NB-IoT Testing using Sage Instruments UCTT 8901

1. The need for NB-IoT testing

NB-IoT stands for Narrow-Band-Internet-of-Things. It is a 5G cellular based wireless wide area networking (WAN) technology defined in 3GPP Release 14, designed for the billions of low-powered IoT devices that will enable smarter and more efficient cities ("Smart City") around the world. Although it is a stripped-down 4G-LTE standard, its signaling details have changed dramatically. Other than the physical layer commonalities such as OFDM and 10 ms frame length, all other aspects, such as design and mapping of each constituent signal and physical channel are drastically different. More specifically, the synchronization signals used in NB-IoT (NPSS and NSSS) differ from those used in 4G-LTE; the mapping of reference signals (NRS) also differ from their counter-parts in 4G-LTE; the MIB-bearing broadcast channel (NPBCH) also differs from the equivalent PBCH channel in 4G-LTE. Suffice it to say, to test NB-IoT deployment, the existing 4G-LTE analysis feature on any test instruments will not work, especially for the Stand-Alone operation mode. Even for In-Band operation, there are two possibilities of "Same-PCI" and "Different-PCI" to consider. In short, NB-IoT technology needs its own dedicated analysis feature.

The 8901 UCTT (Universal Cellular Test Tool) from Sage Instruments is a portable broad-band vector signal analyzer. It not only has a wide-band FFT-based Spectrum Analyzer feature (with analysis bandwidth up to 25 MHz and arbitrary span settings beyond 25 MHz), it also has in-depth signal analysis features for all 2G, 3G, 4G, and now 5G signals. The design principle of UCTT is to bring the precision lab-equipment's performance to the field. The UCTT is a software-digital-radio (SDR) based platform with a future-proof design. It has the capability to accommodate all possible future communication technology changes down the road.

To help operators and manufactures with design and deployment of NB-IoT, Sage Instruments is proud to announce it's newest feature, the NB-IoT Analyzer for UCTT field test set platform (Shown in Figure1).

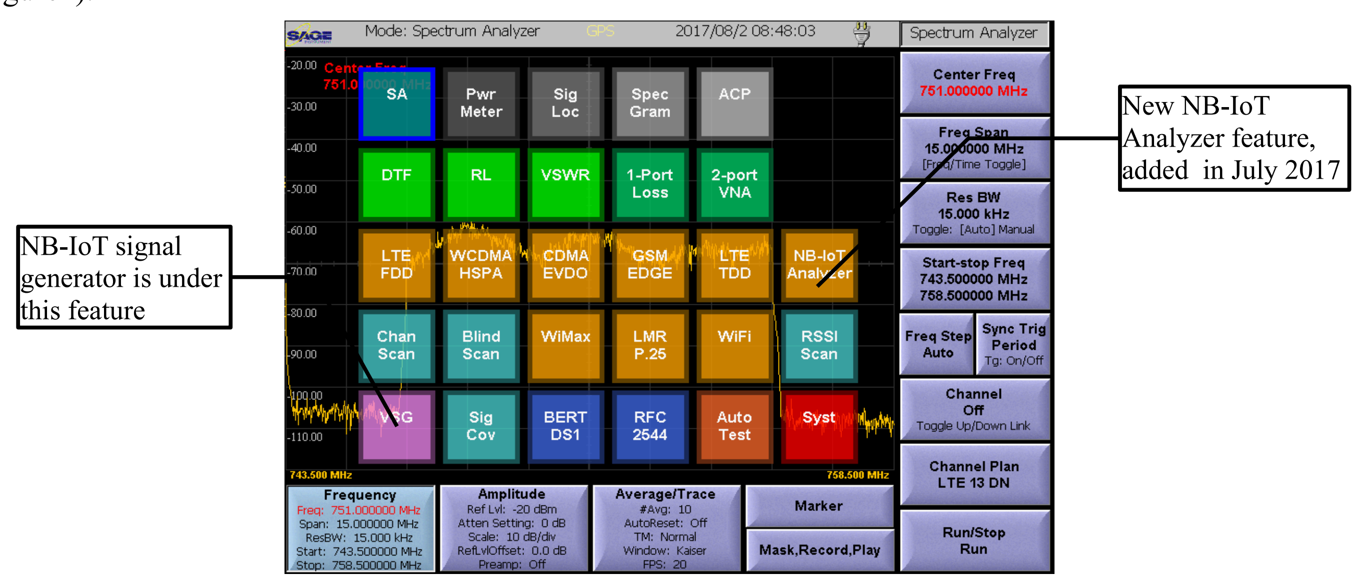


Figure 1: Mode selection dialog on UCTT showing the addition of NB-IoT.

2. NB-IoT Test and Principles

The NB-IoT Analyzer feature offered in the UCTT provides detailed analysis of the down link NB-IoT signal to determine the actual signal coverage area. It can also be used as a complete drive test system with the use of the UCTT's NB-IoT signal generator and up link interference hunting capabilities.

2.1 NB-IoT Signal Coverage Test Items

NB-IoT was designed to provide a wider-area wireless network coverage to low-powered IoT devices in order to build smarter and more efficient cities. Each NB-IoT base station may have as many as 50000 IoT devices connected to it, and some of the IoT devices may be located in places with marginal SNRs (such as buried in soil, tunnels, pipes or hidden inside large buildings etc). The design goal of NB-IoT base stations also aims to cover 20 dB more area than the existing 4G network. For example, if the current 4G RF plan requires uplink signal power of -100 dBm, then the NB-IoT signal should be designed to survive a low limit of -110 dBm.

For a mobile phone user, the signal coverage is probably not that critical. If a user does not have decent signal coverage in one place, they usually move on to another location and try again. But for stationary NB-IoT devices, this is not an option. The NB-IoT signal coverage must be guaranteed. During the initial deployment stage and later trouble-shooting during the maintenance stage, a portable precision tool like UCTT is indispensable.

In terms of signal coverage test, some may argue that the best tool is using the NB-IoT devices themselves. That is a flawed argument. The consumer-grade IoT devices can not provide a calibrated signal power measurements, not to mention precision frequency and signal quality measurements. Using the IoT devices themselves as test tool lacks the scientific objectivity and will likely provide misguided results. Objective coverage testing and trouble-shooting require accurate and repeatable measurements as provided by precision test tools like Sage's UCTT.

Sage UCTT offers the following test features that address the signal coverage issues:

- Signal strength and quality: including all signals and channels' power, EVM, SNR and frequency offset etc.
- Cell-ID (PCI) detection: the detectability of cell-ID and stability of the detected cell-ID give the simplest indication on whether certain area has required signal coverage or not.
- MIB (Master-Information-Block) decoding and CRC checking: this gives the most definitive indication on whether a location has good coverage signal or not.
- Cell-ID scanner: this test feature shows how many signals from adjacent stations and sectors are detectable in a location. This effectively shows the signal overlapping in a location. Ideally, we only want one signal to dominate. Too much overlapping in a location creates in-band interference.

