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Planning and simulation of LTE radio network: case of the city of Yaoundé

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Abstract: *This article is a simulation of the LTE network, in the 1800 MHz band on a 20 MHz channel, using ATOLL software in the city of Yaoundé, the capital of Cameroon, which covers an area of approximately 183 km2. This study, which takes into account existing 3G sites, does a coverage planning based on the COST-231 propagation model and the capacity planning based on a service and traffic models. The simulation results indicate that the city of Yaoundé requires 244 LTE sites. ATOLL simulations then display a received signal level of more than -95 dB in almost all the entire area of interest.*

Keywords: *LTE, coverage, capacity, traffic.*

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I. Introduction

The rapid growth of technologies and mobile communications has contributed to the improvement of our daily lives. From the first generation of cellular networks providing analog communications to those currently developed, the technology is rapidly expanding driven by the search for greater accessibility and a better quality of service [1]. At the same time, user's throughput needs have also shifted from traditional voice communications to the delivery of multimedia content passing from the transmission of text messages to the access of broadband internet. All these requirements have motivated the need for new architectures for the emerging systems with issues related to quality of service, capacity and coverage. It is for this reason that the 3rd Generation Partnership Project (3GPP), which is currently the dominant specification development group for mobile radio communication systems in the world, developed the LTE (Long Term Evolution) standard.

The main aim of the LTE technology is to provide low latency wireless broadband data communications over long distances. It offers spectral flexibility that supports frequency bands from 450 MHz to 4.5 Ghz and bandwidths between 1.4 Mhz and 20 MHz [2]. LTE has an architecture that is based on the IP protocol. It is deployed with the Frequency Division Multiple Access (OFDMA) technique for downlink. While the uplink uses single carrier frequency division multiple access (SCDMA). These techniques provide higher data rates for users and their applications.

Another feature of LTE that increases the throughput over long distances is the Multiple Input and Output System (MIMO). MIMO is a multi-antenna technology that uses M antennas in transmission and N antennas in reception. This configuration is called the MxN MIMO system. The increase in the number of transmission antennas increases the average signal-to-noise ratio of reception and consequently the radius of the cell and the transmission data rates [3]. A simplified 4G LTE architecture is usually composed of "Packet Core", "eNodeB" and the user. The user connects to the network via the wireless air interface to the eNodeB. This wireless support is enhanced by the MIMO system that allows multiple streams of data to be transmitted and received simultaneously by multiple antennas [4]. The competitive advantage of LTE is therefore its ability to provide very high throughput and greater coverage to end users [5]

Several studies on LTE network planning in various parts of the world exist in the literature and are specific to a particular environment characterized by its habitat, urban morphology, terrain models and user density [6] [7] [8] [9].

Also the present work aims to carry out an LTE network planning in the city of Yaoundé thanks to a simulation with the ATOLL software. This is to facilitate the migration of 3G networks to 4G networks.

The rest of this study does, the coverage and capacity planning of the LTE network, the planning results and the simulation results in the city of Yaoundé.

II. Methodology

II.1 Determination of the number of sites to be deployed

This phase, which takes place only after the network deployment parameters have been chosen, has two stages: the coverage and capacity planning. These two steps will determine the number of sites necessary for the setting up of the 4G radio access network. The following figure illustrates the coverage and capacity planning process.

