009

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Page Part Number: 79-002163, Version A0

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SCOPE

This white paper provides an overview of the methods used to test mobile devices deployed on commercial CDMA/EV-DO networks. Topics include several key areas of testing, both as mandated by industry standards bodies and implemented by commercial network operators and mobile device manufacturers.

INTRODUCTION

The internal complexity of a modern cellular device represents an incredible achievement on the part of the wireless engineering community. It is a testament to this that most cellular subscribers will never know everything involved in the little device thrown in a pocket and taken for granted.

In the spirit of competition, the cellular industry long ago moved away from the specter of proprietary systems by enacting technical specifications for cellular devices. Anyone who wanted to build a cell phone could do it, as long as the device complied with the specifications. As part and parcel of this initiative, test specifications were developed so that proof of conformance could be made available.

Ownership of these specifications belongs to standards bodies made up of industry participants. While the standards body is chartered to ensure that the technology works, participants can have very different ideas on who should bear the more egregious burdens of this insurance. In a strange twist of necessity, erstwhile competitors suddenly become allies in deciding what technical traits should and should not be strictly enforced; mobile device manufacturers band together to sway things to their advantage, while the outnumbered network operators attempt to do the same. The result is a compromise that serves its intended purpose, but does not necessarily represent the best interests of any individual entity, including the subscriber.

CDMA/ EV-DO CONFORMANCE TEST SPECIFICATIONS

MINIMUM PERFORMANCE TESTING

A few years ago, the test methodologies driven by the 3GPP2 were thought of in terms of stages. "Stage I" testing, documented in the IS-98 specification (later called TIA-98) was meant to ensure "minimum performance". This vague phrase described testing receiver and transmitter performance under specific conditions and quantifying results to guarantee a specific level of performance.

For example, a receiver can be tested by measuring its ability to demodulate a given signal. Disciplined testing demands a test that is both repeatable and realistic, which is much more complicated than it sounds at first.

In addition to electrical noise that is always present, wireless signals are subject to a phenomenon known as "fading". To describe a very complicated topic in just a few words, fading is the effect of reflected RF signals arriving at a receiver after having traversed different paths. Because the signals arrive at different phase angles (based on the distance traveled), the received signal is affected by constructive and destructive interference. To make matters even more complex, this scenario is constantly changing. For testing, the changes are accurately random while still being repeatable.

Table 1: Minimum Performance Test Specifications

Revision Numbering	Numbering		Document	Diversity Testing Reference	
	3GPP2	TIA		Qualcomm App Note	Title
1x	C.S0011	TIA-98	Recommended Minimum Performance Standards for Dual-Mode Spread Spectrum Mobile Stations	80-V9141-1B	cdma2000® Min. Perf. For Rx Diversity-Capable Mobile Stations Application Note
EV-DO Rev. 0	C.S0033	TIA-866	Recommended Minimum Performance Standards for cdma2000 High Rate Packet Data Access Terminal	80-V8941-1A	Recommended Minimum Performance for CDMA2000® 1xEV-DO Rx Diversity-Capable Access Terminals
EV-DO Rev. A	C.S0033A	TIA-866A	Recommended Minimum Performance Standards for cdma2000 High Rate Packet Data Access Terminal	80-VF496-11A	Recommended Minimum Performance for CDMA2000® 1xEV-DO Revision A Rx Diversity-Capable Access Terminals

Revision Numbering	Numbering		Document	Diversity Testing Reference	
EV-DO Rev. B	C.S0033B	TIA-866B	Recommended Minimum Performance Standards for cdma2000 High Rate Packet Data Access Terminal		

Receive Diversity Testing

In an effort to squeeze the most efficiency out of a given wireless channel, the cellular world has begun implementing the Receive Diversity feature (sometimes abbreviated to “RXDiv”). Wireless channels are never static, so the fading process described above always affects any wireless path between a radio transmitter and a radio receiver.

Diversity is one way to combat this deleterious effect. In a Receive Diversity system, the receiver has two RX antennas, creating two separate signal paths from the transmitter. This is not as complex as more advanced antenna techniques, such as Multiple-In-Multiple-Out (MIMO) or beamforming systems, but it does provide a means of signal redundancy.

In Figure 1, the mobile device is equipped with RXDiv capability. It shows that even when one of the two paths undergoes a seriously deep fade, the other is probably alright. In the worst case, the RXDiv system provides a demodulated signal that is at least as good as the better of the two transmitted paths. Note that RXDiv does not require any additional capabilities on the transmitter side of the RAN, which makes it a desirable “first step” in eventually moving towards more advanced antenna techniques. Note that this is not presently a part of the CDMA/EV-DO roadmap.

