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Dimensioning Tool for 3GPP Long Term Evolution (LTE) Radio Access Network

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ABSTRACT

LTE networks are intended to bridge the functional data exchange gap between very high data rate fixed WLANs and very high mobility cellular networks. For LTE network to experience its full functional capabilities it must be well-planned and deployed effectively. The dimensioning phase which comprises of two fundamental processes namely the coverage planning and the capacity planning is a very crucial step in the deployment of any LTE network. However, it is difficult to come out with a clear model of the coverage and capacity planning and research works are still going on to improve these aspects. In view of this problem, this paper aim at assessing different ways of achieving coverage and capacity planning in LTE network by developing and analytical model based on link budget calculation. The model is later implemented with Visual Basic software as a dimensioning tool named "LTE Smart Planner". The software was first assessed against some manual data in order to prove its effectiveness. The software was further tested against existing tools like Nokia Siemens Network Dim tool (NSN Dimtool) using the COST 231 HATA propagation model. In all it appears that the LTE Smart Planner is very effective and ease the task of coverage and capacity planning of LTE network by providing a very simple and user-friendly programming environment to the user. However some differences were observed in the results of the LTE Smart Planner as compared to the NSN

Dimtool and these were due to the differences in the method used to estimate thermal noise. These differences were much felt for dense urban and urban area.

Keywords: LTE network, coverage planning, capacity planning, link budget, dimensioning tool.

Introduction

Over the last decade, the world of communication has experienced a tremendous increase in mobile data traffic due to the growing popularity of mobile internet, mobile TV, IP telephony, multimedia online gaming, etc… This phenomenon has revealed the inadequacy of 2G networks (GSM, GPRS, and EDGE) and 3G UMTS to support these requirements in order to remain competitive in the near future, thus forcing mobile communication industries to engage in the discovery of new technologies that will enhance user experience by increasing bandwidth and reducing cost per bit usage with higher quality of service (QoS). In order to address the high speed data and multimedia transport needs of operators, the Third Generation Partnership Project (3GPP), a collaborative group of international standards bodies and telecommunications companies, has introduced a new high-speed and low latency radio access method for mobile communications systems -Long Term Evolution (LTE)/LTE-Advanced.

LTE is one of the most recent standard in the mobile communication technologies .The 3GPP’s radio access architecture has evolved due to the enhancement of the Universal Terrestrial Radio Access (UTRA) which gave birth to the Evolved UMTS Terrestrial Radio Access Network (E-UTRAN), the radio access of LTE .This successful improvement allows LTE to have some incomparable features such as: increase in downlink and uplink peak data rate, scalable bandwidth, improvement in system capacity and coverage, latency and cost reduction and being an all IP network.

LTE networks are intended to bridge the functional data exchange gap between very high data rate fixed wireless Local Area Networks (LAN) and very high mobility cellular networks. LTE was designed to be deployed as an overlay to existing networks or to operate separately [1].

However, it is known that initial stage planning of network is greatly influenced by vendors and industries which are very reluctant about releasing information about their advancement and findings. LTE network which has not yet reached its final standardization level, suffers the initial network planning problem just like other radio cellular network.

Moreover, an accurate and cost effective deployment of LTE network involves a proper dimensioning of its radio access network, the core network as well as the transport bandwidths for the X2 and S1 interfaces [2].

Among all the major requirement described above, coverage planning also known as coverage prediction is the most challenging to be modelled. As this involves communications, several models of wireless channel need to be tested under varied environment in order to determine the one that best fit the coverage planning.Syed

(2009) developed the dimensioning of the radio access network of LTE 900/1800/2600MHz, precisely on the radio interface [3]. Methods and models for coverage and capacity planning were developed in [4], to finally estimate network elements count, that is, number of eNodeBs required to support the traffic load of subscribers in a given area. In 2008, Atoll LTE was the first LTE network planning software available on the market. It has since then been used on a number of projects worldwide. Atoll allows planning and analyzing integrated GSM/UMTS/LTE and CDMA2000/LTE networks [5].