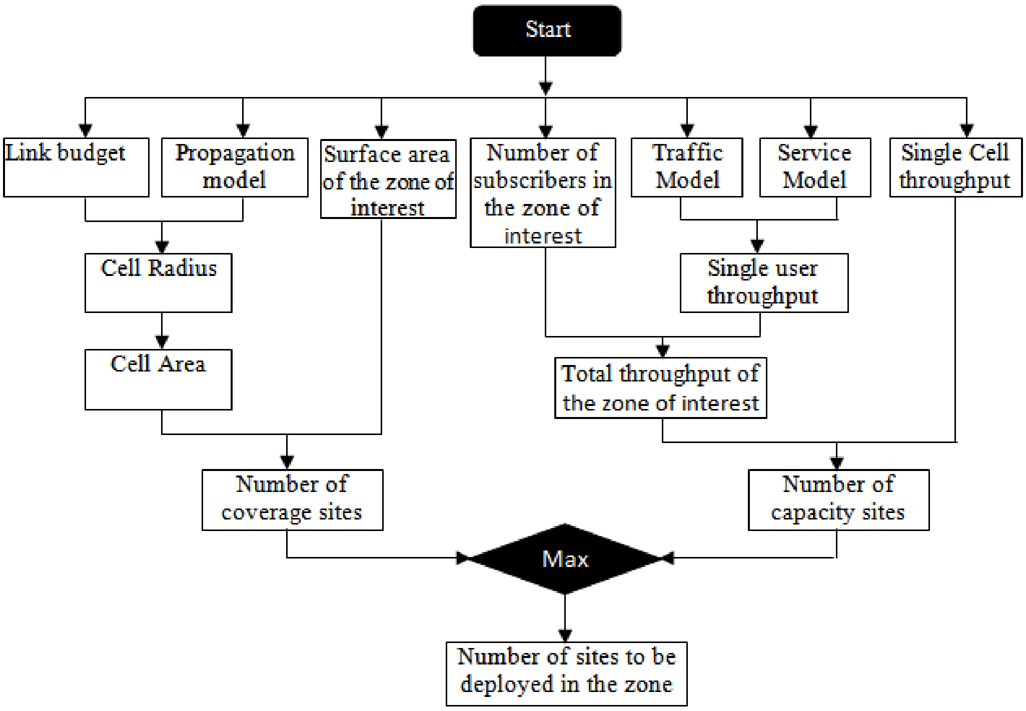

Fig. 1: Diagram illustrating the determination of the number of sites to be deployed

II.1.1 Coverage planning

II.1.1.1 Link budget

a) Downlink link budget

The Effective Isotropic Radiated Power (EIRP) is obtained by adding the gain to the power emitted by the transmitter and subtracting the losses due to cable, connector and the human body.

The equation of the EIRP for the downlink is given by the expression below (1).

$$EIRP = P_{TX} + G_{TX} - L_{TX} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where:

P_{TX} : *Transmission Power* (*dBm*)

G_{TX} : *Antenna Gain* (*dB*)

L_{TX} : *Transmission Losses* (*connector, cable and body*) (*dB*)

The equation of the Receiver Sensitivity (RS) is determined by summing the thermal Noise, Noise Figure and Signal to Interference plus Noise Ratio. It is calculated using equation 2 below:

$RS = kTB + NF + SINR$ ....(2)

$Where:$

$k: Boltzman\,constant\;(1.38x10^{-20}\,mWs/K)$

$T: temperature\,(K)$

$NF: Noise\;Figure\,(dB)$

$B: System\,bandwidth\;(Mhz)$

$SINR: Signal\,to\,Interference\,plus\,Noise\,Ratio\,(dB)$

The equation for the minimum signal reception strength can be formulated by adding the receiver side losses such as body loss, cable loss, interference margin, receiver sensitivity and subtracting the antenna gain. It is calculated using the equation in expression (3) below:

$Minimum\;Signal\;reception\;Strenght = RS + IM + L_{RX} - G_{RX}$ ....(3)

$Where:$

$RS: Receiver\;Sensitivity\,(dBm)$

$IM: Interference\;Margin\,(dB)$

$L_{RX}: Reception\,Losses\,(connector, cabbles\,and\,body)(dB)$

$G_{RX}: Reception\,Gain\;(dB)$

Equation (4) gives the expression for the maximum allowable path loss (MAPL) for downlink.

$MAPL = EIRP - Minimum\,Receeption\,Signal\,Strenght - Penetration\,loss - FM$ ....(4)

$Where:$

$EIRP: Effective\,Isotropic\,Radiated\,Power\,(dBm)$

$FM: Fading\,margin\,(dB)$

b) Uplink link budget
A similar approach to that used for the downlink budget enables us to find path losses in the uplink direction.

