Smart devices > Smart networks > Smart Planning

Technical White Paper

Designing an LTE Network

Using EDX SignalPro

Designing an LTE network using EDX SignalPro

Updated with new SignalPro 7.3 LTE features and studies

Steve Webster
Director, Product Management
EDX Wireless (www.EDX.com)
September, 2010

Overview

This white paper will describe how the many useful LTE tools and studies that are available in SignalPro can be used by the RF engineer to design a well performing LTE network. EDX® SignalPro® is the combination of EDX's comprehensive line of wireless network engineering tools. It offers all of the study types you need to design a basic wireless network, including area studies, link/point-to-point studies and route studies. EDX SignalPro also incorporates the finest telecom-specific mapping features, meticulous equipment data storage capabilities and convenient utility functions. With the LTE-specific features and studies that have been included with the SignalPro Network Design Module, the RF engineer has a comprehensive suite of design capabilities. This white paper will show how these features and studies can be used to design an optimal LTE network.

Specifying LTE system parameters

In order to provide accurate and useful RF predictions, SignalPro allows the user to specify the following LTE system parameters:

- System bandwidth from 1.25 to 20 MHz using 3GPP LTE/E-UTRA standard bandwidths.
- FDD or TDD with the TDD Configuration # (1-6)
- Cyclic Prefix - Normal (4.7 µS) or Extended (16.7 µS)
- Intra-LTE (inter-eNodeB) handoff parameters
- Inter-RAT (Radio Access Technology) handoff parameters including PLMN offset
- Whether uplink power control is to be modeled in uplink studies.
- Optional Fractional Frequency Reuse R1/R3 Resource Block allocation
- Choice of channel plan template file to use for frequency planning
- Service area boundary polygon file
- Measured interference file (optional)

The user also has the option of modifying the default Adaptive Modulation and Coding to C/(I+N) mapping for both uplink and downlink studies. The LTE E-UTRA standard defines 3 modulations (QPSK, 16QAM and 64QAM) with 15 different usable CQI levels (1-15) that determine the modulation and channel coding that is used, based on the radio channel conditions. The CQI Adaptive Modulation and Coding table for LTE is defined in 3GPP TS 36.213 table 7.2.3-1. EDX has stored the default Carrier to Interference plus Noise ((C/(I+N)) values associated with the 15 CQI levels that were determined in a Technical University of Vienna published paper that used MATLAB simulations of the LTE air-interface. If the user wishes to use different C/(I+N) values for any or all of the uplink or downlink CQI levels, they have the option of changing and saving those values in the SignalPro LTE Adaptive Modulation table, which is shown below:

The Power of Smart Planning   2

LTE Adaptive Modulation

Downlink | Uplink

Adaptive Modulation

CQI	Modulation Type	Turbo Coding Rate	Minimum C/(I+N) for 1% SER (db)
0	NO SERVICE		
1	QPSK	0.076	-6
2	QPSK	0.117	-5
3	QPSK	0.188	-3
4	QPSK	0.301	-1
5	QPSK	0.438	1
6	QPSK	0.588	3
7	16QAM	0.369	5
8	16QAM	0.479	8
9	16QAM	0.602	9
10	64QAM	0.455	11
11	64QAM	0.554	12
12	64QAM	0.650	14
13	64QAM	0.754	16
14	64QAM	0.853	18
15	64QAM	0.926	20

OK | Reset to Default Values | Cancel

Due to recent advances in antenna and signal processing technology combined with their effectiveness for OFDMA, the LTE standard supports MIMO-A (Space-Time Coding), MIMO-B (Spatial Multiplexing) and SDMA/AAS (Adaptive Antenna Systems). SignalPro allows the user to independently specify the unique MIMO or SDMA configuration (if used) for each LTE eNodeB (base station) sector. SignalPro also has a table of the downlink gains, interference reduction and data rate increases associated with each of these possible MIMO and SDMA configurations. The user has the option of modifying the default (theoretical) values and storing manufacturers' specified values for each MIMO and SDMA configuration that is used. The user also has the option of using the downlink gains, interference reduction and/or data rate increases for studies that have MIMO or SDMA/AAS enabled sectors in the study group. The MIMO/Adaptive antenna adjustment factor dialog box is shown below:

MIMO / Adaptive Antennas

MIMO/Adaptive Type	eNodeB/UE antenna config	Downlink Coverage Gain (dB)	Uplink Coverage Gain (dB)	Downlink Interference Reduction (dB)	Uplink Interference Reduction (dB)	Downlink Data Throughput Multiplier	Uplink Data Throughput Multiplier
MIMO-A (Space-Time Coding)	2x1 (MISO)	3.00	3.00	0.00	0.00	1.00	1.00
MIMO-A (Space-Time Coding)	2x2	6.00	6.00	0.00	0.00	1.00	1.00
MIMO-B (Spatial Multiplexing)	2x2	3.00	3.00	0.00	0.00	1.90	1.00
MIMO-A (Space-Time Coding)	4x2	9.00	3.00	0.00	0.00	1.00	1.00
MIMO-B (Spatial Multiplexing)	4x2	6.00	3.00	0.00	0.00	1.90	1.00
SDMA/Adaptive (FDD)	4x2	8.00	9.00	10.00	15.00	1.50	2.00
SDMA/Adaptive (TDD)	4x2	9.00	9.00	15.00	15.00	3.00	3.00
MIMO-A (Space-Time Coding)	4x4	12.00	6.00	0.00	0.00	1.00	1.00
MIMO-B (Spatial Multiplexing)	4x4	6.00	6.00	0.00	0.00	3.80	1.00
SDMA/Adaptive (FDD)	8x1	8.00	9.00	15.00	20.00	1.50	2.00
SDMA/Adaptive (TDD)	8x1	9.00	9.00	20.00	20.00	3.00	3.00
SDMA/Adaptive (FDD)	8x2	11.00	12.00	15.00	20.00	2.00	2.50
SDMA/Adaptive (TDD)	8x2	12.00	12.00	20.00	20.00	4.00	4.00
SDMA/Adaptive (FDD)	Custom	0.00	0.00	0.00	0.00	0.00	0.00
SDMA/Adaptive (TDD)	Custom	0.00	0.00	0.00	0.00	0.00	0.00

OK | Assign default (theoretical) values | Cancel | Help

The Power of Smart Planning 3

Coverage prediction

The most important feature in an RF design tool is the ability to accurately model RF coverage. SignalPro excels in performing quick and accurate RF predictions and it has the following propagation modeling features:

- A wide variety of industry-standard propagation models as well as the, unique to EDX, Anderson-2D advanced physical model.
- Support for industry-standard terrain, land-use (clutter) and building data with an easy import facility.
- Includes a large selection of manufacturer's equipment specifications including base station performance characteristics and antenna patterns. Most industry standard antenna pattern formats are supported for easy importing into SignalPro.
- Modeling of MIMO-A (Space-Time Coding), MIMO-B (Spatial Multiplexing) and SDMA/AAS (Adaptive Antenna Systems) performance enhancements for both industry-standard and custom configurations are included in SignalPro.
- Support for a wide frequency range (30 MHz to 100 GHz) of radio systems.
- Support for importing, viewing and analyzing measured coverage data. Measured data can be used to tune the various propagation models and clutter data that is available within SignalPro.

These capabilities combined with a highly-flexible user-interface gives the engineer the ability to accurately model any possible RF system and scenario.

LTE Capacity Predictions and Traffic Planning

LTE is based on an all-IP network, which uses packet-switched traffic definitions. Most internet traffic, such as web browsing, FTP and e-mail (which is defined as "AM" or Acknowledged Mode for LTE RLC) allow the packets that can't be sent due to capacity limitations to not be permanently blocked but delayed until network capacity is available. Packet traffic that is associated with VoIP calls, video conferencing or IPTV (Internet Television) is defined as "UM" or Unacknowledged Mode" for LTE RLC. These packets, if they can't be sent within a very narrow timeframe, are dropped, since their time-sensitive nature makes late UM packets useless. For this reason, LTE traffic is managed by giving priority to UM traffic at the eNodeB and EPC (Evolved Packet Core) schedulers. These traffic types can be both specified and analyzed in SignalPro.

SignalPro allows the user to specify both the Packet Switched Traffic Definitions (the types of subscriber usage, i.e. AMR/VoIP-UM, HTTP/FTP-AM, iPTV-UM, etc.) as well as the Traffic Densities associated with each Traffic Definition. The user has the option of selecting a uniform traffic density or having the predicted traffic based on either land use (clutter) or demographic databases. Once these Packet Switched Traffic traffic parameters are specified, the user can have SignalPro perform a per-sector traffic load prediction. This predicted traffic data is necessary to ensure that certain uplink system performance prediction studies are accurate. For this reason it is important to specify the traffic parameters for the LTE network as accurately as possible.

