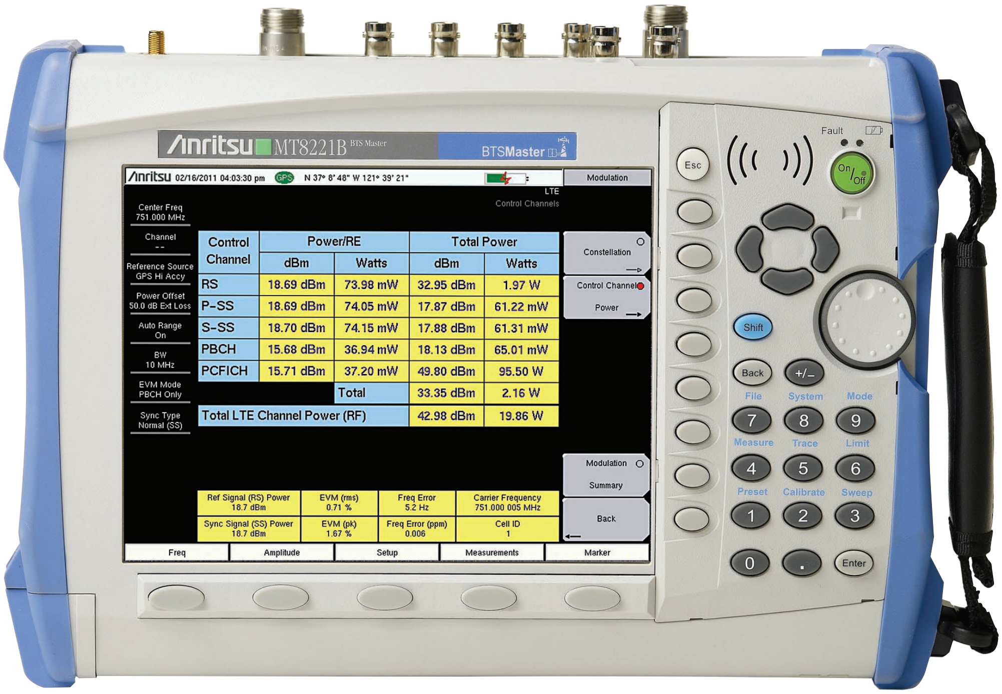
Application Note

Using Sync Signal Power Measurements for LTE Coverage Mapping

The Synchronizing Signal (SS) from LTE base station (eNodeB) is a powerful tool for helping network operators understand the downlink signal quality for LTE networks. The Anritsu Application Note “LTE Downlink Coverage Mapping using a Base Station Analyzer” explains how Anritsu provides mapping of LTE downlink coverage. This functionality is part of the LTE measurement options for Anritsu handheld instruments such as the MT8221B BTS Master. The approach outlined in that document is more convenient and less expensive than drive test systems, which most network operators have only a few of. This application note will explain in more detail how Anritsu handheld instruments use the LTE Evolved Node B (eNodeB) synchronization signal (SS) power to estimate LTE coverage, as well as how you can interpret these measurements in other ways.



Control Channel	Power/RE		Total Power	
	dBm	Watts	dBm	Watts
RS	18.69 dBm	73.98 mW	32.95 dBm	1.97 W
P-SS	18.69 dBm	74.05 mW	17.87 dBm	61.22 mW
S-SS	18.70 dBm	74.15 mW	17.88 dBm	61.31 mW
PBCH	15.68 dBm	36.94 mW	18.13 dBm	65.01 mW
PCFICH	15.71 dBm	37.20 mW	49.80 dBm	95.50 W
		Total	33.35 dBm	2.16 W
Total LTE Channel Power (RF)			42.98 dBm	19.86 W

Ref Signal (RS) Power 18.7 dBm	EVM (rms) 0.71 %	Freq Error 5.2 Hz	Carrier Frequency 751.000 005 MHz
Sync Signal (SS) Power 18.7 dBm	EVM (pk) 1.67 %	Freq Error (ppm) 0.006	Cell ID 1

Figure 1. Anritsu BTS Master MT8221B.