II.1.1.2 Propagation Model
The use of the propagation model makes it possible to calculate the cell radius and the area covered by this cell. The COST 231 propagation model is the most adapted to our problem. It is formulated with the expression (5) in urban area.

$$L_{URBAN} = 46.3 - 33.9\log(f) - 13.82\log(h_{te}) - ah_{re} + (44.9 - 6.55\log(h_{te})\log(r) + CM$$
...................(5)

CM = 3 db for urban areas

II.1.1.3 Calculation of the Cell radius and area

The calculation of the cell radius is given by equation (6) below.

$$r = 10^{\frac{L_{URBAN} - 46.3 - 39.9\log f + 13.82\log h_b + a(h_m)}{44.9 - 6.55\log h_b}} \qquad pour\;1500\;Mhz \le f \le 2000\;Mhz \text{...........(6)}$$

The cell coverage area can be obtained using equations (7) and (8).

For an omnidirectional site

$L_{cell} = 2.6\,x\,r^2$ ....(7)

For a trisectorial site:

$$L_{cell} = 1.95x2.6\,x\,r^2 \text{ ....(8)}$$

II.1.1.4 Number of eNodeBs

The number of eNodeBs needed to cover the area of interest is the ratio of the area of the zone to that covered by a site or a cell:

$$Number\,of\,\,eNodeBs = \frac{area\,of\,\,the\,zone\,of\,\,\text{int}\,erest}{area\,of\,\,a\,site\,or\,a\,cell} \text{ ....(9)}$$

II.1.2 Capacity planning
II.1.2.1 Estimating the number subscribers

An estimated number of subscribers, in the year n, can be calculated using the equation (10).

$$U_n = U_0(1 + f_p)^n \text{...................(10)}$$

U_n : number of subscribers in the year n

U_0 : number of subscribers during the planning of year

f_p : subscriber growth factor

n : number of prediction years

II.1.2.2 Traffic density (Data volume per session) [9]

The data volume per session is given by the formula (11):

$$Data\,volume\;per\;session = bearer\_rate * session\_time * session\_duty\_ratio * \left[\frac{1}{1 - BLER}\right] \text{.............(11)}$$

$bearer\_rate$: Service throughput per session of the application layer

$session\_time$: Mean duration of a session

$session\_duty\_ratio$: Session Data transmission ratio per session

$BLER$: Block Error Rate

II.1.2.2 Single user throughput

$$Single\;user\;throughput\;(Kbps) = (\sum\nolimits_k (session\,data\,volume_k * BHSA_k * penetration\,rate_k) * \frac{1 + Peaktoaverageratio}{3600})$$

…………….. (12)

$BHSA_k$: Number of attempts to service k during busy hours

$penetration\,rate_k$: Penetration rate of service k

$Peaktoaverageratio$: Correction factor that takes into account the ratio between peak and mean traffics

The network throughput for the uplink and downlink directions can be calculated as follows;

$$Network\_throughput\_UL = Total\_Number\_of\,users * \text{Sin}\,gle\_user\_throughput\_UL \text{ …………. (13)}$$

$$Network\_throughput\_DL = Total\_Number\_of\,users * \text{Sin}\,gle\_user\_throughput\_DL \text{ ………… (14)}$$

II.1.2.3 Cell Capacity

For a bandwidth of 20 Mhz in the 1800 Mhz band, the uplink and downlink throughput in a sector of an eNodeB are given by the values below [9] :

$DL\_cell\_capacity\_S = 34.719$ Mbps , $DL\_cell\_capacity = 34.719x3 = 104{,}157$ Mbps
$UL\_cell\_capacity\_S = 21.675$ Mbps, $UL\_cell\_capacity = 21.675x3 = 65{,}025$ Mbps

II.1.2.4 Number of Cells

$$Numbre\_of\_cells = Max\left[\frac{Network\_throughput\_UL}{UL\_cell\_capacity}, \frac{Network\_throughput\_DL}{DL\_cell\_capacity}\right] \quad (15)$$

II.1 ATOLL planning software simulation phase
During this phase, simulations will be made using the ATOLL software following the procedure schematized by the block diagram of Figure 2.