When performing NB-IoT testing, Sage UCTT behaves like an actual IoT device. It constantly searches for the NPSS (Narrow-band Primary Synchronization Signal) to frame up, then decodes the NSSS (Narrow-band Secondary Synchronization Signal) to find out the cell-ID. If the decoded cell-ID is unstable and changes from time to time, then no matter how high the signal level is, the actual signal coverage in that location is poor. Sage UCTT will display "Invalid Signal". Without a detectable cell-ID, no IoT devices can connect to the base station.
NB-IoT's NBPCH (Narrow-band Public Broadcast Channel) also carries an important MIB data block. Relative to 4G-LTE, this NB-IoT MIB data block contains far more information, and every IoT device

is required to decode it first before connecting to the base station. The MIB data is also CRC checked, so naturally, it provides the most definitive indication on an area's of signal coverage quality. If the MIB data is decoded without CRC error, then the signal coverage is good. If the decoded MIB data has incorrectable bit errors that render the CRC check to fail, then the signal coverage is poor, no matter how strong the signal is. Note, the UCTT is also the only portable instrument that is capable of decoding the 4G LTE MIB data block via air (antenna) interface, thus it too is effective for locating 4G LTE site borders (small cells).

2.2 NB-IoT Drive Test

Under user's selection, Sage UCTT can also log (record) the test results along with GPS location and time information. The log file formats can be either CSV (simple text file meant for Spreadsheet type of SW App to open) or KML (meant for GoogleEarth app to open). In this way, Sage UCTT completely replaces the "traditional" drive test system that requires the tethering of a dedicated PC. Sage UCTT is battery-powered and functions independently and does not need any PC to baby-sit it.

2.3 NB-IoT Signal Generator

Sage UCTT can also generate NB-IoT signal. At the initial deployment stage or setting up a temporary base station, the need to determine an optimal location for the base station (antenna siting) naturally arises. For this task, a portable signal generator should be very useful. Using actual base station equipment becomes impractical due to its size and amount of support gear. Using a portable UCTT as a signal generator, and another UCTT as signal analyzer, a team can quickly solve the antenna siting problem in the most economical way.

2.4 NB-IoT up link interference hunting

Before deploying NB-IoT signal, one has to make sure the designated frequency channel is free from any interference signals, especially at the uplink channel. The NB-IoT devices are designed to be low-powered devices, and some of them may also be located far away from the base station. So the up link signal received by the NB-IoT base station will be considerably lower than the down link signal. Any slightest interference signal present in the up link will cause "connection blocking" at the uplink.

When hunting for spectrally-stable interference signal, any Spectrum Analyzer will "probably" work. However, if the interference signal is a spectrally-unstable time-varying transient (short-durationed) signal, then the traditional "swept-analyzer" will not be effective. The effective POI (Probability of Intercept) of a swept-analyzer is just too low to meaningfully capture any short-duration broad-band signal. As a broad-band FFT analyzer, Sage's UCTT has the highest effective POI among all portable RF instruments. Its 3-trace mode, burst-mode, power-spectral-density display mode and real-time trace recording features are field proven providing UCTT users the best probability of finding those hard-to-find short-duration interference signals. Even for the continuous, spectrally-stable interferers like cable leaks etc. The UCTT allows hunters to drive and detect low level interference signals where sweepers miss due to their noise floors being too high (fast sweeping mode) or missed because sweep time is too slow (low noise mode).

UCTT's NB-IoT test offers 5 sub-features, each with different displays. We will go through each of them in the following sections.

3. NB-IoT test sub-feature 1: synchronized time-domain power and spectral displays

The first sub-feature shows the NB-IoT signal power characteristics in both time-domain and frequency domain, as shown in Figure 2. The NB-IoT signal mapping scheme simply maps different signals and channels to different sub-frames (each sub-frame is 1 ms long), so the time-domain power display clearly shows the power envelop of different physical signals and channels. Each of them is also colored differently as shown in Figure 2. The decoded cell-ID and measured frequency offset information is also shown in the lower spectrum display. If the MIB data is decoded successfully, the display will also indicate “MIB OK” with decoded SFN (Sequence Frame Number) number. If MIB contains error, it will display “MIB error”. If the cell-ID is not even decodable or unstable, then the whole string will read “Invalid Signal”.