Frequency planning and Interference prediction

Once coverage and subscriber traffic load have been predicted for a system of sites, a frequency plan needs to be created. LTE has a wide range of adaptive modulation and coding (CQI) levels that supports a wide-range of C/(I+N) ratios. Optimal performance (user capacity and data speeds) requires C/(I+N) ratios of at least 11 dB for 64QAM. Higher coding rates for 64QAM are available for improved C/(I+N) ratios of up to 20 dB. For this reason, sufficient spectrum to support at least 4-cell reuse is necessary. Fractional Frequency reuse using R1/R3 is also supported in LTE, but it requires an optimal RF design and cell layout to work well.

The Power of Smart Planning   4

SignalPro allows the user to manually specify a frequency plan, modify an existing frequency plan or create a new frequency plan using Automatic Frequency Planning (AFP). The advanced SignalPro AFP algorithm balances the many needs of the network to produce the most optimal frequency plan.

Uplink and downlink interference and system performance predictions

For most wireless networks, downlink C/(I+N) predictions are deterministic since the locations of the interferers (the eNodeB's) are known. This is not the case for uplink interference, which is based on the location and usage of the subscribers' terminals (UE's). Predictions of uplink interference can be made based on statistical studies or Monte Carlo simulations, but it is important to understand the advantages and disadvantages of each approach as well as what the studies or simulations can or can't predict.

SignalPro offers a statistical approach to predicting LTE uplink interference that takes advantage of the time and frequency band segmentation in the SC-FDMA uplink PRB (Physical Resource Block) allocations for its statistical predictions. The unique to EDX software SignalPro LTE Uplink Interference Stochastics study quantifies uplink interference predictions using statistical (probabilistic) methods. Based on the user-specified UE traffic definitions and densities, the stochastic study analyzes the probability that any given UE will interfere with other co-channel eNodeB's based upon their propagation characteristics and the duration of the UE's transmissions. Since the probability that one of UE's PRB's served by the eNodeB will be interfered by a co-channel UE served by another eNodeB's is simply the frame fraction of the UE: The number of PRB's in the UE's transmission divided by the number of PRB's in the frame. The LTE uplink interference stochastics study determines sum of these frame fraction probabilities for each LTE sector based on its specified UE traffic. This study produces a plot showing the percentage of PRB's in the eNodeB's frame that should be clear of interference in each grid square. This study also produces a statistical distribution of coverage and interference signal levels that can be used for other uplink studies. An example of the sector-level predicted uplink coverage and interference curves is shown below:

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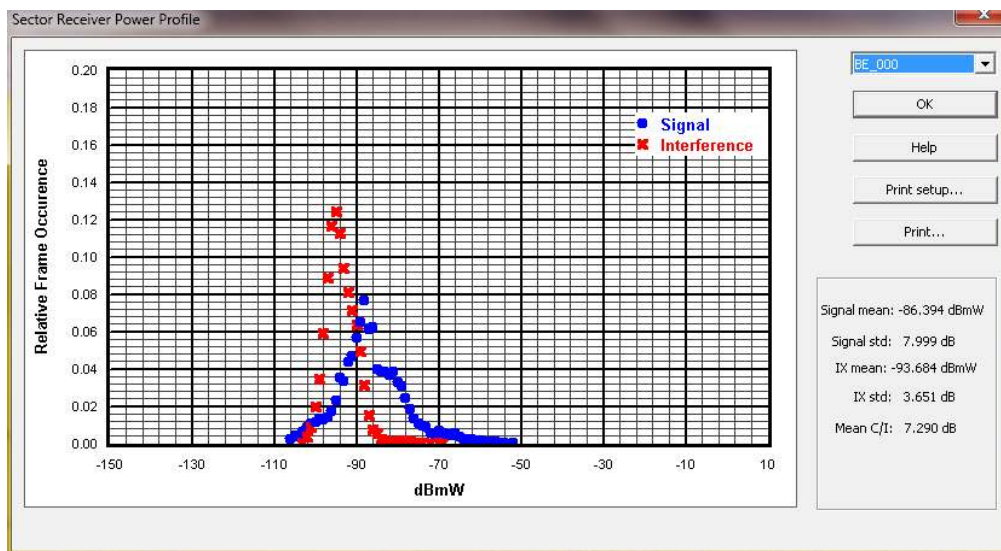
An example of an uplink stochastics study plot showing percentage of successful uplink data transmissions is shown below:
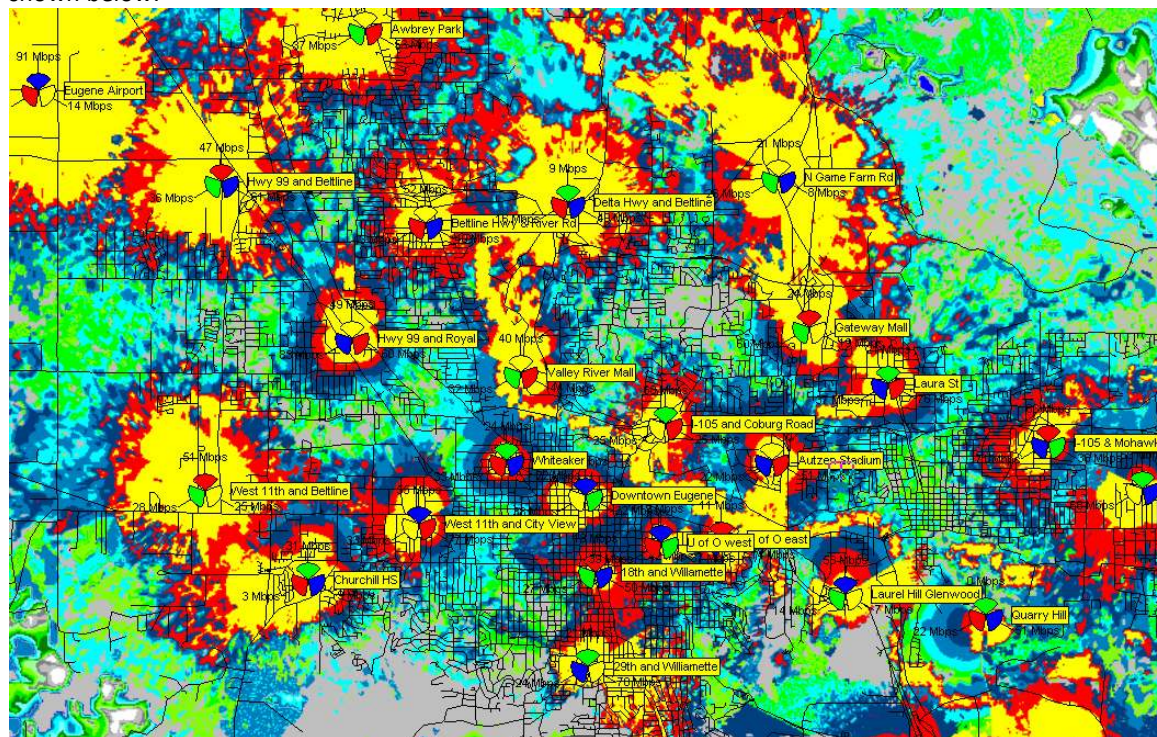
SignalPro's extensive database allows the user to store uplink interference levels for each eNodeB sector for use in uplink studies. Once each sector's interference level statistics have been determined by using the LTE Uplink Interference Stochastics study, the user has the option of storing the mean (50%) or 90% confidence interference level from the stochastics study. The user also has the option of manually entering the uplink interference levels, either on a per-sector basis or by using the same absolute (i.e. -100 dBm) or noise-relative (i.e. 10 dBm above the noise floor) value that will be applied to each sector in the project group. The system level and sector receiver uplink interference dialog boxes are shown below:

This predicted interference level, along with the calculated or user-specified noise floor values allow the SignalPro user to make accurate uplink performance predictions with the following choice of uplink studies:

- LTE Average Uplink C/(I+N)
- LTE SC-FDMA Modulation Regions – Uplink
- LTE CQI Regions - Uplink
- LTE Adaptive modulation uplink data rate