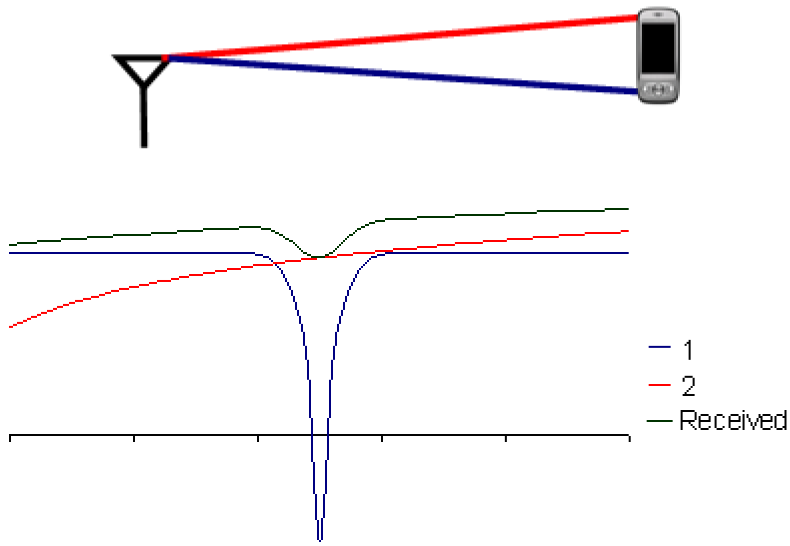

Figure 1: Receive Diversity System

To accurately test RXDiv devices, the test system must include a way to precisely control the emulated effects on the two RF paths. This is not as simple as controlling two independent paths, because the relationship between the paths is important. Simply put, a concept called “correlation” quantifies the similarity between two paths as to the effects of the RF environment. If two paths react to RF environmental changes in exactly the same way at the same time, the inter-path correlation is 1. If one path bears no relationship to the other, the correlation is 0. Let it suffice to say that the wireless channel emulator used for RXDiv testing must have complete control over both the time-varying fading and the correlation between the two paths.

Note that this is a very basic topical overview of minimum performance testing. The knowledge required to successfully implement this testing can (and does) fill hundreds of books on realistic RF environmental effects and the math required to model it.

RF Testing Specific to EV-DO Rev B

Conceptually, the radio link of RF EV-DO Rev B is little more than multiple EV-DO RevA carriers being used in parallel. At the radio layer, Rev B adds seven test cases to the industry standard Minimum Performance Conformance Tests. As with any other conformance testing performed by a professional automated system, the conformance test cases can be used again to automate device performance testing.

The Minimum Performance test cases specific to Rev B are modified versions of traffic demodulation tests and pure RF testing (for instance, receiver sensitivity, dynamic range, spurious emission testing, etc).

PROTOCOL AND INTEROPERABILITY TESTING

“Stage II” testing was roughly defined as “signaling testing” and its test cases were documented in specification number IS-898 (later named TIA-898). This included both signaling and interoperability testing, and did not discriminate between RAN signaling and inter-network-element signaling.

More on Stage II testing

A few years ago, the 3GPP2 realized that the mass of test cases contained in the TIA-898 specification was confusing to the intended audience. While the spec contained any test case roughly based on protocol, cases were not delineated in terms of the intent of the tests.

As an example, one test case was meant to ensure the proper working of the system’s Call Forwarding function. This was intended to be an interoperability test, meant to guarantee that a particular device and a particular network could successfully work with each other. But the same document was being used to test mobile device designs to ensure proper signaling. When a tester or engineer used TIA-898 to test cellular device performance, they would come to the Call Forwarding test, dutifully connect the device to the network or network emulator being used for testing, and step through the process.

In the best case, the device would display the requisite “Call Forwarded” message and testing would continue. However, because the mechanism behind call forwarding sat entirely within the network, this test merely proved that the MS received and handled the Flash With Information message properly; a function that had already been tested elsewhere.

In other cases, the engineer would begin to spend time “debugging” a problem that did not exist on the device under test. To prevent this, the 3GPP2 moved to a system wherein device signaling conformance and interoperability tests are kept separate. In addition, specific test areas, such as SMS and MEID are called out in separate documents.

This breakdown is illustrated in Figure 2 and summarized in Table 2.