Despite all these efforts, more need to be done about the modelling process in order to improve upon the accuracy and also to personalize them with local information. With regard to this problem, our paper seek to develop an analytical model of LTE coverage and capacity planning and further build a dimensioning tool to enhance its usability.

Methodology

In this section, we present an analytical model of coverage and capacity planning of an LTE network and also, some essential propagation models involved in the link budget calculation.

Coverage planning

The objective of the coverage planning is to essentially estimate the size of the cell. The cell radius is obtained following the completion of a radio link budget for both the downlink and the uplink that determines the maximum allowed path loss (MAPL).This value will be used for the propagation model to determine the cell radius.

The analytical methods of solving coverage planning for both uplink and downlink, is depicted in figure 1 and figure 2 respectively.

Propagation Models

An RF propagation model is a mathematical formula used to characterize the radio wave propagation between the transmitter on one end and the receiver at the other end of the RF path. It is typically a function of frequency, distance, antenna height, terrain, clutter and other conditions. They are also used to convert the path loss into the cell radius. In this paper, three main propagation models have been selected and these are: COST 231 HATA, HATA OKUMURA, ERICSSON 9999 models.

COST 231 HATA Model

The COST-231 Hata model has been tailored for the following limits:

- Frequency (f) 1, 500 to 2, 000 MHz
- Base Station Height (H_b) 30 to 200 m
- Mobile Height (H_m) 1 to 10 m
- Distance (d) 1 to 20 km.

It is further assumed that the base station antenna heights are above roof-top levels of buildings adjacent to the base station.

Urban

$$L_u(dB) = 46.3 + 33.9\log(f) - 13.82\log(H_b) - a(H_m) + [44.9 - 6.55\log(H_b)] \cdot \log(d) + C_m \quad (1)$$

Where $a(H_m)$ correction factor for vehicular station antenna height

$$a(H_m) = [1.1\log(f) - 0.7] \times H_m - [1.56 \cdot \log(f) - 0.8] \quad (2)$$

For a medium-small city (Urban): C_m= 0.
For a large city (Dense Urban): C_m = 3.

Suburban

$$L_{su}(dB) = L_u - 2 \times \left[\log\left(\frac{f}{28}\right)\right]^2 - 5.4 \quad (3)$$

Rural Quasi Open

$$IL_{qo}(dB) = L_u - 4.78 \times [\log(f)]^2 + 18.33 \cdot \log(f) - 35.94 \quad (4)$$

Rural Open

$$L_{ro} = L_u - 4.78 \times [\log(f)]^2 + 18.33 \cdot \log(f) - 40.94 \quad (5)$$

HATA OKUMURA Model

The Hata OKUMURA, [6, 7] model has been tailored for the following limits:

- Frequency (f) 1, 500 to 2, 000 MHz
- Base Station Height (H_b) 30 to 200 m
- Mobile Height (H_m) 1 to 10 m
- Distance (d) 1 to 20 km.

It is further assumed that the base station antenna heights are above roof-top levels of buildings adjacent to the base station.

Urban

$$L_u(dB) = 69.55 + 26.16\log(f) - 13.82\log(H_b) - a(H_m) + [44.9 - 6.55\log(H_b)] \cdot \log(d) \quad (6)$$

$a(H_m)$ correction factor for vehicular station antenna height. For a medium-small city (Urban):

$$a(H_m) = [1.1\log(f) - 0.7] \times H_m - [1.56 \cdot \log(f) - 0.8] \quad (7)$$

For Dense Urban:

$$a(H_m) = 8.29 \times [\log(1.54 \times H_m)]^2 - 1.1 \text{ for } f \leq 200MHz$$
$$a(H_m) = 3.2 \times [\log(17.75 \times H_m)]^2 - 4.97 \text{ for } f \geq 400MHz \quad (8)$$

Suburban

$$L_{su}(dB) = L_u - 2 \times \left[\log\left(\frac{f}{28}\right)\right]^2 - 5.4 \quad (9)$$