An example of the LTE CQI Regions – Uplink study plot using per-sector predicted uplink interference is shown below:
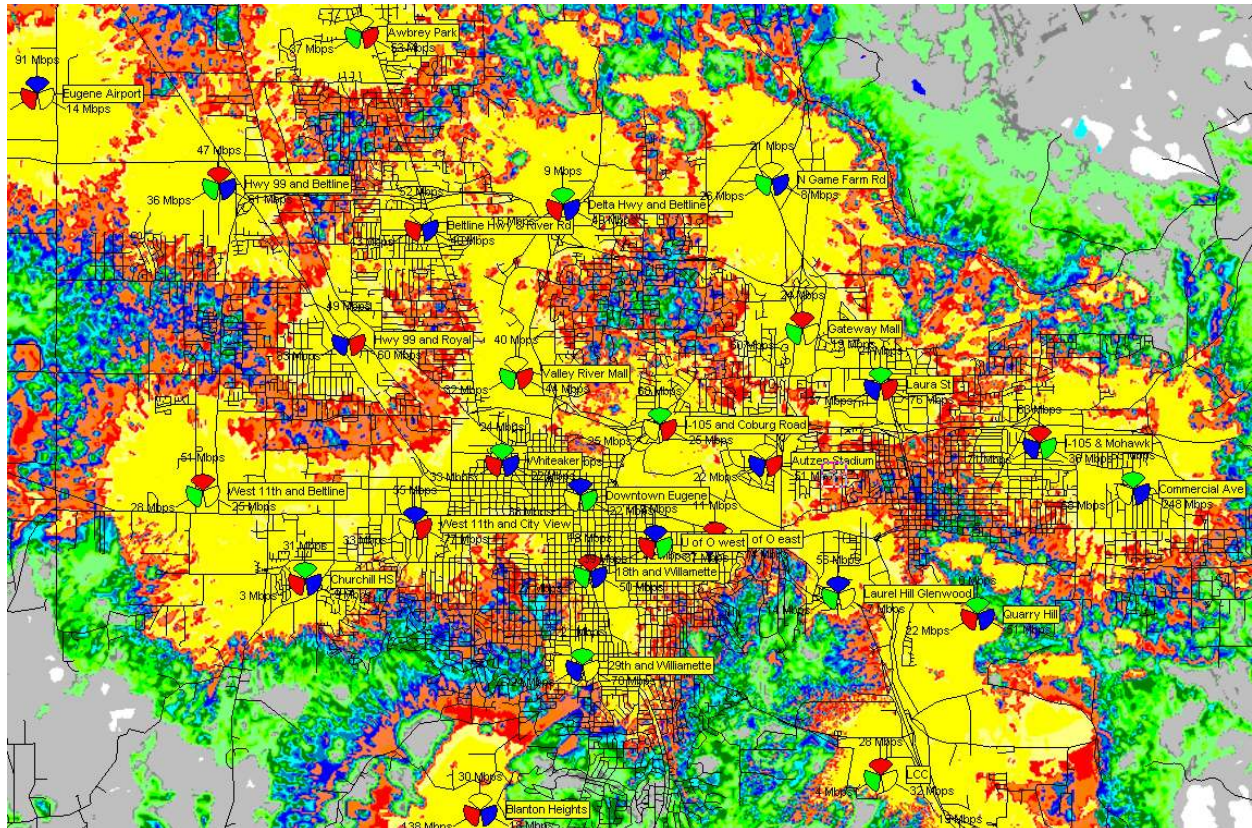
SignalPro also has the following additional LTE uplink performance studies:

- LTE Maximum Uplink C/(I+N), which analyses each co-channel sector's coverage areas and determines the UE location that would cause the most uplink interference.
- UE Power when using Power Control
- LTE Uplink Interference Stochastics (shown previously)
- LTE Average Uplink CQI using Monte Carlo simulations

The SignalPro Monte Carlo simulation allows the user to predict the system performance based on repeated simulations of statistically weighted UE locations with user-defined traffic characteristics. The study determines uplink interference and capacity at each interval and produces both a predicted uplink CQI plot as well as a detailed report for both the system and each sector's predicted service to their UE's.

The Power of Smart Planning   7

SignalPro also offers the following LTE-specific downlink performance studies in addition to the basic (but useful) Received Power at Remote and C/(I+N) at remote for strongest desired base station:

- LTE OFDMA Modulation Regions – Downlink
- LTE CQI Regions – Downlink
- LTE Adaptive modulation downlink data rate

