LTE PROPAGATION STUDIES

Transmit & Receive Test Equipment

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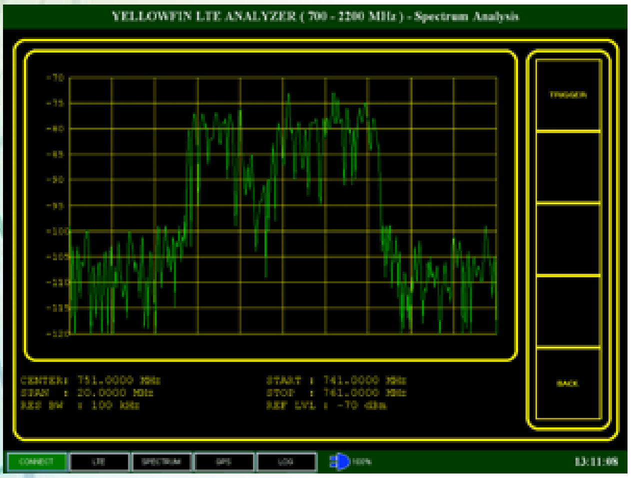
Introduction

LTE signals propagate through a channel that often exhibits broadband fading characteristics due to multipath. Narrowband pre-deployment studies, which transmit and receive a carrier signal, use 40-lambda averaging to eliminate fast fading created by multipath while preserving terrain based fading due to propagation loss and obstructions. Narrowband pre-deployment studies rely solely on averaged received signal strength. Modulated wide-band pre-deployment studies can consider Received Signal Strength (RSSI), as well as, broad-band fading due to multipath, channel noise sources, and the cyclic prefix length. These are important because LTE and OFDM technology do not eliminate fading or multipath on the RF channel.



CENTER: 751.0000 MHz
SPAN : 20.0000 MHz
RES BW : 100 kHz
START : 741.0000 MHz
STOP : 761.0000 MHz
REF LVL : -70 dBm

Figure 1. A YellowFin-LTE™ spectrum shot of an LTE signal propagating through a channel with broadband fading

Narrowband Propagation Studies

Two types of fading are relevant to narrowband propagation studies. Fast fading, also known as Rayleigh fading is due to multipath reflections. Terrain based fading is due to propagation loss and obstructions. Rayleigh fading can produce large variations of signal strength over a fraction of a wavelength. Narrowband coverage studies are conducted in a manner that rejects Rayleigh fast fading so that accurate measurements of terrain based fading can be made. A data filtering technique known as 40-lambda averaging is a widely accepted method of removing Rayleigh fast fades and retaining the slower terrain based fades [1].

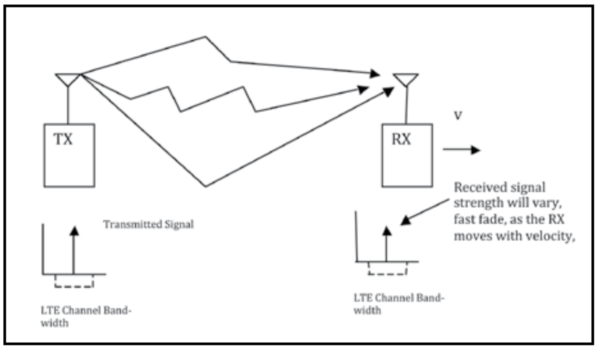


Figure 2: CW narrowband Drive Study

Wide-band Propagation Studies

Wide-band propagation studies use a modulated transmitter source that occupies the entire LTE channel bandwidth. Multipath, the Carrier to Interference plus Noise Ratio (CINR) and the Received Signal Strength (RSSI) can be measured on the entire LTE channel.