Rural Quasi Open

$$L_{qo}(dB) = L_u - 4.78 \times [\log(f)]^2 + 18.33\log(f) - 35.94 \quad (10)$$

Rural Open

$$L_{ro}(dB) = L_u - 4.78 \times [\log(f)]^2 + 18.33\log(f) - 40.94 \quad (11)$$

ERICSSON 9999 Model

To predict the path loss, the network planning engineers used a software provided by Ericsson Company known as Ericsson model. This model also stands on the modified Okumura-Hata model to allow room for changing in parameters according to the propagation environment. Path loss according to this model is given by equations 12 and 13:

$$PL = a_0 + a_1\log_{10}(d) + a_2\log_{10}(h_b) + a_3\log_{10}(h_b) \cdot \log_{10}(d) - 3.2[\log_{10}(11.75h_r)]^2 + g(f) \quad (12)$$

Where $g(f)$ is defined as follow:

$$g(f) = 44.49\log_{10}(f) + 4.78[\log_{10}(f)]^2 \quad (13)$$

- f: Frequency [MHz]
- h_b: Transmission antenna height [m]
- h_r: Receiver antenna height [m]

The default values of these parameters (a_0, a_1, a_2 and a_3) for different terrain are given in the following table:

Table 1: Correction factor with respect to the environment. (Ericsson model)

Environment	a_0	a_1	a_2	a_3
Urban	36.2	30.2	12.0	0.1
Suburban	43.20	68.93	12.0	0.1
Rural	45.95	100.6	12.0	0.1

Capacity planning

The main objective of the capacity planning of any LTE network is to determine the ability of the system, based on the required resources, to support a given number of subscribers considering a specific QoS level. Both calculations and simulations are involved in determining the capacity based site count. The first step is to determine the network throughput resulting from the traffic model analysis. Thereafter the site capacity will be assessed based on the simulations results. Finally, the ratio of the network throughput to the site capacity determines the number of sites due to capacity planning with respect to each type of morphology. Figures 3 and 4 depict the calculations involved in the capacity planning.

Site Capacity

The average site capacity for both uplink and downlink of LTE networks is obtained from manual calculations as well as simulation results. Factors like UE mobility, slow/fast fading, scheduling, power control etc… are taken into account during the simulations which principle is to assume a subscriber density given a cell area and a particular SINR conditions for each subscriber depending on its location in the cell [3].

Having obtained the required inputs, the steps involved in calculating the site capacity are given as follow:

Cell Throughput (DL) = Interpolate Spectral Efficiency × Channel Bandwidth × (1+MIMO Gain) × Cell Load × Scaling Factor. (14)

Cell Throughput (UL) = Interpolate Spectral Efficiency × Channel Bandwidth × (1+MRC Gain) × Cell Load × Scaling Factor (15)

Site Capacity = Cell Throughput × # Cells/Site. (16)

Number of sites based on capacity planning

Knowing the network throughput and the site capacity, the capacity based site count can be simply obtained by:

Sites (capacity) = Network Throughput / Site Capacity. (17)

The following diagrams describe the basic procedure that will be strictly followed to determine the number of sites due to capacity planning:

Results

This section deals with the development of a dimensioning tool, called “LTE Smart Planner”. This was developed with Microsoft Visual Basic 2010 to facilitate the calculations made during the dimensioning process and to perform some network parameters simulations. Figure 5, shows the general architecture of the LTE Smart Planner