An example of the LTE Adaptive modulation downlink data rate study plot is shown below:
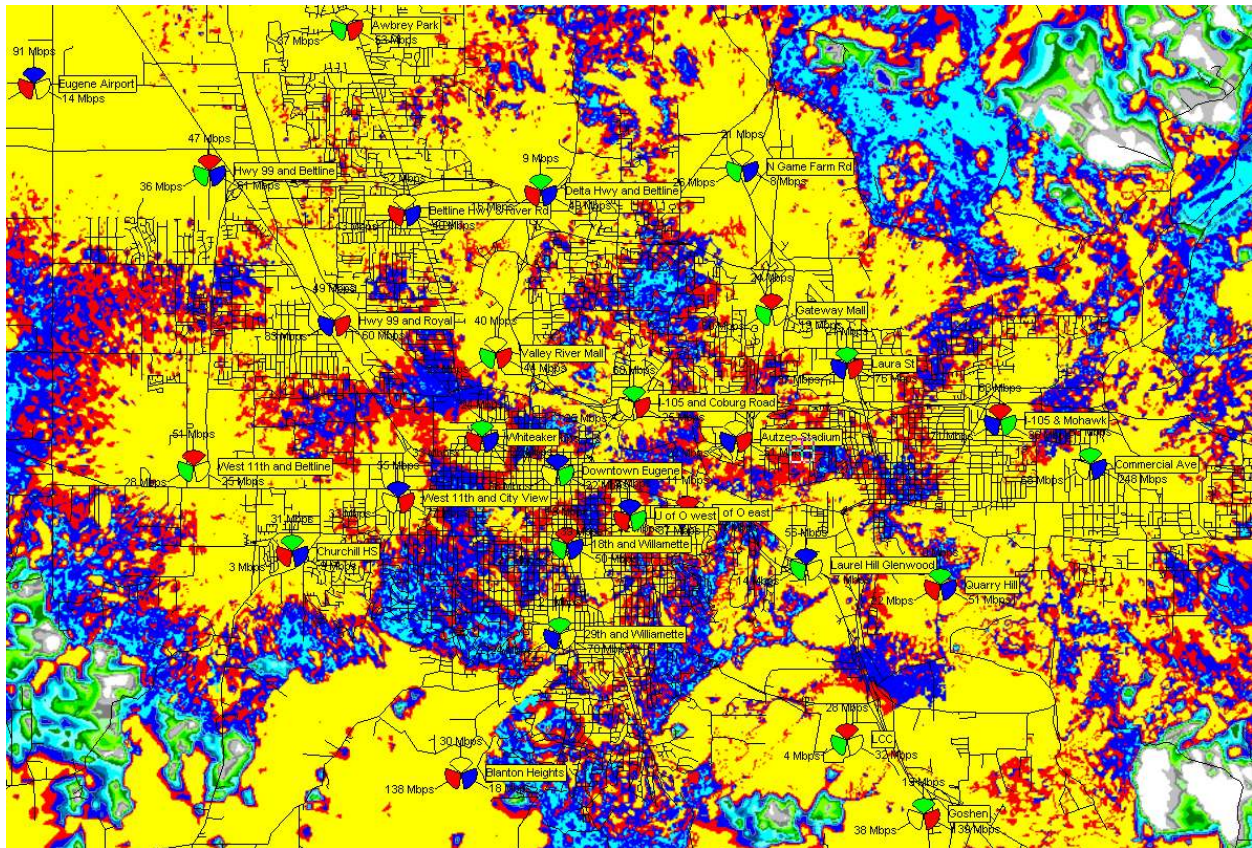
Additional LTE studies and reports in SignalPro

The LTE standard allows for a number of optional system features that include, FFR (Fractional Frequency Reuse) and intra-system ("I-RAT") handover between the LTE network and another 3GPP or 3GPP2 standard underlay network. The following studies are available in SignalPro that allow the user to model these advanced features as well as additional LTE physical layer simulations:

- Fractional Frequency Reuse (R1/R3) zones
- Inter-eNodeB Handoff Regions
- Inter-RAT handover
- Strongest (most likely) Server using best channel
- 2nd Strongest Server at Remote
- C/(I+N) at Remote for Best Channel
- LTE Interference for Focus Sector

The FFR zones study determines where the R1 and R3 FFR (Fractional Frequency Reuse) zones would be, if R1/R3 FFR was implemented in an LTE system. This study will produce a plot like this one below as well as a report that includes the following for each sector:

Sector BE_240	R3 C/(I+N) cutoff =	8.1 dB
Zone	sq. km	Mbps
R1	15.59	7.83
R3	26.5	2.84
Totals	42.09	10.67

Below is a sample R1/R3 FFR zone study plot. The blue areas are R1 (1/1 reuse) zones, the green areas represent R3 (1/3 reuse) zones, the red areas (not shown in plot) represent regions which would not have coverage if FFR was not in use and the black areas represent regions that have no LTE coverage.