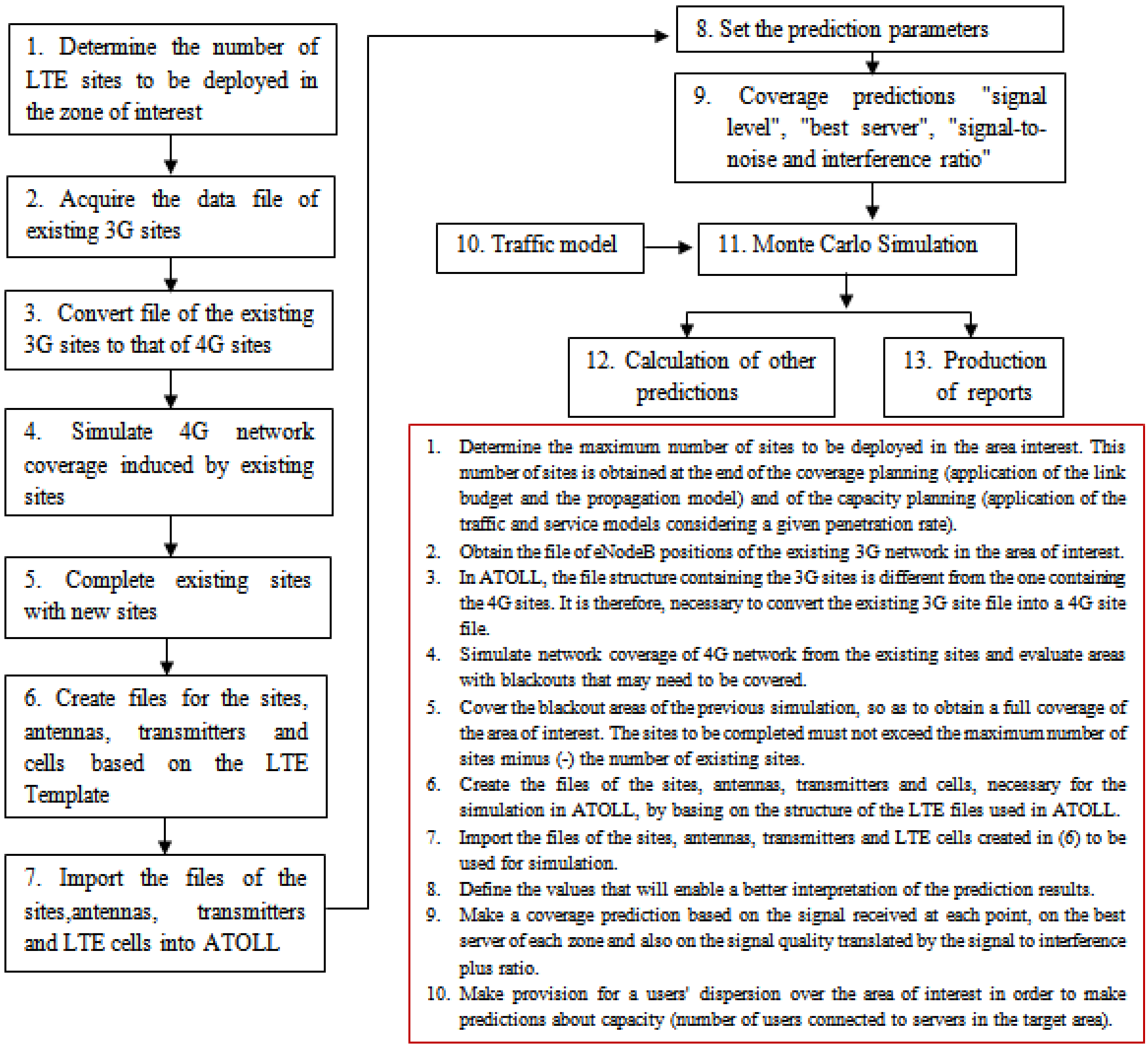

Fig. 2. Flow diagram illustrating LTE Network Planning taking into account existing sites using ATOLL

III. Planning Results

III.1 – Site presentation

The city of Yaounde is located in the Centre region of Cameroon and lies between 3 ° 52 'north latitude and 11 ° 31' east longitude, with a population of 3.5 million inhabitants (estimated in 2018). The relief of the city is hilly and made of plateaus, a set of hills from that vary in altitude from 600 to 700 m and dominated by the mountains Mbam Minkom (1 295 m) and Mount Nkolodom (1 221 m) in the north western side and by Mount Eloumden (1,159 m) to the south western part. This city is spread over an area of 183 km^2 [11].