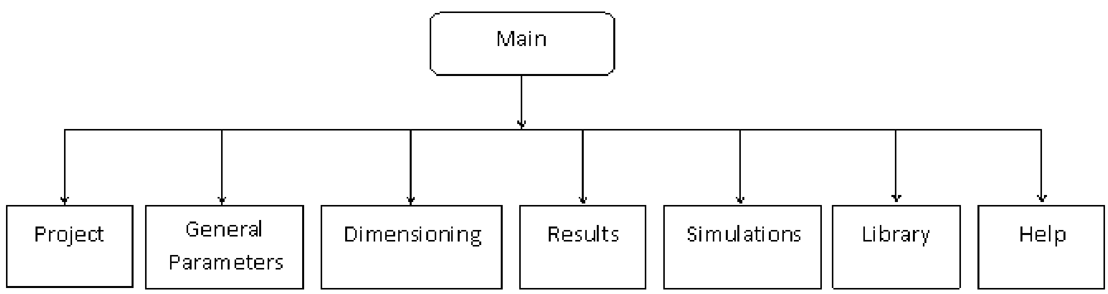

Figure 5: Dimensioning tool main menu diagram

When launching the application, an interface containing designer's names, copyrights notes and specifications appears as shown in figure 6.

Figure 6: Dimensioning tool launching interface

The homepage interface follows as shown in figure 7:

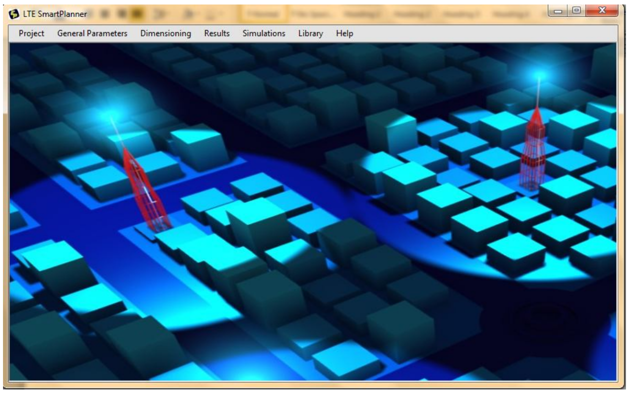

Figure 7: Dimensioning tool main interface

Project tab

The project tab is the first of the main items of the tool and it provides the following options to the users:

- New: starts a new project with the defaults parameters of the library.
- Open: opens an existing project.
- Save: saves an ongoing project in a specific directory.
- Save As: saves the current project under a different directory and/or with a different project name.
- Print: provides to the user a preview of the hard copy of all the results and simulations of the carried project.
- Close: closes the carried project without exiting the application.
- Exit: exits the whole application.

General parameters

Under the general parameters, the user defines all the parameters related to the radio planning (frequency band, modulation code scheme, number of resource blocks…), the geographical layout, the site configuration and the different propagation models as illustrated in figure 8. These parameters are needed for the coverage and capacity planning process.

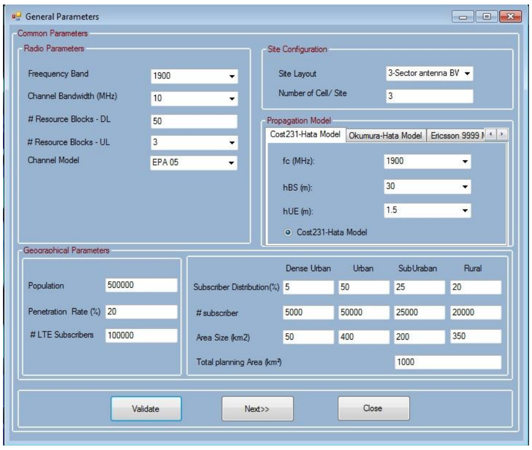

Figure 8: General Parameters Interface

Dimensioning

Once the general parameters of the network are defined, the next step to undertake is the coverage and capacity dimensioning found under the dimensioning tab.

The coverage dimensioning aims at finding the number of base stations based on the size of the cell. The user performs the dimensioning for both uplink and downlink by providing the values for the eNodeB parameters, UE parameters and the isotropic power required in order to obtain the MAPL, the cell range, the cell/site area and the coverage based site count. Figure 9 illustrates the capacity planning interface.