The Power of Smart Planning   9
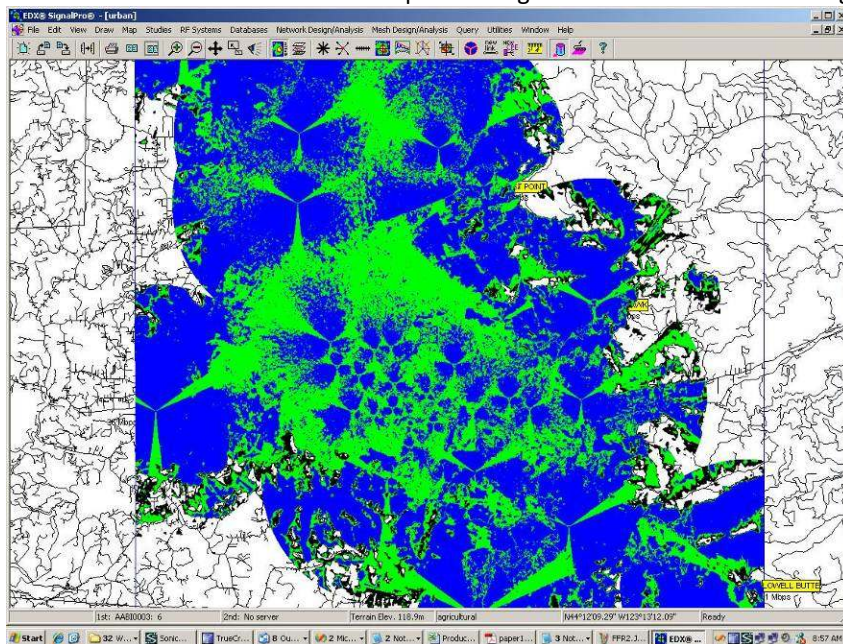
The LTE inter-RAT handover regions study uses the underlay and overlay (LTE) network parameters as well as the user-specified I-RAT handover parameters to determine whether the underlay or overlay network is providing service to the UE. An example I-RAT study plot is shown below:
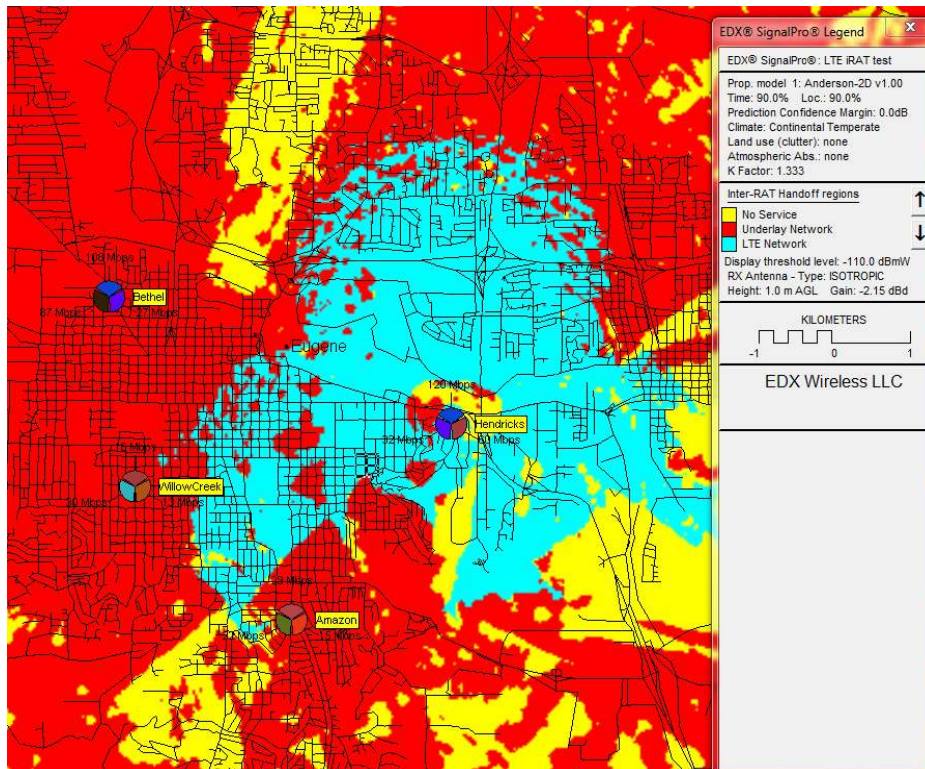
Cell Group ID, Cell ID and Neighbor Cell list determination

SignalPro can determine certain LTE network parameters based on LTE system analyses. These parameters include the Cell Group ID associated with each eNodeB site as well as the Cell ID and neighbor cells for each eNodeB sector. These parameter settings from SignalPro can be exported to the LTE system's eNodeB's and EPC during system or node setup.

Conclusion

SignalPro's Network Design Module has the tools that the RF engineer requires to produce useful and accurate predictions that result in best-fit LTE designs. This is especially useful for LTE rollouts where spectrum is limited, forcing close reuse of channels. The power of smart planning using EDX's SignalPro provides the RF engineer and LTE operator with the tools to succeed.

For more information and access to other whitepapers on this and related subjects visit www.edx.com or call us at +1 541 345 0019

The Power of Smart Planning   10

Glossary of LTE acronyms used in this document

16QAM – 16 Quadrature Amplitude Modulation. In 16QAM 4 different phases and 4 different amplitudes are used for a total of 16 different symbols.

3GPP - 3rd Generation Partnership Project. The ETSI group that promotes the UMTS and LTE standards.

64QAM – 64 Quadrature Amplitude Modulation where 8 different phases and 8 different amplitudes are used.

AAS - Adaptive Antenna Systems. A general term for a family of antennas that can electronically change their patterns to improve the C/(I+N) of the radio links that they support.