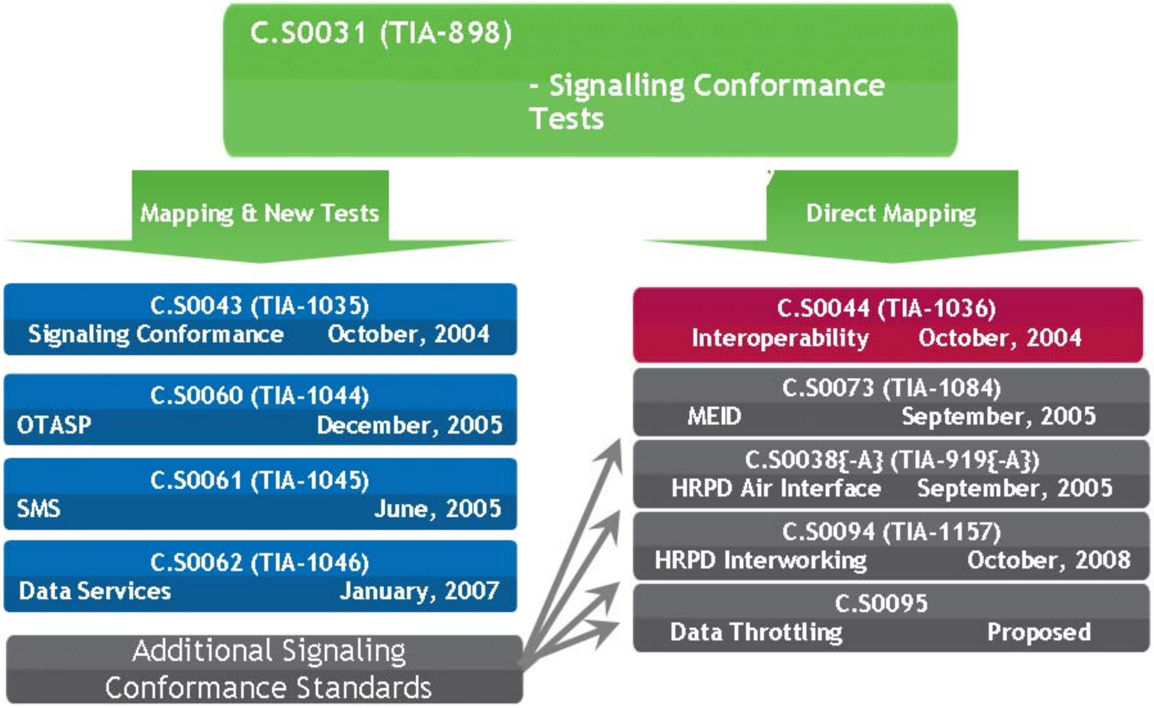

Figure 2: Evolution of TIA-898 into Separate Specifications

Table 2: Signaling Conformance Test Specifications

	3GPP2 Numbering	TIA Numbering	Document
1x	C.S0031	TIA-898	Signaling Conformance Tests for cdma2000 Spread Spectrum Systems
	C.S0043	TIA-1035	Signaling Conformance Test Specification for cdma2000 Spread Spectrum Systems
	C.S0060	TIA-1044	Signaling Conformance Test Specification for Over-the-Air Service Provisioning
	C.S0061	TIA-1045	Signaling Conformance Test Specification for Short Message Service
	C.S0073	TIA-1084	Signaling Test Specification for Mobile Station Equipment Identifier (MEID) Support for cdma2000 Spread Spectrum Systems
	C.S0044	TIA-1036	Interoperability Specification for cdma2000 Air Interface
	C.S0062	TIA-1046	Signaling Conformance Test Specification for cdma2000 Data Services
Hybrid Mode	C.S0094	TIA-1157	Signaling Conformance Test Specification for Interworking of cdma2000 1x and High Rate Packet Data Systems
EV-DO Rev. 0	C.S0038	TIA-919	Signaling Conformance Specification for High Rate Packet Data Air Interface
EV-DO Rev. A	C.S0038A	TIA-919A	Signaling Conformance Specification for High Rate Packet Data Air Interface
	C.S0073-A	TIA-1084-A	Signaling Test Specification for Mobile Station Equipment Identifier (MEID) Support for cdma2000 Spread Spectrum Systems
EV-DO Rev. B	C.S0038B	TIA-919B	Signaling Conformance Specification for High Rate Packet Data Air Interface
	C.S0073-B	TIA-1084-B	Signaling Test Specification for Mobile Station Equipment Identifier (MEID) Support for cdma2000 Spread Spectrum Systems
eHRPD/LTE	C.S0095	‹PROPOSED›	Signaling Test Specification for E-UTRAN – cdma2000 Connectivity and Interworking

Signaling Testing for EV-DO Rev B

Industry standard testing for EV-DO Rev B devices requires some additional testing beyond the test cases used for EV-DO Rev A. Specifically, there are new test functions to verify correct routing update (basic service connection and handover functionality) and for the MAC layer.

FIELD TESTING

"Stage III" testing is field testing. Although it is indispensible, field testing is neither controllable nor repeatable. Field testing is an overview, meant to ensure that the previous testing steps were performed correctly. When lab-based testing is approached with rigor and forethought, field testing is merely a "sanity check". When lab-based testing is not done correctly, prolonged field testing becomes a very expensive proposition.