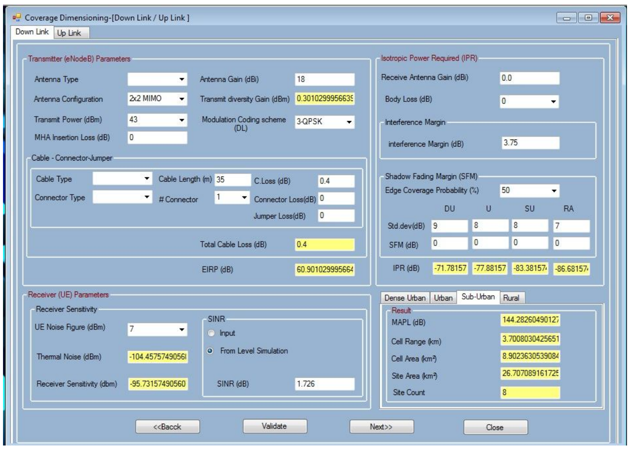

Figure 9: Coverage dimensioning (DL) interface

The next step under the dimensioning is the capacity dimensioning which purpose is to determine the final number of base stations for both links (DL and UL) according to each type of morphology. Some parameters like the total number of users, the cell load and PAR are provided by the user while other parameters are coming from the coverage dimensioning (figure 10).

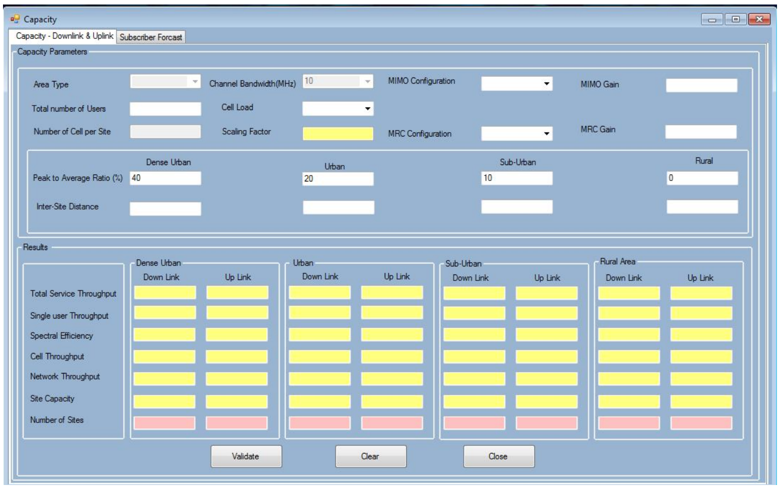

Figure 10: Capacity dimensioning Interface

After completing the dimensioning stages, the results item allows the user to view the results of both coverage and capacity dimensioning and proposes a final result which is the highest number of base stations obtained as illustrated in figure 11.

In addition to the dimensioning, LTE Smart Planner contains a library with different databases related to the coverage and capacity dimensioning. These databases are provided with some values that the user can edit if necessary as shown in figure 12. The access to the library requires the user to provide a username and password. The following are the different databases found in the library:

- Antennas
- Connectors
- Feeder cables
- Single Service Throughput
- Throughput per Session
- Single User Throughput

In terms of specification, the LTE planner runs on PCs under Windows environment, compatible XP Pro, XP SP2, Vista and 7. Any PC that has the drive requires the following minimum performance:

- 256 MB RAM
- 1Ghz CPU
- 40 GB hard drive with at least 400MB free for software maintenance.