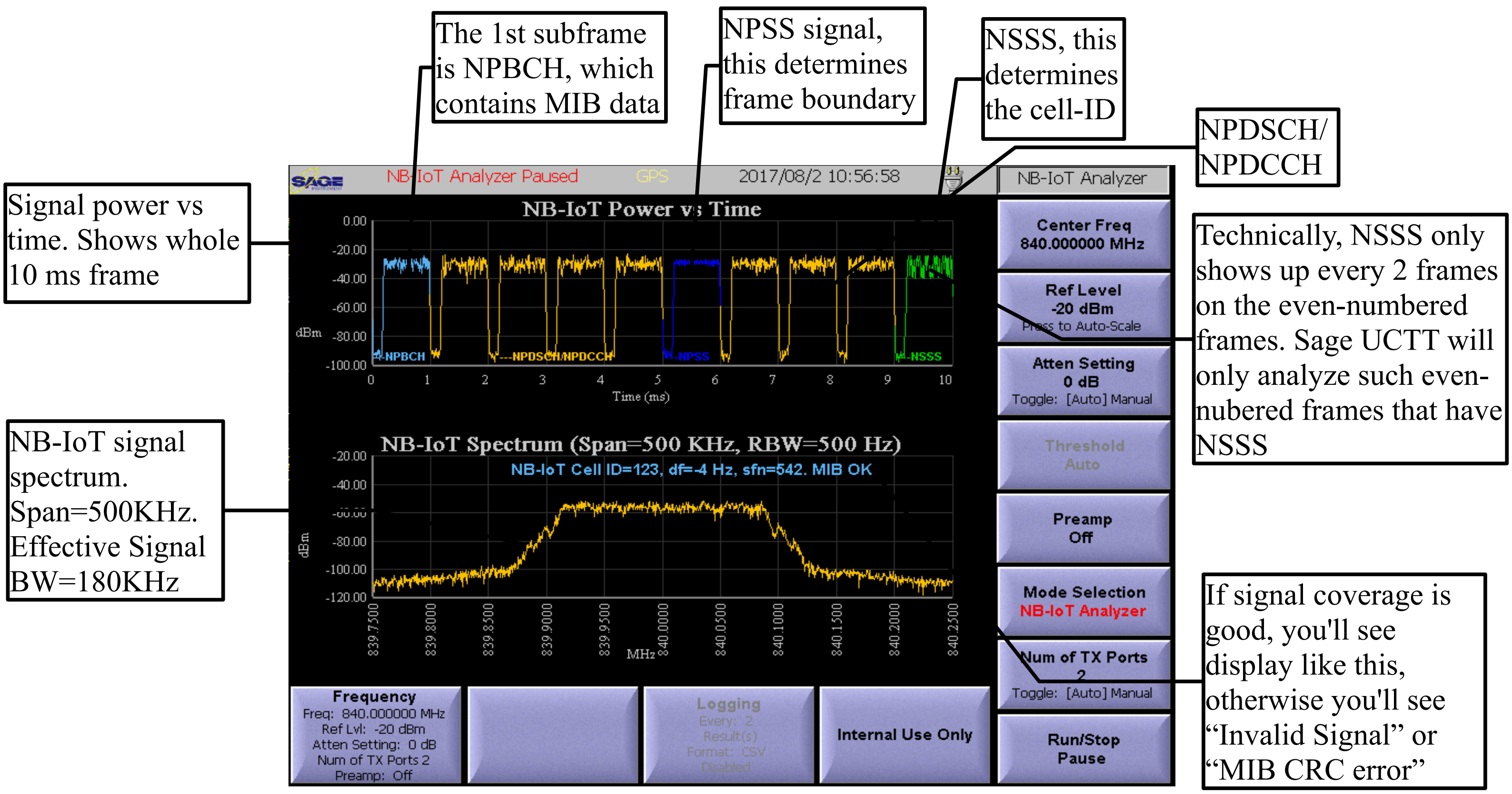


Figure 2: NB-IoT test's Sub-feature, signal power time and frequency-domain characteristics

The upper part of Figure 2 shows the signal power envelop in the whole 10 ms frame, which contains 10 sub-frames. The light-blue-colored first sub-frame is NPBCH; the yellow-colored sub-frames are NPDCH/NPDCCH channels; the middle deep-blue-colored sub-frame is the NPSS signal and the last green-colored sub-frame is the NSSS signal. You'll notice that there are low-powered gaps at the beginning of each sub-frame. This is required by the standard to keep the first 3 symbols (each sub-frame has 14 symbols) free of any NB-IoT signal in order to maintain backward compatibility with the existing 4G-LTE signals. If you look further, you'll see the NPSS signal is slightly less than the NSSS signal. We'll come back to this point later with detailed explanations.

The lower part of Figure 2 shows the NB-IoT signal's spectrum. The whole displayed span is 500 KHz wide, and the effective signal bandwidth of NB-IoT signal is 180 Khz, corresponding to exactly one 4G-LTE resource block.

At the lower spectrum display, the text string also shows the detected “cell-ID”, frequency offset, SFN number and MIB status. If the cell-ID is non-decodable or unstable, UCTT will display “Invalid Signal”. If only MIB fails (has CRC error), it will then show (toward the end) “MIB CRC error”. This display is the simplest signal coverage quality indicator.

4, NB-IoT frame summary

The 2nd sub-feature of NB-IoT test shows the key quality indication parameters of all constituent signals and physical channels within a frame, as shown in Figure 3.

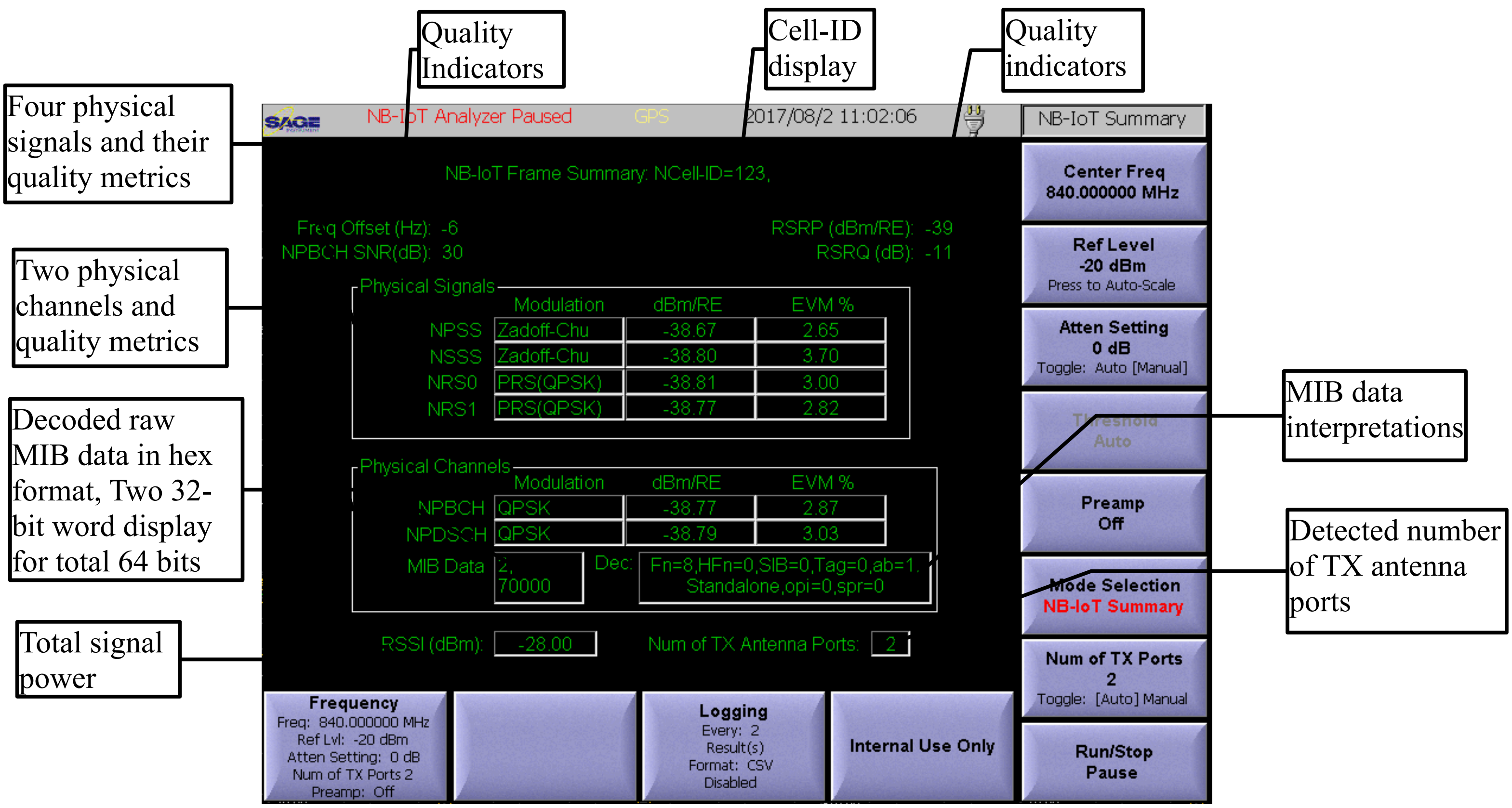


Figure 3, NB-IoT Frame Summary screen.