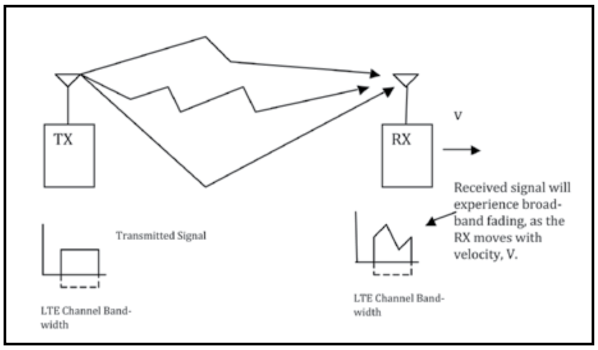


Figure 3: Modulated wide-band Drive Study

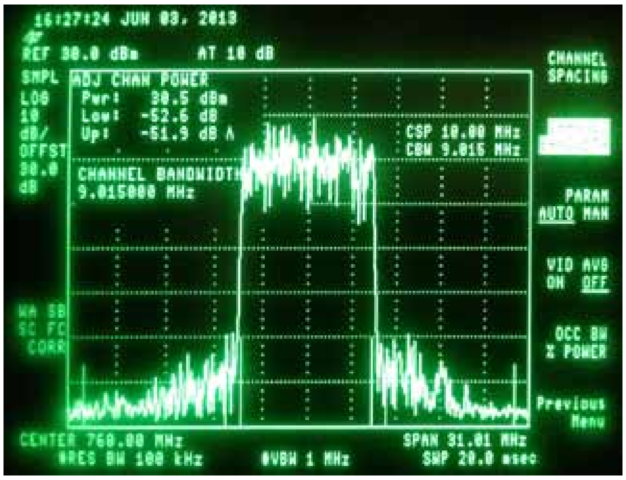


Figure 4: LTE Modulated Tortoise™ Stimulus Transmitter Output

Modeling Multipath

Multipath is the propagation of an RF signal to a receiver via two or more paths. The different delays of the paths form a convolution of the transmitted signal and the channel impulse response [2]. Convolution in the time domain is equivalent to multiplication in the frequency domain [3]. Multipath seen in the time domain is seen as frequency selective fading in the frequency domain.

Multipath can result in constructive interference, destructive interference and phase shifting of the signal. The two most obvious cases are two sinusoids of the same frequency that are in phase, constructive, and two sinusoids of the same frequency that are a ½ cycle out of phase, hence destructive. Combining sinusoids of the same frequency with a delay, convolution, still results in a sinusoid of the same frequency, but it may have a different amplitude and phase.

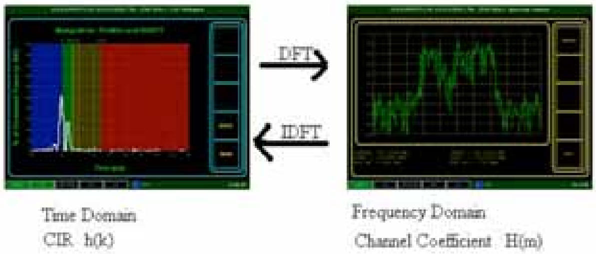


Figure 5: Relationship between time and frequency via the convolution theorem

h(k) * x(k) <=> H(m) • X(m). Multipath in the time domain creates frequency selective fading in the frequency domain.

LTE Synchronization Codes

The LTE downlink transmits several synchronization codes that have good auto-correlation properties and can be used to measure multipath, to calculate a channel impulse response estimate and a CINR measurement. The LTE down-link transmits the Primary Synchronization Sequence (PSS), the Secondary Synchronization Sequence (SSS) and the Reference Signal (RS) [4].

The PSS code is used to measure multipath. The PSS is a punctured (the code is zeroed at the carrier frequency) Zadoff-Chu sequence that has good auto-correlation properties. There are 3 different PSS codes specified for the LTE downlink; neighboring Base Stations are set to different PSS codes. A PSS code is shown in figure 6 in the frequency domain, and except for the carrier, is spectrally flat. The PSS is shown in the time domain in figure 7. The PSS is a complex code, having both in-phase and quad-phase components.

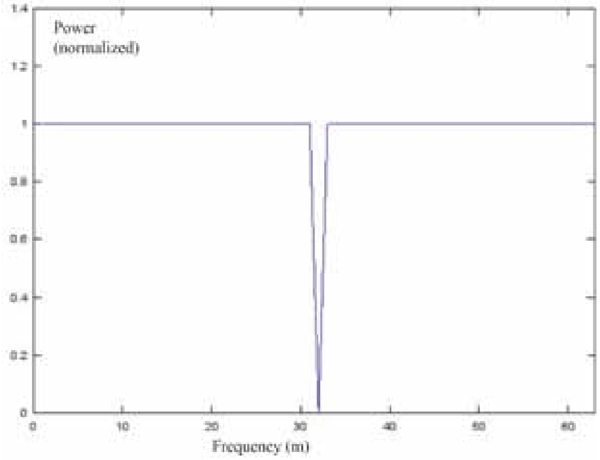


Figure 6: Frequency Spectrum of an LTE Primary Synchronization Sequence (PSS)