TESTING FOR THE DATA-CENTRIC WIRELESS WORLD

LOCATION-BASED SERVICES (LBS) TESTING

Advances in technology brought further testing requirements, whether they were driven by industry bodies or not. Because most CDMA/EV-DO devices incorporate GPS receivers, the industry added cases specifically to test them. The TIA-916 standard outlines this mechanism.

However, the original drivers for A-GPS testing were emergency-services location capabilities mandated in some countries. In most of the world, the real driver for A-GPS functionality is the promise of revenue based on commercial location-based services. While commercial and emergency location services usually use different methodologies (IP-based user-plane communication rather than standard-driven control plane communication), the testing methodology is sound for both types of services. GPS testing is far from a stochastically exact science, and the statistical testing methods require a lot of data gathered over a long period of time. The methods used in TIA-916 are very useful in ensuring the quality of commercial services, and commercial testing systems use similar methods to quantify device performance for commercial LBS.

Table 3: Location-Based-Services Test Specifications

	3GPP2 Numbering	TIA Numbering	Document
1x	C.S0036	TIA-916	Recommended Minimum Performance Specification for C.S0022-0 Spread Spectrum Mobile Stations
1x	User Plane	User Plane	‹PROPRIETARY›
EV-DO Rev. 0	User Plane	User Plane	‹PROPRIETARY›
EV-DO Rev. A	User Plane	User Plane	‹PROPRIETARY›
Autonomous Mode			‹PROPRIETARY›
Over-The-Air (OTA)			‹CTIA PROPRIETARY›

Understanding the issues in testing A-GPS-based LBS requires some understanding of the concepts that make LBS work. The following is a very brief summary of a very complex topic.

A GPS satellite is an accurate clock that continually transits timing information. Any GPS receiver (including cellular devices) uses this timing information to calculate its distance from each satellite. Theoretically, each distance can be thought of as the surface of a sphere. When the distances to three satellites are known, the device has enough information to pinpoint its position at an intersection of the three spheres, as shown in Figure 3.

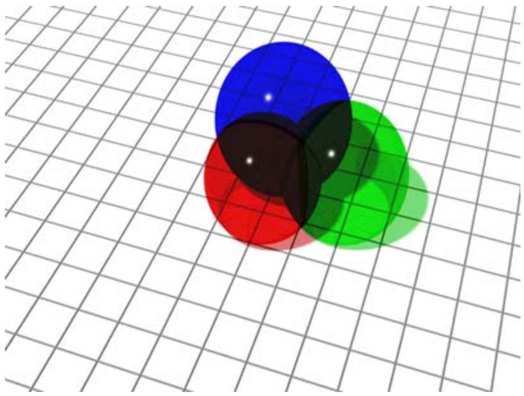

Figure 3: GPS Positioning Based on Satellite Distances

In reality, the inherent inaccuracies can be thought of as "thicknesses" in the surfaces of the spheres. These "thicknesses" are statistical, not discrete in nature, and are based on a large number of factors out of the scope of this paper. The meaningful point is that A-GPS testing is iterative, and the results analysis is statistical.

LBS testing provides an extreme example of the inherent dangers of relying on field testing. As an example, let us look at what sounds like a reasonable field testing scenario. Suppose a handset manufacturer has upgraded supporting firmware in a device, and wants to find out if the firmware provides any real improvements. The manufacturer has already invested a lot of time and money into collecting data in the field.

In the first place, there is no such thing as a small set of A-GPS test data. Because of the intrinsic variability of GPS testing, the approach is statistical rather than stochastic. In most cases, the device must make a large number of calls. For each call, the true position of the device is compared to the position as reported.

After data is gathered, each type of test normally requires two statistical calculations. Typically, the requirements look something like this:

$$C.L.\{P(\varepsilon < \sigma_1) > 0.67\} > 90\%$$

and

$$C.L.\{P(\varepsilon < \sigma_2) > 0.95\} > 90\%$$

For example, the first equation can be read as follows: "There is a sufficient amount of data gathered to say with a confidence level greater than 90% that the probability of a distance error being less than σ_1 is 67% percent, or that the probability of a distance error being greater than σ_1 is less than or equal to (1 – 0.67)" For the data in Figure 4, σ_1 is 25 m. It seems apparent that more than 67% of the data points fall within the required distance, so this test probably passes, provided a sufficient number of calls were made to calculate a confidence interval of more than 90%. In reality, this data would likely be analyzed a second time to ensure that 95% or more of the data points fall within a greater distance range (σ_2).