Background on LTE Sync Signals

When LTE User Equipment (UE) connects to an LTE network, it must first do a cell search. This involves synchronizing the radio's symbol and frame timing with the base station. There are 3 steps for this:

1. Symbol timing acquisition, which is needed to determine the correct symbol start point in time.
2. Carrier frequency synchronization, which helps compensate for effect of frequency errors resulting from Doppler shift and frequency reference drift in the UE
3. Sampling clock synchronization.

The UE also needs to obtain other information from the base station, including the physical cell identification code (PCID), and cyclic prefix length. This information is provided by two synchronizing signals broadcast by each eNodeB. The primary synchronization signal (P-SS) is used to synchronize slot timing and provides part of the PCID, called the Physical-Layer Identity, which has three possible values. The secondary synchronization signal (S-SS) is used to synchronize frame timing by identifying the slots within the frame. The S-SS also provides the rest of the PCID, called the Physical-Layer Cell-Identity Group, which has 168 possible values. The Physical-Layer Identify and Physical-Layer Cell-Identity Group together define 3*168=504 different PCIDs.

The base station sends the sync signals twice during each 10 ms radio frame. For Frequency Division Duplex (FDD) mode, they are located in the last 2 OFDM symbols of the first and 11th slot of each radio frame, with the P-SS following the S-SS. The Time Division Duplex (TDD) mode uses a somewhat different position for the sync signals – the last symbol in second slot (end of subframe 0) & third symbol of the third slot which is also the beginning of subframe 1.

These locations allow the UE to capture the slot boundary timing regardless of the cyclic prefix length. The S-SS provides frame timing by alternating in a specific manner between the 2 different locations in the frame. So called "Zadoff-Chu" sequences are used by the sync signal to indicate the PCID independent of delay from the eNodeB, and therefore UE position. The UE can also determine the cyclic prefix length by checking the time difference between the P-SS and the S-SS.

In the frequency domain, the P-SS and S-SS always occupy the central six resource blocks, or 1.4 MHz, for both duplex modes. This arrangement makes it possible for the UE to synchronize to the network without advance knowledge of the allocated bandwidth. A total of 62 subcarriers (out of the 72 subcarriers available) are used for the sync signals, with 31 subcarriers mapped on each side of the DC subcarrier. See Figure 2 for a graphical depiction of where the Sync Signals are located inside the LTE Radio frame.