As shown in Figure 3, this frame summary screen contains the largest amount of information. The power and quality (EVM) of each one of the four signals and each one of the two physical channels are all measured and displayed, along with the overall frequency offset, SNR, RSRP, RSSI and the number of TX antenna ports being detected. If a user has *a priori* information on the TX antenna ports (1 or 2), he/she can also enter it manually using the right menu button 2nd from the bottom.

The MIB data block deserves further explanations. The MIB raw data is 34-bit long, which requires 9 hex digits to represent (each hex digit represents 4 bits). The 34-bit data represent the following information:

systemFrameNumber-MSB(4-bit),
hyperSFN-LSB(2-bit),
schedulingInfoSIB1(4-bit),
systemInfoValueTag(5-bit),
ab-Enabled(1-bit),
operationMode(2-bit,0=>Inband-SamePCI, 1=>inband-DifferentPCI, 2=>guardband, 3=>standalone),
operationModeInfo(5-bit),
spare(11-bit)

If the MIB data block contains CRC errors, the raw data display will be “N/A”. The MIB data decoding not only provides the best indicator of signal coverage quality, it also verifies the configuration and parameter settings of a particular base station or sector.

5. NB-IoT Resource Elements View

The 3rd sub-feature of UCTT's NB-IoT test displays every RE (Resource Element) within the 10 ms frame and they are colored differently for easy identifications. The vertical axis shows the 12 sub-carriers, and each “bar” height indicates the power level of a particular RE. The horizontal axis corresponds to the 140 symbols within the 10 ms frame.

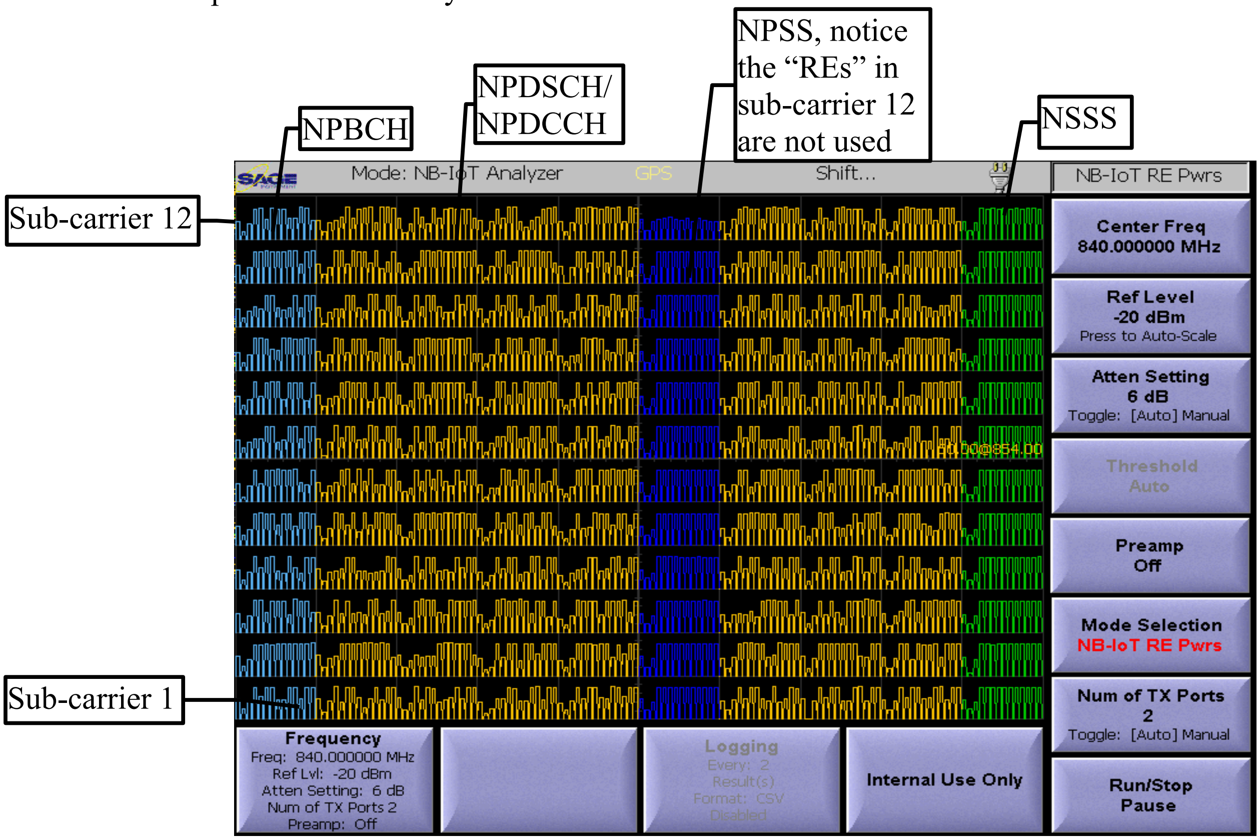


Figure 4, the Resource Elements View of a whole 10 ms frame worth of NB-IoT signal.

Figure 4 shows all the 12x140=1680 Resource Elements within a 10ms frame. The “bar” height of each RE corresponds to its power level. From here, one can see the detailed mapping of each signal and channel to the resource elements. For example, the NPBCH channel uses the first 14x12 elements, but the first 3 symbols are not used (so as to be compatible with the existing 4G-LTE signal for in-band operation), hence the actual RE used is 11x12. The same goes with NSSS signal. Even stranger is the NPSS signal. It not only just uses the last 11 symbols of sub-frame 5, it also does not use the highest sub-carrier either. So the actual RE used for NPSS is only 11x11=121. This is to preserve the unique auto-correlation property of the signal, and this also explains why in Figure 2, the NPSS's power level is slightly lower than the others. Leaving the first 3 symbols unused for each sub-frame seems wasteful, but this makes NB-IoT compatible with the existing 4G-LTE signal. Technically, only the in-band operation modes require this, but the out-of-band operation also follows the same convention. A necessary resource waste in order to preserve compatibility. In further details, the RE locations reserved for RS (Reference Signals) of 4G-LTE signal (in symbols 0, 1 and 4 of each time slot) associated with all 4 antenna ports (which means every 3 RE) can not be used either to avoid conflict with LTE signal. The RS signals of NB-IoT itself are mapped to symbols 5 and 6 of each time slot.

6. NB-IoT Signal I-Q Constellations

The 4th sub-feature of UCTT's NB-IoT shows the I-Q constellations of all the constituent physical signals and channels as shown in Figure 5. Both the NPSS and NSSS signals come from the Zadoff-Chu sequence, so their constellations look bit confusing. The NSSS signal involves further “frequency-shifting” based on frame number, making its constellation more mysterious. Both NPBCH and NPDSCH, after MIMO decoupling, exhibit the standard QPSK constellation. In Figure 5, the different signals and channels are scaled differently so that they can all be displayed in the same screen without too much overlapping.