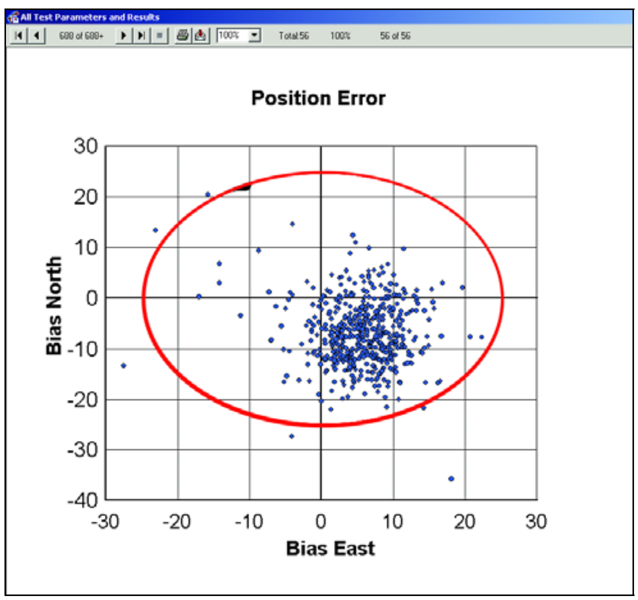

Figure 4: Graphical Representation of a Data Set for A-GPS Testing

Testing an A-GPS receiver requires a GPS satellite field (a constellation of GPS satellites) as well as a supporting network that includes the "number-crunching" element called a Position Determination Entity (PDE). While some mobile devices are able to autonomously calculate latitudes and longitudes, others offload the number-crunching to the network-based PDE. In the latter cases, the mobile devices capture satellite readings, send the captured data to the PDE, and receive latitude/longitude information in return.

There are several problems with trying to gather this kind of information in the field:

- A-GPS (or any GPS-based) testing usually takes place in a sparsely-populated area, away from skyscrapers and mountains. Most busy labs are far from these isolated areas, and travel to these areas is never cheap.

- Satellites will have changed position by the time a test is iterated. Contrary to popular belief, GPS satellites are not geo-stationary, they are “geo-synchronous”. This is a reference to the fact that they orbit the Earth roughly once every twelve hours. In addition, their paths are not as predictable as one may assume. In other words, one cannot develop a repeatable GPS field test by testing in the same place at the same time of day.

- The CDMA environment may also have changed.

- The most efficient way to perform these tests is to calculate confidence intervals as data is gathered. Otherwise, there is the risk of wasting time gathering more data than is necessary.

The solution is an automated testing system that includes not only a complete emulated CDMA network (including PDE), but a GPS satellite simulator as well. A commercial GPS satellite emulator can accurately emulate multiple GPS satellites either artificially (by providing control over individually satellites) or based on realistic testing scenarios (by replicating the satellite field at a known place and time). Figure 5 shows a simulator’s satellite field (or satellite constellation) in action. The outer ring of the diagram represents the horizon, the inner ring represents all points on the circle seen at a 45°angle, and the center point represents the point directly overhead. The right side of Figure 5 shows a close-up view of the apparent satellite movement (movement relative to a fixed position on Earth) being tracked over time.

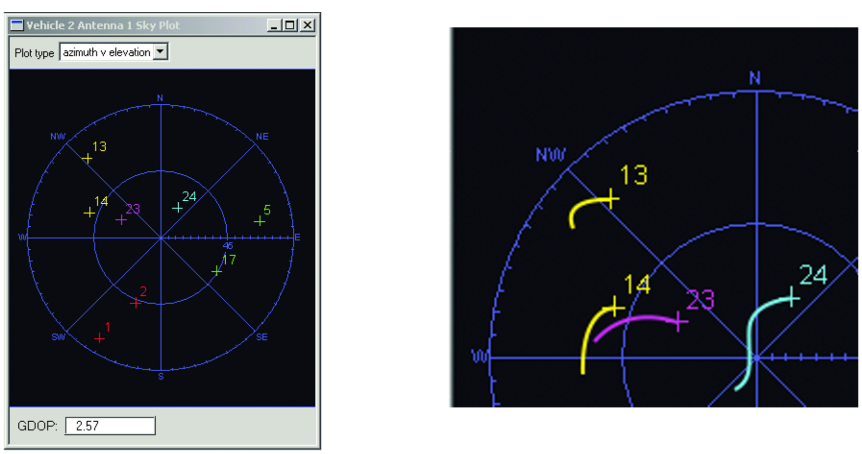

Figure 5: GPS Simulator Satellite Field View with Relative Movement

DATA SERVICE TESTING

Data service testing is an area where some of the best practices evolved without benefit of industry standards. To be clear, the TIA-918 specification does call out a set of tests meant to ensure IP functionality. For example, PPP negotiation and registration tests are called out in this spec. Once again, standards bodies have ensured that the technology works, but operators have taken it upon themselves to develop refined testing standards. The reason is apparent; if data communications are not implemented well on devices, operators bear the costs of 1) maintaining a network that spends much of its time re-transmitting data and 2) supporting subscribers who have paid for data service.