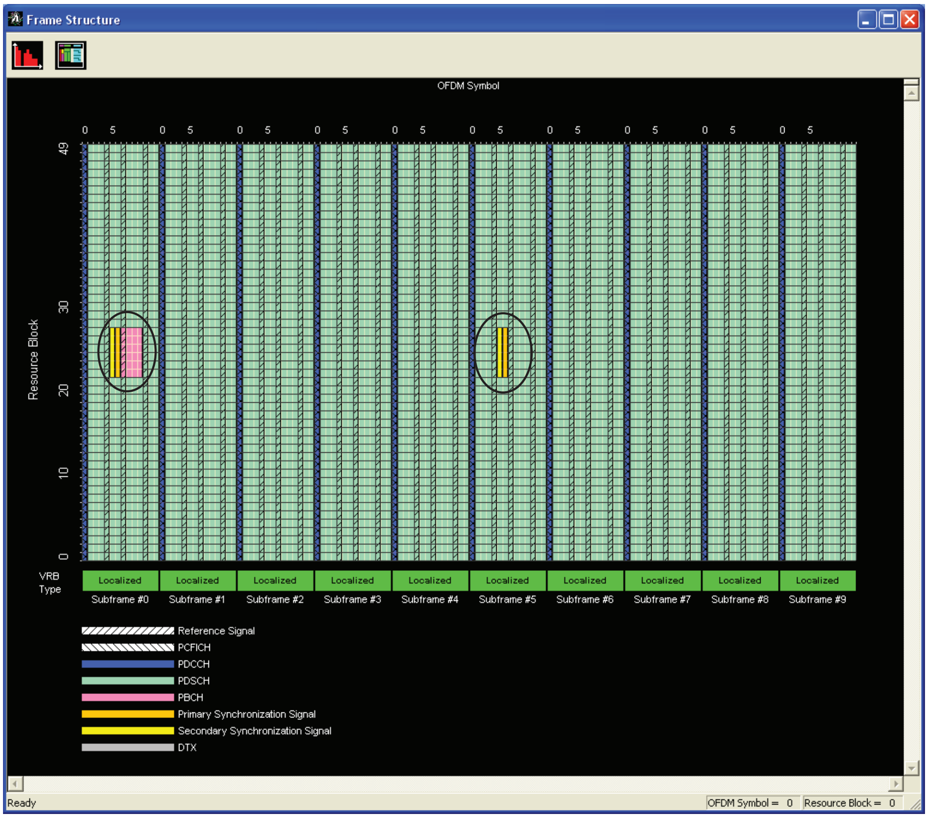


Figure 2. Sync Signal locations for FDD mode are shown in orange and yellow for a 10 MHz channel bandwidth.

Using SS Power to Estimate Total Power and Coverage

The SS can provide surprisingly accurate proxy power measurements, because SS power is a static value that correlates to the eNodeB maximum output power, and the maximum output power relates to the UE sensitivity. When all the Resource Blocks are occupied and no power control is used (such as in the 3GPP LTE Test Model 1.1 signal[1]), the P-SS and S-SS subcarriers are at the same power level as the other subcarriers. Then SS power per subcarrier and symbol (also called Energy per Resource Element or EPRE in the standard), is 10*log10(subcarriers) lower than the total power[2]. At 10 MHz, this formula yields a value of 27.78 which means that the SS power is 27.78 dB below the maximum channel power. Table 1 shows the relationship between SS power and maximum output power at all applicable LTE bandwidths, for the nominal SS power setting where all REs have the same power level.

Bandwidth	Number of Resource Blocks	Maximum total output power / RS EPRE (dB)
1.4 MHz	6	18.57
3 MHz	15	22.55
5 MHz	25	24.77
10 MHz	50	27.78
15 MHz	75	29.54
20 MHz	100	30.79

Table 1: Total output power as a function of SS power (for nominal SS power setting).

However, the SS power can be adjusted in the eNodeB. The values in Table 1 will vary based on this adjustment – if the SS power is 1 dB lower than nominal, then the ratio between SS power and total power will be about 1 dB higher[3]. For the most accurate measurements, use the Test Model 1.1 signal from the eNodeB. If you need to measure on live traffic, you'll need to know what the SS Power setting is on the eNodeB. If the ratio between the rated output power and the SS Power is different from Table 1, you can compensate by referring to different colors in the coverage map.

For example, if you have a 10 MHz channel bandwidth and a 40 W (46 dBm) output power (total for all transmitters), the expected SS Power would be 46-27.78 or about 18.2 dBm (33.3 mW). If the eNodeB is set to provide SS Power of 21.2 dBm, this is roughly the difference between 2 adjacent colors in the coverage map.

Given a known relationship between the SS Power and the maximum output power, and a UE sensitivity specification (which is based on the maximum output power), we can determine an equivalent sensitivity based on the SS power.

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1. Note that while Test Model 1.1 is not used for UE Sensitivity measurements, it is instructive to consider this simple signal to understand how SS Power relates to maximum output power.
2. See Anritsu Application Note 11410-00575A for a more complete description of how the eNodeB control channel power relates to the maximum output power. Transmitter test signals can also be used to measure coverage if the eNodeB can't generate live signals for some reason, such as no backhaul connection.
3. To be precise, the ratio will change by slightly more than 1 dB, as the power unused by the SS can be used by other subcarriers, but in general this effect is very small.

Interpreting an SS Power Map

The quality of downlink coverage at a particular location can be determined by comparing the measured SS values with the UE receiver sensitivity specifications as defined in the LTE standards document (see Table 2) or with some other specification provided by a network operator. We need to keep in mind, of course, the relationship between the SS Power (which we are measuring), and the maximum output power (which is what the UE sensitivity spec uses).