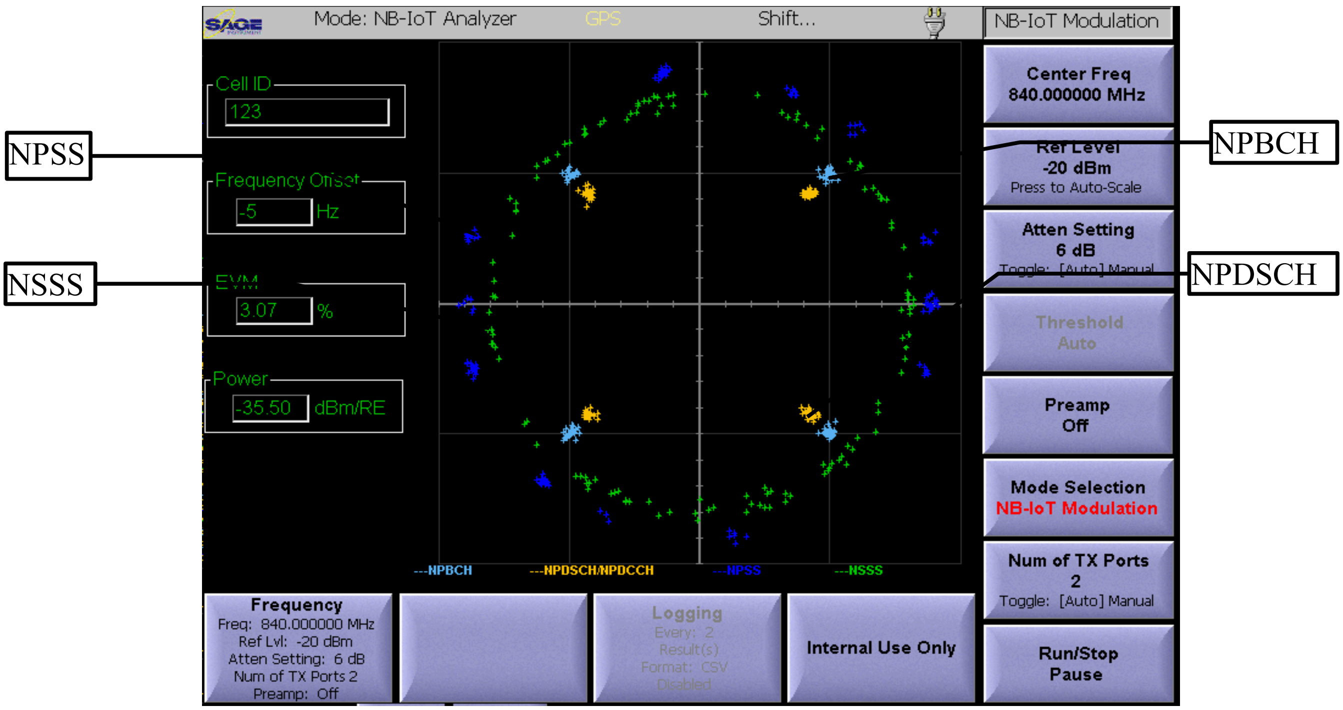


Figure 5, constellation display of all signals and channels of the NB-IoT signal.

7. NB-IoT cell-ID scanner

The 5th sub-feature of UCTT's NB-IoT test is the cell-ID scanner. We want good signal coverage for every location, however, at each location, we also only want one base station's one sector's signal to dominate. If a location receives too much signal overlapping from adjacent sectors and base stations, that will seriously degrade the signal quality due to in-band interference. The purpose of this cell-ID scanner is to find out how much signal overlapping there is at a test location. It can display up to 9 cell IDs, with detection threshold adjustable by the right menu button labeled “Threshold” shown in Figure 6.

Figure 6, NB-IoT test's cell-ID scanner results display.

7.1 Discussion of RSRP vs Sync-Power

The cell-ID scanner in Figure 6 shows both RSRP and Sync-power. RSRP stands for Reference Signal Received Power and Sync-power is the power level of NSSS signal that determines the cell-ID. In 4G-LTE, the SSS signal only occupies the mid 62 RE on two symbols in a frame, whereas the RS signal shows up on 40 symbols. Take the 20-MHz LTE signal as an example, the RS signal occupies 8000 RE whereas the SSS only occupies 2x62. So for cell-ID scan in 4G-LTE, it is common to actually search for the RS signals, not relying on the weak SSS signal, and it is also customary to use the RSRP as an indicator for the overall signal strength associated with a particular sector.

For NB-IoT, however, the situation has changed. Within a 10 ms frame, the RS signal only occupies 64 RE, whereas the NSSS actually takes up 132 RE. Furthermore, the NSSS signal has better orthogonality design for countering in-band interference, hence the NSSS-based Sync-power metric is a better overall signal strength indicator associated with a particular sector. Also keep in mind that both the Sync-power and RSRP metrics in the table of Figure 6 are “correlated powers”, not simple raw RMS powers. The correlated power measurements better correct the in-band interference in an area with lots of signal overlapping.

8, NB-IoT Signal Source Function

To help deploy the NB-IoT service, we also added the NB-IoT signal generator function into our VSG feature. Please refer to Figure 1 on how to access the VSG (Vector Signal Generator) feature. Once entering VSG feature, pressing the “Modulation” button, you'll see a list of signal types, as shown in Figure 7. Notice that we have added two NB-IoT types: NB-IoT 4/5 Frame and NB-IoT Full-frame. To simulate an NB-IoT base-station, you must use the “NB-IoT Full Frame” on one dedicated UCTT, and then use another UCTT to analyze the generated signal as various locations. The “NB-IoT 4/5 Frame” is only used to simulate the spectrum of an NB-IoT signal and a single UCTT can leave the generator running in the background while also switching to the Spectrum Analyzer.