It is obvious that this data service testing involves throughput measurements using common protocols (for instance, FTP, UDP, HTTP, etc). What may not be as obvious is that channel setup/teardown times, RLP operation, round-trip message delays, and more can have expensive effects if they are not implemented well. Over the years, operators have added requirements based on other lessons learned in deployment.

A prime example is what is called “data retry testing”. Data retry testing was born when operators realized that they could not maintain complete control (the “walled garden”) over the applications that would eventually be run on their networks. After IP capabilities were available over the air, consumers demanded an increasingly varied array of services, some of which would be delivered by third parties. The question that cannot be answered without data retry testing is: “What happens when a popular wireless-based service suddenly becomes unavailable?”

In the hard-wired networking world, bandwidth is relatively cheap, so if an application begins repeatedly requesting a data connection, not much is lost. This is not the case in the wireless world. Imagine a popular client being used by tens of thousands of wireless users spread out across a country. What happens when the base stations suddenly cannot support the required service option? Or when the AAA server becomes too busy to service subscribers, or when the application server itself goes down? Network operators need to know that a simple server glitch will not cause tens of thousands of devices to simultaneously begin repeatedly inundating the network with connection requests; bringing the network to its knees.

Another example is the concept of “throttling”. Operators sometimes find that a new device or service catches on with the public, instigating an immediate increase in data usage. Because the operator needs to distribute service across all its subscribers, the operator needs a “valve on the data pipe”. This is called throttling, and its functionality must be tested on mobile devices. In this case it was the CDMA Certification Forum™ (CCF) who stepped up and reacted to the need, after some operators began to develop their own applicable test plans.

Table 4: Data Services Testing

	3GPP2 Numbering	TIA Numbering	Document
1x, EV-DO Rev 0 and EV-DO Rev A	C.S0037	TIA-918	Signaling Conformance Specification for Wireless IP Networks Version 1.0
	01-06-09-TG-Data Session Throttling Test Case Specification-1.0.0 (Contribution)		CDMA Certification Forum™ (CCF) Data Session Throttling Test Case Specification

PERFORMANCE TESTING WITH CONFORMANCE TEST CASES

While the industry relies on specific pass/fail limits to ensure the viability of a technology, existing test cases can be used to gather data that is useful throughout the lifecycle of a product. For example, by adding a few key functions to an automated system's test executive software, an automated "pass/fail" testing system can be turned into a diagnostic tool, a debugging station, a place to gather data for technical strategy planning, and more. Network operators can run comparative analyses to determine the devices that will drive positive user experiences, as well as those that will unduly burden network resources; two handsets can present the same user experience, while one eats up a disproportionate share of transmit power and/or network data bandwidth. A smart operator wants this information before tens of thousands of units start appearing on the network. Along similar lines, a handset designer can use the same set of tests to prove out incremental improvements based on firmware changes.

For example, "swept parameter" analysis is a very effective way to pinpoint surprising differences between commercially available (or approved) phones. For example, Figure 6 gives an example of a swept-parameter test suite, ready to run on the automated systems. Figure 7 shows a typical set of resulting responses for three similar handset devices when subjected to an increasingly significant impairment.

All three of the devices described in Figure 7 may meet the standard requirements, but one of them (in green) demands a greater share of network resources as the network continually re-transmits information. Owners of this device eventually become unsatisfied, affecting revenues and support costs for both the manufacturer and the network operator.