AFP - Automatic Frequency Planning. A sophisticated software routine to assign radio channels based on propagation and traffic/capacity constraints.

AM - Acknowledged Mode for LTE RLC. Used for Best Effort types of IP traffic (such as TCP/IP)

AMR - Adaptive Multi-Rate vocoder. The standard vocoder used for GSM and UMTS voice calls.

C/(I+N) – The ratio of Carrier (desired) signal level to the sum of the Interference and Noise levels.

CQI - Channel Quality Index. CQI is defined in both the 3GPP UTRA (UMTS) and E-UTRA (LTE) standards to define specific Adaptive Modulation and Coding levels as well as for radio channel quality reporting.

Downlink (not an acronym) is the radio path from the eNodeB (base station) to the UE (mobile).

eNodeB or eNB - Evolved Node B. This is the 3GPP E-UTRA (LTE) term for an LTE base station.

EPC - Evolved Packet Core. This is the 3GPP E-UTRA (LTE) term for an LTE core network ("switch").

ETSI - European Telecommunications Standards Institute. Guardian of GSM, GPRS, EDGE, UMTS and LTE/E-UTRA standards

E-UTRA - Evolved Universal Terrestrial Radio Access. This is the 3GPP E-UTRA (LTE) term for an LTE radio network.

FDD - Frequency Division Duplex. Supports simultaneous uplink and downlink radio transmission on frequency channel pairs.

FFR – Fractional Frequency Reuse is when the channels are assigned in two zones based on the radio link C/(I+N). High C/(I+N) radio links reuse all channels (1/1 reuse or "R1 zone") and lower C/(I+N) radio links towards the cell edge use 1/3 of the radio channels ("R3 zone"). FFR-A separates the R1 and R3 zone (technically 1/1 and 1/3) radio channel assignments and FFR-B has one common (shared) R1 and R3 radio channel group (1/3 and 2/3 reuse).

FTP - File Transfer Protocol is used to transfer files across an IP connection using TCP/IP. Uses LTE AM RLC.

HTTP - Hypertext Transfer Protocol is the standard for viewing web pages using TCP/IP. Uses LTE AM RLC.

The Power of Smart Planning   11

iPTV - Internet Protocol television is the standard for RTP (Real Time Protocol) streaming of video feeds. Uses LTE UM RLC.

LTE - Long Term Evolution. The 3GPP marketing term for E-UTRA technology.

MIMO-A (Space-Time Coding) - Multiple Input Multiple Output method that uses multiple antennas on one or both ends of the radio link to improve the C/(I+N) of the radio link.

MIMO-B (Spatial Multiplexing) - Multiple Input Multiple Output method that uses multiple antennas on one or both ends of the radio link to improve the data rate (capacity) of the radio link.

OFDMA - Orthogonal Frequency Division Multiple Access is a multi-user version of OFDM that assigns portions of the OFDM channel for defined periods of time to different users.

PLMN - Public Land Mobile Network, a generic ETSI term for a radio-telephone system.

PRB - Physical Resource Block. A PRB is 12 OFDM tones (180 kHz) assigned to a user for a 0.5 second interval. It is the basic unit of capacity that an eNodeB scheduler can use.

QPSK - Quadrature Phase-Shift Keying. A fairly simple and robust modulation that represents each bit as one of four phases (45, 135, 225 or 315 degrees).

RAT - Radio Access Technology. A 3GPP term for the network of base stations that a PLMN has.

RLC - Radio Link Control is an LTE Layer 2 sublayer that manages the physical resources for each data session.

SC-FDMA - Single Carrier Frequency Division Multiple Access is a variant of OFDM used for the LTE uplink.

SDMA - Spatial Division Multiple Access is a form of MIMO that also uses adaptive antenna beamforming.

TCP/IP - Transmission Control Protocol/Internet Protocol is used for for Best Effort (FTP, HTTP, etc.) data transmission across IP networks. The majority of IP network traffic uses TCP/IP.

TDD - Time Division Duplex is when uplink and downlink transmissions share the same radio channel but are separated into different time slots.

TDD Configuration Number – The 3GPP/E-UTRA standard defines six different possible TDD Configurations to allow the operator to tailor their LTE RAN to best fit the uplink and downlink traffic of its subscribers.

UE - User Equipment. The 3GPP/E-UTRA standard term for the subscriber's terminal (a.k.a. "the mobile")

UM - Unacknowledged Mode" for LTE RLC

Uplink (not an acronym) is the radio path from the UE (mobile) to the eNodeB (base station).

VoIP – Voice over Internet Protocol. A set of standards allowing for phone calls to be carried on an IP network.

The Power of Smart Planning   12

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