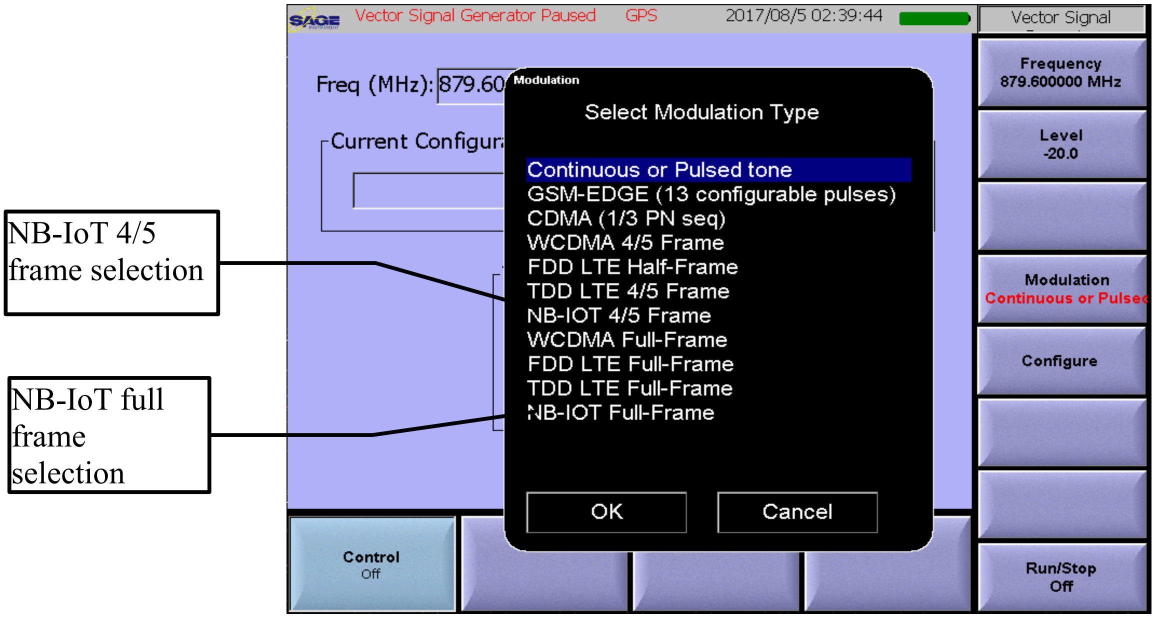


Figure 7, Signal type selection showing NB-IoT additions.

9, NB-IoT up link interference clearance

UCTT is not only a full-featured vector signal analyzer, it is also a broad-band FFT Spectrum Analyzer ideal for finding the weak intermittent interference signals in the up link. The SA feature (see Figure 1) supports a wide list of special trace modes that are designed for finding transient short-durationed burst signals or finding weaker signals under stronger signals. Coupled with the built-in user-adjustable synchronous triggering, UCTT's SA feature can also be fine-tuned to analyze the exact time-slot of an NB-IoT or 4G-LTE signals. Here we only show two pictures, in Figures 8 and 9, the 3-trace mode and the Power-Spectral-Density View. Both demonstrate UCTT's unique capability to show weaker interference signals hidden under stronger time-varying signals.

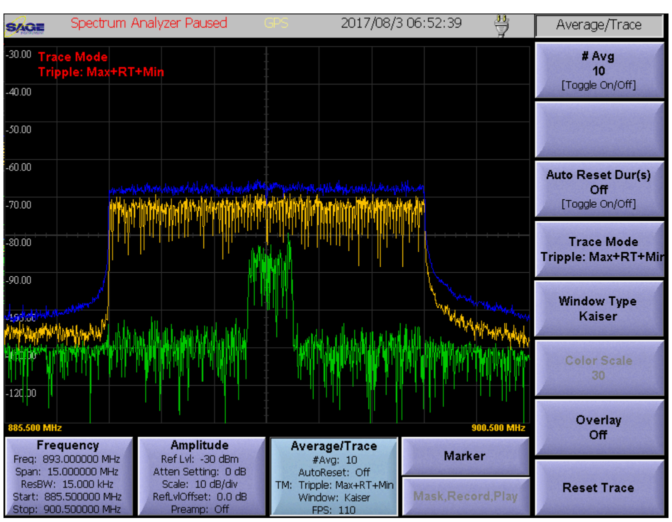


Figure 8, 3-trace mode display, showing the clear presence of an EVDO signal hidden under the stronger TDD-LTE signal.

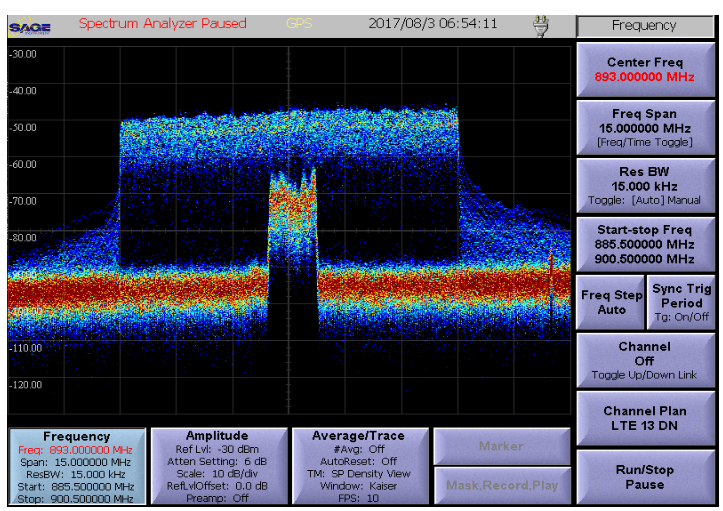


Figure 9, Spectral-power-density view also shows the EVDO signal underneath the stronger TDD-LTE signal.

Other trace modes, such as the max-energy burst mode and continuous max-energy burst mode, will enable the 100% POI (Probability-of-Intercept) for signal as short as 100 us. See Figures 10 and 11 for examples.

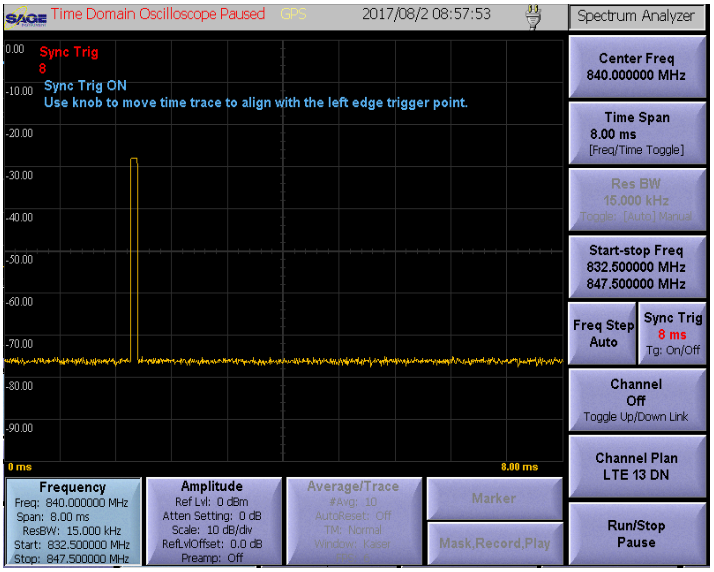


Figure 10, time-domain (zero-span) view of a 100 us long signal pulse.