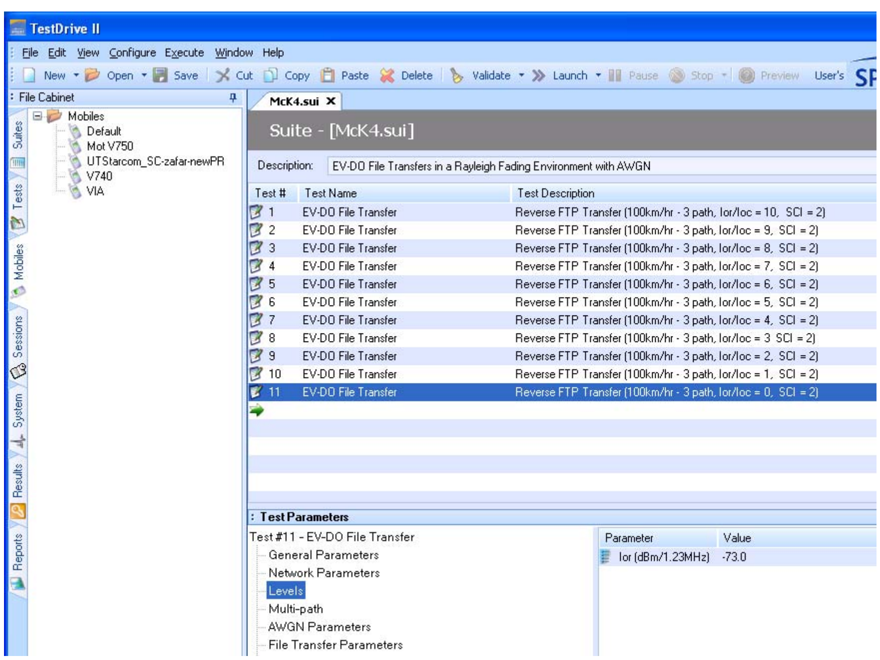

Figure 6: "Swept-parameter" Test Suite on an Automated Testing System

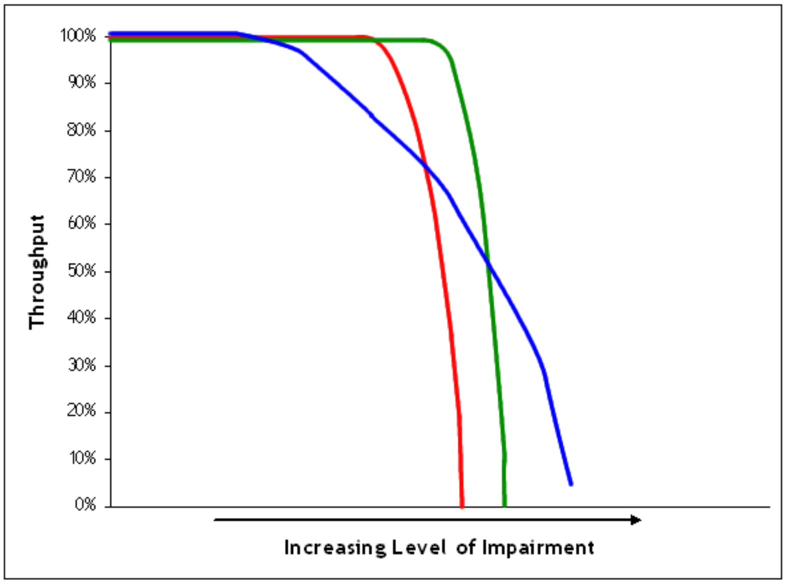

Figure 7: Throughput/Impairment Curves for Three Similar Devices

Another example would be the predictive analysis of what will happen to the LBS in the near future. As stated above, the orbits of GPS satellites are not absolutely predictable, but near-future time frames can be calculated with reasonable accuracy.

Suppose an operator notices it is three weeks away from seeing a sub-optimal satellite configuration in a heavy-usage urban area.

Referring once again to Figure 3 and its accompanying text, GPS-based location determination is based on distances thought of as spherical surfaces. The inherent errors can be thought of as "thicknesses" of these surfaces. Ideally, GPS satellites are spread out across the satellite field.

But what happens when the satellites eventually align in one way or another? The term Geometric Dilution of Precision (GDOP) is a measure of how optimally satellites are spread in the constellation. To visualize this, imagine the thick-shelled spheres generated from the satellite field shown in the right-hand side of Figure 8. Even when the "spheres" are known for all five of the satellites, their intersections are relatively large volumes. This can be interpreted to mean that GPS-based measurements will be fairly inaccurate at a specific time and place.