Figure 11: Results Interface

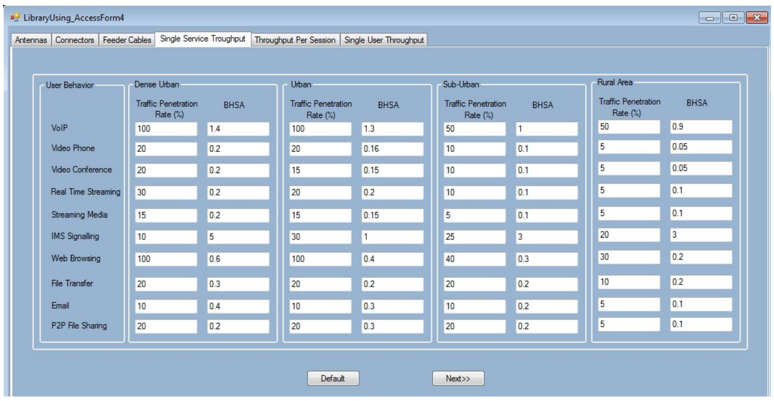

Figure 12: Library Interface

Discussion

The previous section gives profound details about the dimensioning of any LTE network by giving an exposure of a mathematical model which helps to obtain the final coverage and capacity based site counts. Thereafter, a tool has been developed and implemented based on the dimensioning process. The purpose of this section is to analyze the results of our planning tool, to test its efficiency and discuss its advantages and limitations.

First we started by testing the validity of our tool by examining the results we obtained from the tool with a simple calculator and this process was successful as the results obtained were the same. Then a case study has been conducted and the results were compared with those of Nokia Siemens Network Dimtool (NSN Dimtool) in order to determine the reliability of our dimensioning tool.

Case Study: Nokia Siemens Networks Dim tool vs. LTE Smart Planner [8]

- Coverage Dimensioning

Table 2: General Parameters of Coverage

Parameters	Units	Values
Frequency Band	MHz	1900
Channel Bandwidth	MHz	10
# RB downlink		43
# RB uplink		5
Site Layout		Omni
UE Power Class		Class 3

Table 3: Common Parameters for Coverage

	Dense Urban	Urban	Sub Urban	Rural
Building Penetration Loss (dB)	23	16.5	11	7
Gain against Shadowing (dB)	2.8	2.4	2.4	1.7
Area to be covered	50	400	200	350
Edge Probability	90%			

Table 4: Downlink parameters for coverage

Parameters	Units	Values	
		NSN Dimtool	LTE Smart Planner
Antenna Gain	dBi	18	18
Transmit Diversity Gain	dBm	3	3
Transmit Power	dBm	43	43
MHA Insertion Loss	dB	0.0	0.0
Total Cable Loss	dB	0.4	0.4
EIRP	dB	63.6	63.6
UE Noise Figure	dBm	7	7
Thermal Noise	dBm	-132.17	-105.11259
SINR	dB	0.6	0.6
Receiver Sensitivity	dBm	-96.79	-97.51259
Receive Antenna Gain	dBi	0.0	0.0
Interference margin	dB	3.75	3.75

Table 5: Uplink parameters for coverage

Parameters	Units	Values	
		NSN Dimtool	LTE Smart Planner
Transmit Power	dB	23	23
Antenna Gain	dBi	0.0	0.0

Body Loss	dB	0.0	0.0
EIRP	dBm	23.0	23.0
NodeB Noise Figure	dB	2.2	2.2
Thermal Noise	dBm	-132.17	-114.458
SINR	dB	1.28	1.28
Receiver Sensitivity	dBm	-110.91	-110.97757
Receive Antenna Gain	dBi	18	18
Cable Loss	dB	0.4	0.4
MHA Benefit	dB	0.0	0.0
Cell Load		50%	50%
Interference margin	dB	1.81	1.8

Table 6: Final Results on Coverage Estimation

	Dense Urban		Urban		Suburban		Rural	
	NSN	SP	NSN	SP	NSN	SP	NSN	SP
MAPL (dB)	119.27	118.03	125.14	124.13	130.14	129.63	133.07	132.93
Cell Range (km)	0.257	0.238	0.459	0.431	1.410	1.364	6.360	6.307
Cell Area (km^2)	0.172	0.147	0.549	0.48	5.168	4.84	105.17	103.44
Site Area (km^2)	0.172	0.147	0.549	0.48	5.168	4.84	105.17	103.44
Site Count	291	340	729	826	39	42	4	4
Propagation Models	COST 231 HATA (one slope) used by NSN Dimtool				COST 231 HATA (normal) used by LTE Smart Planner			