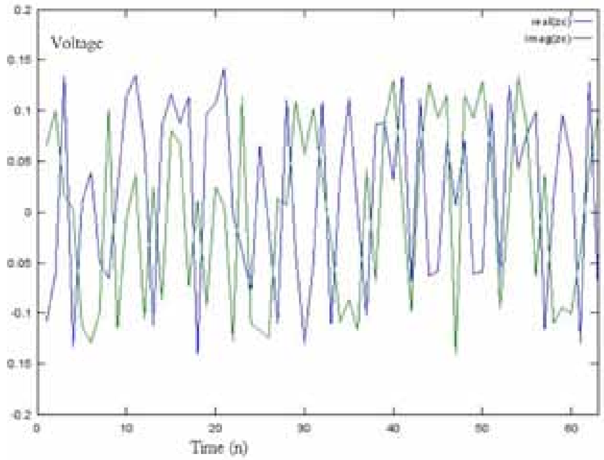


Figure 7: In-phase and Quad-phase time samples of an LTE Primary Synchronization Sequence (PSS)

Auto-Correlation

Auto-correlation is a measure of correspondence between a code and all of the phase shifted versions of that code [5]. The auto-correlation of a PSS code approximates an impulse. The auto-correlation is 1, or 0 dB, when the PSS is aligned, in time, with a time shifted copy of the PSS code, and is over 30 dB down when the codes are not aligned. The auto-correlation of a PSS is shown in figure 8.

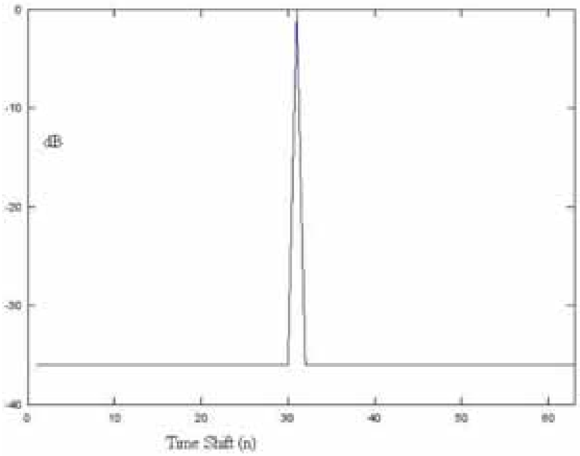


Figure 8: Auto-correlation of an LTE Primary Synchronization Sequence (PSS). Note that the auto-correlation peak is shifted for clarity of the figure.

Measuring Multipath and Correlation

Figure 9 illustrates the correlation of 3 multipath components. A copy of the PSS code at the receiver is correlated against the received signal and then shifted in time. When the reference PSS code is aligned with a multipath component, a correlation is produced proportional to the power in that multipath component. Three correlations are shown in figure 9. These three components add together to form the multipath display is shown in figure 10, and a multipath measurement from a deployed LTE downlink is shown in figure 11.

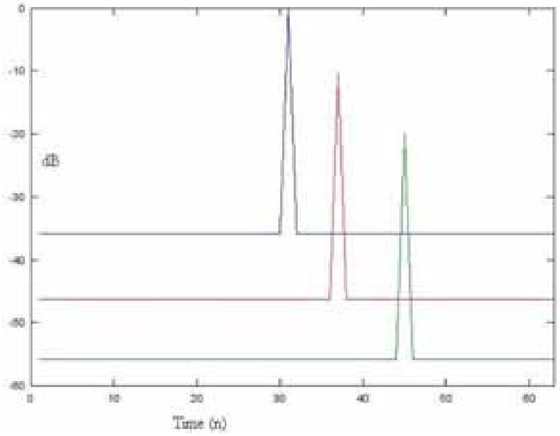


Figure 9: Illustration of three multipath components

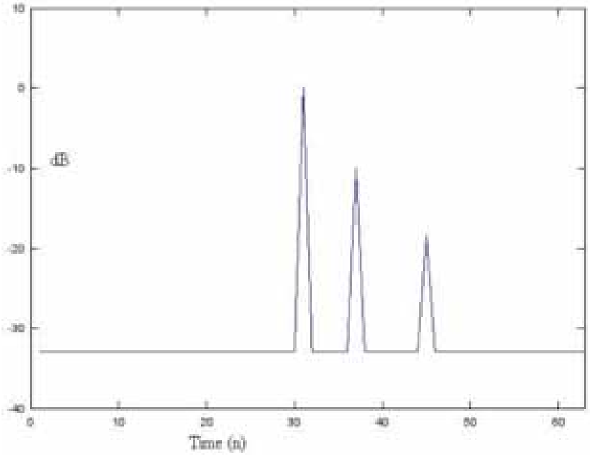


Figure 10: Multipath display of 3 multipath components with resulting noise floor