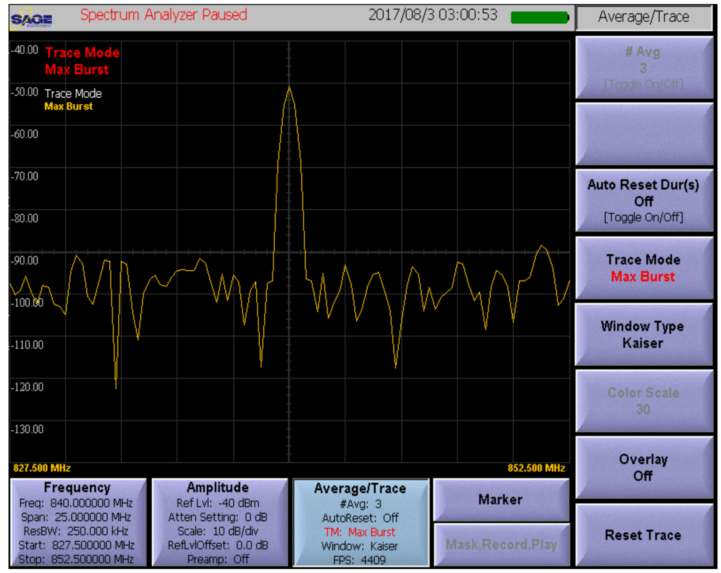


Figure 11, Spectral view of the pulsed-signal at the left in Max-burst mode with 100% POI. The displayed frame rate is over 4400 for this Span/RBW (25MHz/250KHz) setting.

10. Other wireless wide-area-network IoT technologies

Although we have been focusing on NB-IoT here, it does not mean that UCTT does NOT test the other technologies. To the contrary, UCTT provides features to test all other forms of WAN-IoT technologies. Figure 12 is a list of the other IoT technologies from 3GPP.

Summary for eMTC, NB-IOT and EC-GSM-IoT

	eMTC (LTE Cat M1)	NB-IOT	EC-GSM-IoT
Deployment	In-band LTE	In-band & Guard-band LTE, standalone	In-band GSM
Coverage*	155.7 dB	164 dB for standalone, FFS others	164 dB, with 33dBm power class 154 dB, with 23dBm power class
Downlink	OFDMA, 15 KHz tone spacing, Turbo Code, 16 QAM, 1 Rx	OFDMA, 15 KHz tone spacing, 1 Rx	TDMA/FDMA, GMSK and 8PSK (optional), 1 Rx
Uplink	SC-FDMA, 15 KHz tone spacing Turbo code, 16 QAM	Single tone, 15 KHz and 3.75 KHz spacing SC-FDMA, 15 KHz tone spacing, Turbo code	TDMA/FDMA, GMSK and 8PSK (optional)
Bandwidth	1.08 MHz	180 KHz	200kHz per channel. Typical system bandwidth of 2.4MHz [smaller bandwidth down to 600 kHz being studied within Rel-13]
Peak rate (DL/UL)	1 Mbps for DL and UL	DL: ~50 kbps UL: ~50 for multi-tone, ~20 kbps for single tone	For DL and UL (using 4 timeslots): ~70 kbps (GMSK), ~240kbps (8PSK)
Duplexing	FD & HD (type B), FDD & TDD	HD (type B), FDD	HD, FDD
Power saving	PSM, ext. I-DRX, C-DRX	PSM, ext. I-DRX, C-DRX	PSM, ext. I-DRX
Power class	23 dBm, 20 dBm	23 dBm, others TBD	33 dBm, 23 dBm

* In terms of MCL target. Targets for different technologies are based on somewhat different link budget assumptions (see TR 36.888/45.820 for more information).

Figure 12, summary of all WAN IoT technologies.

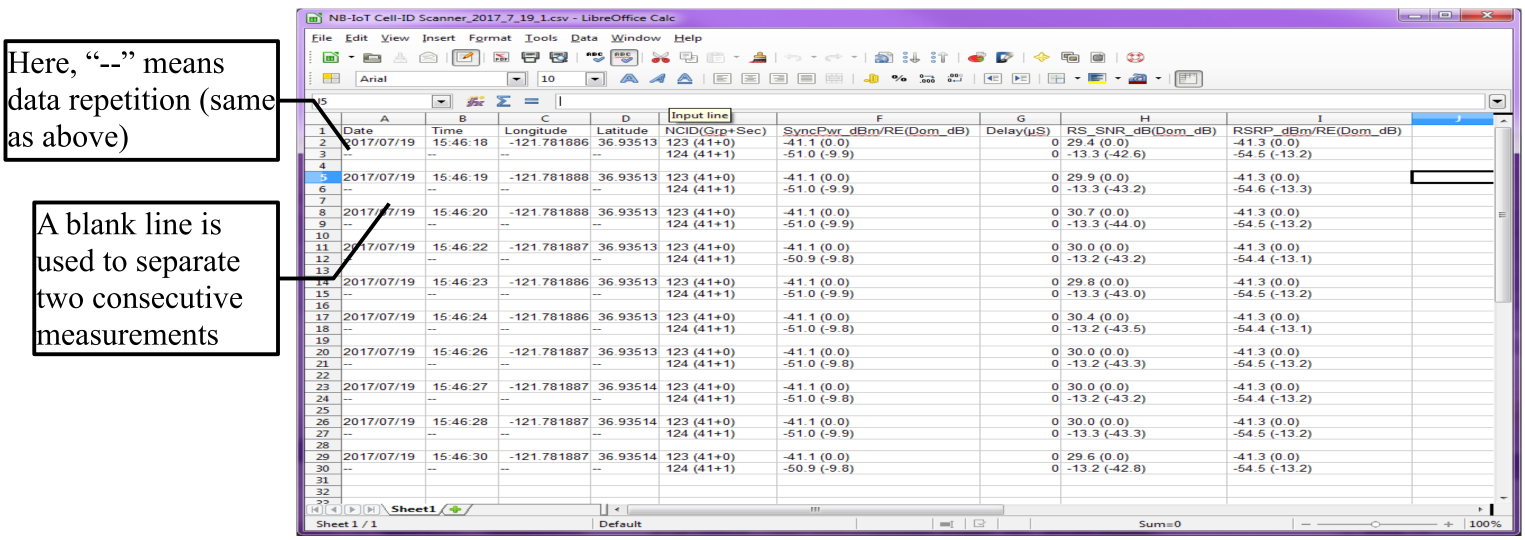
As shown in Figure 12, the eMTC is just a narrow-band LTE, and Sage UCTT offers in-depth LTE analysis features for both FDD and TDD across all possible bandwidths from 1.4 (or 1.08) MHz to 20 MHz. The other EC-GSM-IoT is just GMSK-based GSM/EDGE. UCTT's GSM analysis feature autodetects GSM and EDGE and presents full analysis capabilities.

In short, with this latest NB-IoT addition, Sage UCTT offers test solutions to all WAN IoT technologies.

11. Data logging file examples and NB-IoT drive test

Sage UCTT comes with built-in GPS receiver and also has data logging features that render it a good drive test system. Even better than the other drive system that needs a PC to baby-sit it, Sage UCTT is fully independent that does not need any PCs. When logging data, the test results are logged along with GPS locations and time information. Two file formats are provided: CSV and KML. CSV file format provides a simple text-file format suitable for opening by Spreadsheet type of SW application. KML is designed for working with GoogleEarth.