The required sensitivity in Table 2 varies with the bandwidth and frequency band. For example, the table provides a reference sensitivity of –94 dBm in the 10 MHz bandwidth for Band 3, so the corresponding SS power would be –94–27.8 or –121.8 dBm.

Band #	Downlink Frequency (MHz)	Channel bandwidth (MHz)					
		20	15	10	5	3	1.4
1 (FDD)	2110 - 2170	–94	–95.2	–97	–100		
2 (FDD)	1930 - 1990	–92	–93.2	–95	–98	–100.2	–103.2
3 (FDD)	1805 - 1880	–91	–92.2	–94	–97	–99.2	–102.2
4 (FDD)	2110 - 2155	–94	–95.2	–97	–100	–101.7	–105.2
5 (FDD)	869 - 894			–95	–98	–100.2	–103.2
6 (FDD)	875 - 885			–97	–100		
7 (FDD)	2620 - 2690	–92	–93.2	–95	–98		
8 (FDD)	925 - 960			–94	–97	–99.2	–102.2
9 (FDD)	1844.9 - 1879.9	–93	–94.2	–96	–99		
10 (FDD)	2110 - 2170	–94	–95.2	–97	–100		
11 (FDD)	1475.9 - 1495.9			–97	–100		
12 (FDD)	728 - 746			–94	–97	–99.2	–102.2
13 (FDD)	746 - 756			–94	–97		
14 (FDD)	758 - 768			–94	–97	–99.2	
17 (FDD)	734 - 746			–94	–97		
33 (TDD)	1900 - 1920	–94	–95.2	–97	–100		
34 (TDD)	2010 - 2025	–94	–95.2	–97	–100		
35 (TDD)	1850 - 1910	–94	–95.2	–97	–100	–102.2	-106.2
36 (TDD)	1930 – 1990	–94	–95.2	–97	–100	–102.2	–106.2
37 (TDD)	1910 - 1930	–94	–95.2	–97	–100		
38 (TDD)	2570 - 2620	–94	–95.2	–97	–100		
39 (TDD)	1880 - 1920	–94	–95.2	–97	–100		
40 (TDD)	2300 - 2400	–94	–95.2	–97	–100		

Table 2: Reference sensitivity for QPSK mode, in dBm (from 3GPP TS 36.101 V8.10.0 (2010-06)).

The coverage maps produced by the Anritsu instruments (using the Anritsu Master Software Tools) are color-coded. The power level used for red dots on the coverage map is based on the relationship between the output power implied by the SS measurement and the UE sensitivity specifications. The –124 dBm threshold equates to a sensitivity of –96.2 dBm, which is roughly in the middle range of the sensitivity specifications.

This sensitivity spec is for QPSK operation, which will be used at the cell edge. However we also want an indication of where faster data rates are possible. The coverage map uses different colors to indicate this.

The power levels used for the other color steps are based on estimates of the additional power required for using higher-level modulation formats such as 16QAM, 64QAM, and even spatial multiplexing (MIMO). LTE also has a variable amount of error protection coding, so there are many more steps than are shown in the graph. In general, however, higher power allows the more complex modulation format and less error protection, which allows faster data transmission to that user. While these thresholds are not a precise determination of what modes should be used by the UE, it is a useful indication of performance levels from “just barely good enough” (QPSK, Transmit Diversity, high coding rate required) to “really good” (64 QAM, Spatial Multiplexing, low coding rate). Technicians and engineers can easily drill down to the underlying data when they need the actual measurement values. Just click on one of the dots in Google Earth.

While the discussion above focuses on thresholds for 10 MHz channel bandwidth, note that as the bandwidth changes, the relationship between SS power and maximum power changes the same as the sensitivity— e.g. when the channel bandwidth is doubled, the sensitivity is 3 dB higher, and the relationship between SS power and maximum power also increases by 3 dB[4]. This means that the same thresholds are usable for all bandwidths. A list of computed SS power measurements that indicate the same sensitivity limits as Table 2 are shown in Table 3.