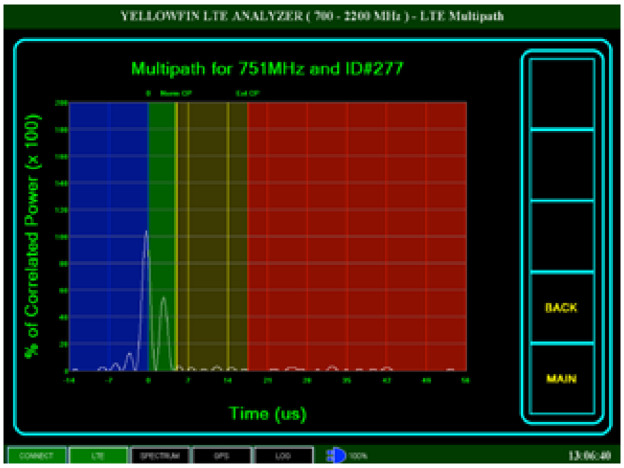


Figure 11: A YellowFin-LTE™ multipath display. This multipath creates broadband frequency selective fading. Note 2 distinct paths within the normal guard period (NormCP).

Cyclic Prefix/Guard Period

Delay spread, T_d, is the amount of time between the first (non-negligible) path and the last (non-negligible) path received, see figure 11. LTE adds a guard time between each OFDM symbol that is called the cyclic prefix, of length T_{cp}. If the $T_{cp} < T_d$, Inter Symbol Interference (ISI) is present. The receiver cannot sample the entire symbol without having a mixture of two or more symbols. The LTE system must be set-up so that $T_{cp} > T_d$ and ISI is not present [6]. If ISI exists, the receiver would need knowledge of both the multipath and the data modulated onto the RF carrier to flatten the received spectrum, and this requires a more complex equalizer that typically suffers from poorer performance when compared to a system that does not need to correct for ISI.

Broadband Fading and CINR

Figure 1 is a spectrum plot of a received LTE downlink signal experiencing broadband fading. This frequency selective fading is quite severe, over 10 dB, in some frequency bins. A channel frequency response estimate is calculated from the RS code. The channel estimate for each frequency bin is then multiplied onto the received signal's corresponding frequency bin to correct for both amplitude and phase.

The channel estimate may perfectly correct the magnitude and phase of each subcarrier, but subcarriers that are received (assuming equally distributed noise across the band) with lower signal strength will have a lower CINR, since both the signal and noise are amplified.

Drive Study Recommendations for LTE

Detect interference and noise sources before analyzing coverage, if possible. Measure the channel in the drive area without a stimulus transmitter. Use spectrum analysis or the RSSI over the entire LTE channel bandwidth. Any received signals represent interference plus noise, the denominator in the CINR equation. Investigate and mitigate, where possible, these interference and noise sources.

Use a modulated stimulus transmitter source that transmits LTE synchronization signals. This will transmit energy over the entire channel and provide reference signals to measure CINR, multipath and the Received Signal Strength over the entire LTE channel.

Collect and analyze CINR, and RSSI. The performance of LTE is primarily determined by CINR, not RSSI.

Analyze areas with low CINR. Determine if low RSSI, interference, multipath outside the cyclic prefix, or severe broad-band fading is responsible for areas with low CINR.

Berkeley Varitronics Systems' Tortoise Dual Band Transmitter (above) and YellowFin LTE Analyzer (below) are both used worldwide for the build out and optimization of 4G LTE networks.

REFERENCES

[1] William C.Y. Lee, "Mobile Communications Engineering," 2nd-ed., McGraw-Hill, 1997

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[4] 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures (Release 8); 3GPP TS 36.213 V8.6.0 (2009-03).

[5] R. C. Dixon, "Spread Spectrum Systems with Applications," John Wiley & Sons, Inc., 1994.

[6] S. Stefania, I. Toufik and M. Baker, "LTE-The UMTS Long Term Evolution: From Theory to Practice", John Wiley & Sons, Inc., 2009.