For this NB-IoT test, two of the sub-features allow data logging, the "Frame Summary" sub-feature (Figure 3) and "Cell-ID Scanner" sub-feature (Figure 6). We provide some data-logging file examples here in Figures 13 and 14.



	A	B	C	D	E	F	G	H	I
1	Date	Time	Longitude	Latitude	NCID(Grp+Sec)	SyncPwr_dBm/RE(Dom_dB)	Delay(µS)	RS_SNR_dB(Dom_dB)	RSRP_dBm/RE(Dom_dB)
2	2017/07/19	15:46:18	-121.781886	36.93513	123 (41+0)	-41.1 (0.0)	0	29.4 (0.0)	-41.3 (0.0)
3	--	--	--	--	124 (41+1)	-51.0 (-9.9)	0	-13.3 (-42.6)	-54.5 (-13.2)
4									
5	2017/07/19	15:46:19	-121.781888	36.93513	123 (41+0)	-41.1 (0.0)	0	29.9 (0.0)	-41.3 (0.0)
6	--	--	--	--	124 (41+1)	-51.0 (-9.9)	0	-13.3 (-43.2)	-54.6 (-13.3)
7									
8	2017/07/19	15:46:20	-121.781888	36.93513	123 (41+0)	-41.1 (0.0)	0	30.7 (0.0)	-41.3 (0.0)
9	--	--	--	--	124 (41+1)	-51.0 (-9.9)	0	-13.3 (-44.0)	-54.5 (-13.2)
10									
11	2017/07/19	15:46:22	-121.781887	36.93513	123 (41+0)	-41.1 (0.0)	0	30.0 (0.0)	-41.3 (0.0)
12	--	--	--	--	124 (41+1)	-50.9 (-9.8)	0	-13.2 (-43.2)	-54.4 (-13.1)
13									
14	2017/07/19	15:46:23	-121.781886	36.93513	123 (41+0)	-41.1 (0.0)	0	29.8 (0.0)	-41.3 (0.0)
15	--	--	--	--	124 (41+1)	-51.0 (-9.9)	0	-13.3 (-43.0)	-54.5 (-13.2)
16									
17	2017/07/19	15:46:24	-121.781886	36.93513	123 (41+0)	-41.1 (0.0)	0	30.4 (0.0)	-41.3 (0.0)
18	--	--	--	--	124 (41+1)	-51.0 (-9.8)	0	-13.2 (-43.5)	-54.4 (-13.1)
19									
20	2017/07/19	15:46:26	-121.781887	36.93513	123 (41+0)	-41.1 (0.0)	0	30.0 (0.0)	-41.3 (0.0)
21	--	--	--	--	124 (41+1)	-51.0 (-9.8)	0	-13.2 (-43.3)	-54.5 (-13.2)
22									
23	2017/07/19	15:46:27	-121.781887	36.93514	123 (41+0)	-41.1 (0.0)	0	30.0 (0.0)	-41.3 (0.0)
24	--	--	--	--	124 (41+1)	-51.0 (-9.8)	0	-13.2 (-43.2)	-54.4 (-13.2)
25									
26	2017/07/19	15:46:28	-121.781887	36.93514	123 (41+0)	-41.1 (0.0)	0	30.0 (0.0)	-41.3 (0.0)
27	--	--	--	--	124 (41+1)	-51.0 (-9.9)	0	-13.3 (-43.3)	-54.5 (-13.2)
28									
29	2017/07/19	15:46:30	-121.781887	36.93514	123 (41+0)	-41.1 (0.0)	0	29.6 (0.0)	-41.3 (0.0)
30	--	--	--	--	124 (41+1)	-50.9 (-9.8)	0	-13.2 (-42.8)	-54.5 (-13.2)
31									
32									

Figure 13, CSV file format example for the NB-IoT Cell-ID scanner feature.

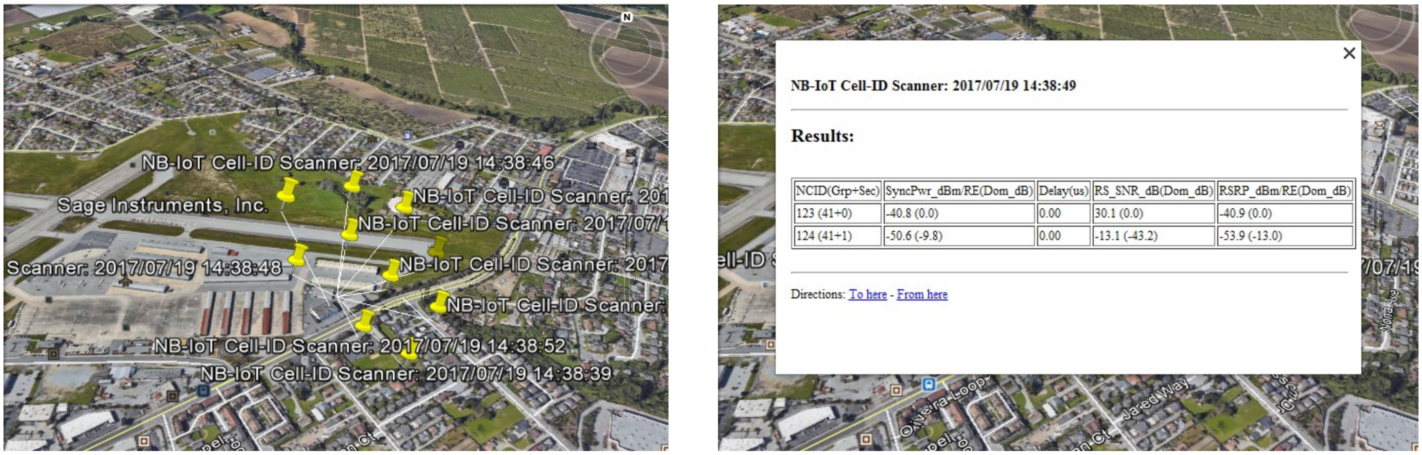


Figure 14, KML data logging example. The left shows how GoogleEarth opens the KML file. Click on any one of the yellow pin, you'll see a table of results shown at the right.

12. About Sage Instruments

Sage Instruments is a leader in the telecommunications and wireless test industry. Building test sets, automated test systems, local loop test systems, and automated wireless test systems used worldwide by leading telecom and wireless providers, manufacturers, and end users. Each of our products provide customers with the value, performance, and reliability demanded in the dynamic and competitive telecommunications and wireless industries. The company offers innovative solutions for the development, installation, management and maintenance of converged, IP fixed and mobile networks—from the core to the edge. Key technologies supported include 2G/3G/4G/5G, IMS, and VoIP supporting more than 20,000 telecom customers worldwide. For more information, visit www.sageinst.com.