Band #	**Downlink Frequency (MHz)**	**Channel bandwidth (MHz)**					
		20	**15**	**10**	**5**	**3**	**1.4**
1 (FDD)	2110 - 2170	–124.8	–124.8	–124.8	–124.8		
2 (FDD)	1930 - 1990	–122.8	–122.8	–122.8	–122.8	–122.8	**–123.1**
3 (FDD)	1805 - 1880	–121.8	–121.8	–121.8	–121.8	–121.8	**–122.1**
4 (FDD)	2110 - 2155	–124.8	–124.8	–124.8	–124.8	**–125.3**	**–125.1**
5 (FDD)	869 - 894			–122.8	–122.8	–122.8	**–123.1**
6 (FDD)	875 - 885			–124.8	–124.8		
7 (FDD)	2620 - 2690	–122.8	–122.8	–122.8	–122.8		
8 (FDD)	925 - 960			–121.8	–121.8	–121.8	**–122.1**
9 (FDD)	1844.9 - 1879.9	–123.8	–123.8	–123.8	–123.8		
10 (FDD)	2110 - 2170	–124.8	–124.8	–124.8	–124.8		
11 (FDD)	1475.9 - 1495.9			–124.8	–124.8		
12 (FDD)	728 - 746			–121.8	–121.8	–121.8	**–122.1**
13 (FDD)	746 - 756			–121.8	–121.8		
14 (FDD)	758 - 768			–121.8	–121.8	–121.8	
17 (FDD)	734 - 746			–121.8	–121.8		
33 (TDD)	1900 - 1920	–124.8	–124.8	–124.8	–124.8		
34 (TDD)	2010 - 2025	–124.8	–124.8	–124.8	–124.8		
35 (TDD)	1850 - 1910	–124.8	–124.8	–124.8	–124.8	–124.8	**–124.1**
36 (TDD)	1930 - 1990	–124.8	–124.8	–124.8	–124.8	–124.8	**–124.1**
37 (TDD)	1910 - 1930	–124.8	–124.8	–124.8	–124.8		
38 (TDD)	2570 - 2620	–124.8	–124.8	–124.8	–124.8		
39 (TDD)	1880 - 1920	–124.8	–124.8	–124.8	–124.8		
40 (TDD)	2300 - 2400	–124.8	–124.8	–124.8	–124.8		

Table 3: SS Power required for QPSK sensitivity, for nominal SS Power setting. ***Bold*** *values indicate levels different from the 10 MHz channel bandwidth.*

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[4] There are several minor exceptions, pointed out in Table 3: 0.5 dB high for band 4 with 3 MHz BW, 0.3 dB high for 1.4 MHz bandwidth (most bands) and 0.7 dB low bands 35 & 36 for 1.4 MHz BW

Measurement Details

It’s important to note that the eNodeB scheduler usually implements power control in which higher power is used to transmit data to UEs on the edge of the cell and lower power to UEs near the middle of a cell. Combined with the fact that schedulers are eNodeB vendor specific, it becomes impossible to predict exactly what transmission scheme (modulation, coding, and MIMO mode) will actually be used for any specific power level. The transmission scheme can even dynamically change during a data session, even from a fixed location. These factors indicate that the different thresholds should be used as a general indication of downlink signal quality, rather than a precise measurement.

It’s also worth noting that some service providers are setting their own UE requirements. For example, Verizon Wireless public documents for open UE development require –97 dBm sensitivity (per port) for band 13, versus the 3GPP requirement of –94 dBm (per port).

The broadband instruments used to perform the measurements can never provide the same sensitivity as a band-specific UE. The sensitivity of the instruments varies by model but a typical value is –122 dBm, which is from about 0 to 3 dB higher than for a UE. So the user may never see measurements in the red zone on the downlink coverage map. If possible, increasing the SS Power by several dB can compensate for this effect while doing coverage mapping.