Capacity Dimensioning

Table 7: General Parameters of Capacity

Parameters	Values
Cell Load	100%
MIMO Settings	2×2 OL MIMO Mode3 (DL) 2Rx MRC (UL)
Channel Bandwidth	10 MHz
Site Layout	Omni
# Subscribers	100000
Traffic model	Same for both NSN and SP

Table 8: Other Parameters necessary for Capacity estimation

Parameters	Dense Urban		Urban		SubUrban		Rural	
	NSN	SP	NSN	SP	NSN	SP	NSN	SP
Inter Site Distance (m)	446	411	796	746	2442	2361	11016	11091
Spectral Efficiency(bps/Hz ; DL)	1.42	1.18	1.39	1.17	1.17	1.04	0.74	0.67
Spectral Efficiency(bps/Hz ; UL)	1.00	0.67	1.02	0.65	0.90	0.50	0.24	0.13

Table 9: Final Results on Capacity Estimation

Parameters	Dense Urban		Urban		SubUrban		Rural	
	NSN	SP	NSN	SP	NSN	SP	NSN	SP
Network Throughput (Mbps)	223.8		1818.51		491.85		114.102	
Cell Throughput (kbps)	14226.48	15456.23	13906.04	13950	11691.46	11820	7418.03	7410
Site Capacity	14.22648	15.45623	13.90604	13.950	11.69146	11.820	7.41803	7.410
# Sites	15	15	131	131	43	42	16	16
# Subscribers	5000		50000		25000		20000	

After running the test, it can be observed that, there is a slight difference between the values obtained for the Receiver Sensitivity which is mainly caused by the difference between the thermal noise values of both tools. The reason explaining this difference is that NSN Dimtool and LTE Smart planner use different formulas to determine the thermal noise.

NSN Dimtool: Thermal Noise = Thermal Noise Density + 10log(Subcarrier Bandwidth×1000) (18)

LTE Smart Planner: Thermal Noise = $K_B \times T \times B$ (19)

Where

K_B = Boltzmann's constant, 1.38e-23 Ws/K

T = receiver temperature, 293K

B = Bandwidth

Since our work did not consider the subcarriers parameters in order to calculate for the thermal noise value, the receiver sensitivity which depends mainly on the thermal noise will also differ, hence the maximum allowed path loss will be different from both tools. The benefits of using the general formula for thermal noise is for the user to feel comfortable in understanding the process even though the considerations of NSN Dimtool brings some more precision in the output.

On the other hand, the adopted propagation model is the main factor responsible for the conversion of the maximum allowed path loss into the cell range of a specific area type. Its choice has a considerable impact on the final site count because it is related to the cell range. In the conducted comparison with Nokia data, we restricted the dimensioning by selecting the COST 231 HATA model while NSN Dimtool selected the COST 231 HATA model with one slope. The difference in the choice is due to the fact that we were limited to the most common propagation models used in such exercise while NSN Dimtool for the sake of precision, brought about some specificities in their model based on the simulations performed on the field. Also it must be acknowledged that the difference in the final output is much felt only for the dense urban and urban areas because the purpose of choosing such model in NSN Dimtool is to have accurate results in these types of area.

Conclusion

In summary, this paper dealt with the development of a mathematical model for LTE Radio Access Networks which was implemented with Visual Basic as a dimensioning tool called “LTE Smart Planner”. A sound analysis of the obtained results show some limitations as well as some advantages. The channel models supported by LTE Smart Planner were limited due to the absence of appropriate link level and system level simulators such as 4G Max, UPRISE etc…

Despite the fact that standards do present only general information on LTE network planning, the LTE Smart Planner go further by allowing the designer to alter any specific parameters and therefore making the design more friendly, more easy and more attractive. Also the traffic model considered in this paper, took into consideration a variety of types of service related to LTE networks which gives some accurate results according to the users behavior towards the network.

It is our recommendation that the dimensioning of the S1 and X2 should further be added to the LTE Smart Planner. In addition, a mapping tool should be associated with the design to ease the task of configuring basic parameters related to the environment.

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