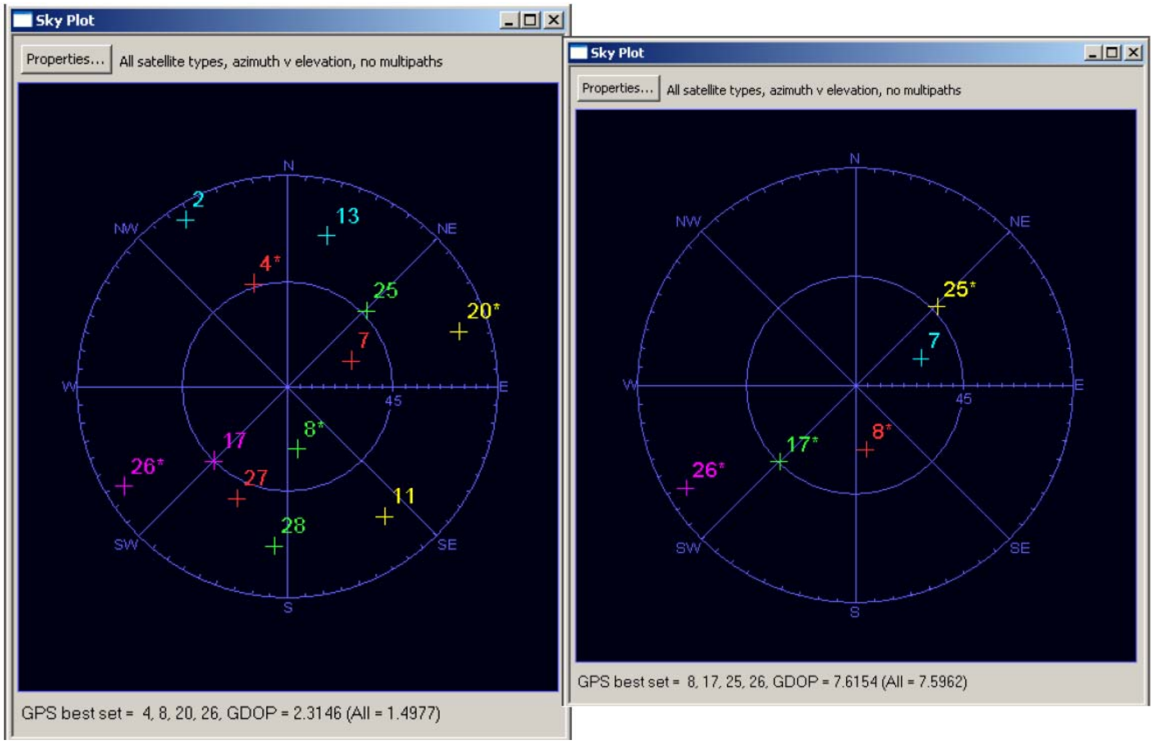

Figure 8: Satellite Fields with Good (left) and Bad (right) GDOPs

To quantify this effect, engineers can use TIA-916-based test cases with simulated satellite fields set to mimic an upcoming satellite configuration. Ideally, this is as simple as entering time and place information into software running on the automated system, as shown in Figure 9.

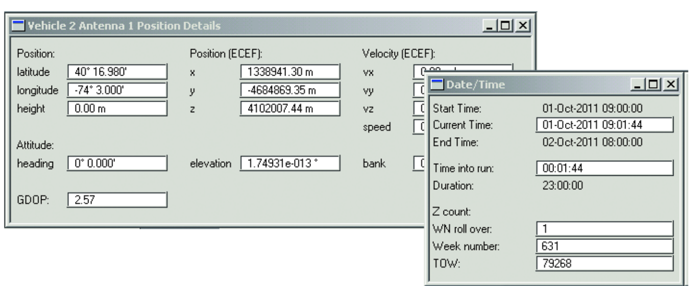

Figure 9 - Controlling GPS Satellite Fields with Time/Place Information

SUMMARY AND CONCLUSION

A standards body such as 3GPP2 takes on the monumental responsibility of ensuring that a technology works according to a set of documented requirements. Yet the charter of a standards body seems limited when compared to the charter of an operator or cell-phone maker, both of whom must maximize profits.

This paper has presented an extremely high-level overview of the basic elements of testing a CDMA/EV-DO mobile device. Any single topic presented here can easily be the subject of years of detailed study. Fortunately for device makers and operators alike, this study has been completed by manufacturers of professional automated testing systems.

The paper discussed conformance and performance testing in several key areas:

- **Minimum Performance (transmitter and receiver) Testing**: Including a discussion of RX Diversity testing.
- **Signaling Conformance Testing**: Including a discussion of how the industry standard specifications have evolved in this area.
- **Data service Testing**: Including discussions of throughput testing and “safe-for-network” Data Retry testing.
- **LBS Testing**: Including both government-mandated emergency service systems and commercial location-based services.

Thoroughly testing a mobile device is a daunting task. For CDMA and EV-DO devices, thousands of pages are devoted to the test specifications alone. Each test case is traceable to a specific requirement called out in the technical specs. Very few engineers will ever read all of the documentation that applies to device testing.

It is tempting to assume that device testing is complete after the required conformance tests are finished. However, the needs of a wireless network operator or device manufacturer are very rarely in line with the charter of the typical standards body. For this reason, the industry has adopted a de facto standard automated testing system that is flexible enough to support a wide range of controllable, repeatable performance testing.

ACRONYMS

3GPP2	3rd Generation Partnership Project (2)
AAA	Authentication, Authorization, and Accounting.
A-GPS	Assisted GPS
CDMA	Code Domain Multiple Access
EV-DO	EVolution, Data Only
GDOP	Geometric Dilution Of Precision
GPS	Global Positioning System
IP	Internet Protocol
IS	Industry Standard
LBS	Location-Based Services
MEID	Mobile Equipment Identification
OTA	Over The Air
PDE	Position Determination Entity
PPP	Point-to-Point Protocol
RAN	Radio Access Network
SMS	Short Message Service
TIA	Telecommunications Industry Association