02/16/2011 04:09:24 pm N 37° 8' 48" W 121° 39' 21"

Center Freq 751.000 MHz
Channel --
Reference Source GPS Hi Accy
Power Offset 0.0 dB Ext Loss
Auto Range On
BW 10 MHz
EVM Mode PBCH Only
Sync Type Normal (SS)

Cell ID	Group ID	Sector ID	Sync Signal (S-SS) Power
1	0	1	-97.0 dBm
--	--	--	--
--	--	--	--
--	--	--	--
--	--	--	--
--	--	--	--
Dominance			--

Auto-save: On File: 20110216160846.lte [Internal] Records: 14

PBCH Modulation Results (Strongest SS) Off

Figure 3. Option 546 (LTE Over-The-Air Measurements).

Anritsu Products

There are a wide variety of Anritsu instruments that can make LTE coverage measurements, including BTS Master MT8221B and MT8222B, BTS Master MT8222A, Spectrum Master MS2712E, MS2713E, MS2721B, MS2722C, MS2723C, MS2724C, MS2725C and MS2726C, and Cell Master MT8212E and MT8213E. These instruments provide the measurements that allow push-button coverage mapping on your PC. These measurements are made on instruments that are already used by many technicians and engineers servicing base stations, thus providing a simple complement to complex drive-test systems. These instruments can be easily upgraded with Option 546 (LTE Over-The-Air Measurements) to perform downlink coverage mapping whenever the need arises. The instruments can automatically measure and save the SS power from up to 6 Base Stations or eNodeBs roughly every 5 seconds. If desired, the modulation quality of the strongest transmitter can also be measured and stored at the same time, by adding option 542 (LTE Modulation Measurements) and if necessary option 543 (15 & 20 MHz bandwidth support). These measurements include the rms and peak Error Vector Magnitude (EVM), the carrier frequency and frequency error in both Hz and parts per million, and the Reference Signal power. The instrument also automatically stores the cell ID of every received signal as well as the time and location of the measurements. The data can be stored on the internal instrument memory or on a USB stick.

After capturing the data, the user can open the file using Anritsu Master Software Tools, which is included with the instrument and also available as a free download. Master Software Tools is then used to export the measurement data to a Google Earth KML file. Later, users can upload the data to a computer and view it on a map showing the coverage at each measured point with color codes. When the file is opened the user sees a satellite view of the area whose coverage was mapped as shown in Figure 4. Each point where data was captured appears on the map.

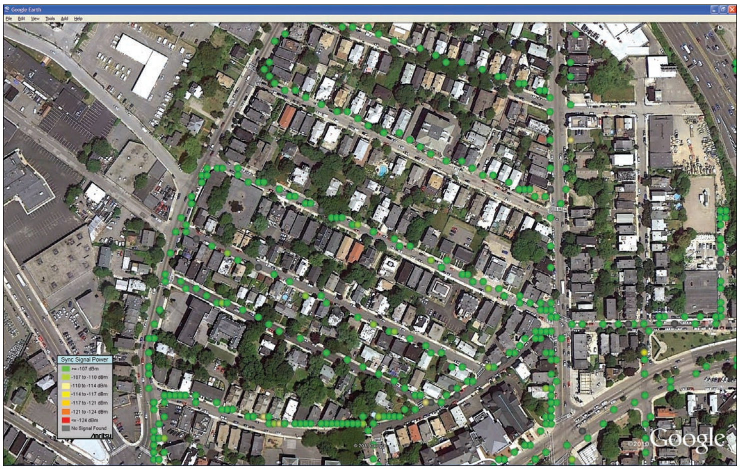

Figure 4. Anritsu LTE downlink coverage map opened in Google Earth. Clicking on a point reveals all measurement data available for that position.

Conclusion

Measuring SS power level with a handheld instrument makes it possible to easily make calibrated LTE downlink coverage maps using the same instrument that is used for many other tasks such as base station installation, commissioning, maintenance and troubleshooting for 2G/3G and LTE networks. This new approach helps improve productivity for more reliable and efficient base station operations.

References

3GPP TS36.104 V8.6.10 Base Station Radio Transmission and Reception
3GPP TS 36.101 V8.10.0 (2010-06)) UE Radio Transmission and Reception

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