III.2 Coverage planning

Table 1 shows that the coverage planning of a 4G LTE network in the city of Yaoundé leads to the obtaining of a potential number of 145 eNodeBs.

Table 1: Results of the coverage network planning of the city of Yaounde.

General parameters	Uplink	Downlink
Duplex mode	FDM	FDM
Channel bandwidth (MHz)	20	20
Carrier frequency (MHz)	1800	1800
Target surface area (km2)	183	183
Transmitter	Tx = UE	Tx = eNodeB
Morphology	Urban	Urban
Maximum total T_r power (dB)	23	46
Resource to distribute power	4	100
Subcarriers to Distribute Power	48	1200
Tx Antenna Gain (dBi)	0	18
Tx Cable Loss (dB)	0	0,5
Tx Body loss (dB)	0	0
EIRP per Subcarrier (dBm)	**6,19**	**32,71**
Receiver	Rx-eNodeB	Rx-UE
Noise Figure (dB)	2,5	7
thermal noise (dBm)	-132,23	-132,24
SINR (dB)	-2,52	-3,39
Receiver Sensitivity (dBm)	-132,25	-128,63
Rx Antenna Gain (dBi)	18	0
Rx Cable Loss (dB)	0,5	0
Rx Body Loss	0	0
Interference Margin (dB)	0,87	3,67
Req Min received signal strength(dBm)	-148,88	-124,96
Penetration Loss (dB)	20	20
std of Shadow Fading (dB)	11,7	11,7
shawdow fading marging (dB)	9,48	9,48
Path loss	**125,59**	**128,19**
Propagation Model	COST 231 HATA	
eNodeB Antenna Height (m)	30	30
UE Antenna Height (m)	1,5	1,5
AHM	0,04	0,04
Cell Radius (km)	0,50	0,59
Cell Area for trisector (km2)	1,27	1,78
Site count	**145**	**103**
Number of coverage sites	**145**	

III.3 Capacity planning

The succession of tables 2, 3 and 4 below led to the obtaining of 244 capacity eNodeBs with a penetration rate of 20% for 4G services in the city of Yaounde.

III.3.1 Service model

Table 2 : Service model [10]

Traffic parameters	**UL**				**DL**			
	Bearer rate (kbps)	**PPP session time(s)**	**PPP session duty ratio**	**BLER**	**Bearer rate (kbps)**	**PPP session time(s)**	**PPP session duty ratio**	**BLER**
Voip	26,9	80	0,4	0,01	26,9	80	0,4	0,01
Video Phone	62,53	70	1	0,01	62,53	70	1	0,01
Video Conferencing	62,53	1800	1	0,01	62,53	1800	1	0,01
Real Time Gaming	31,26	1800	0,2	0,01	125,06	1800	0,4	0,01
Streaming Media	31,26	3600	0,05	0,01	250,11	3600	0,95	0,01
IMS Signalling	15,63	7	0,2	0,01	15,63	7	0,2	0,01
Web Browsing	62,53	1800	0,05	0,01	250,11	1800	0,05	0,01
File Transfer	140,69	600	1	0,01	750,34	600	1	0,01
Email	140,69	50	1	0,01	750,34	15	1	0,01
P2P file sharing	250,11	1200	1	0,01	750,34	1200	1	0,01

III.3.2 Traffic Model and Single user throughput

Table 3 : Single user throughput [10]

User behavior	URBAN			
	Traffic penetration ratio	BHSA	Busy Hour Throughput per user (kbps)	
			UL	DL
Voip	100%	1,3	0,38	0,38
Video Phone	20%	0,16	0,05	0,05
Video Conferencing	15%	0,15	0,85	0,85
Real Time Gaming	20%	0,2	0,15	1,21
Streaming Media	15%	0,15	0,04	6,48
IMS Signalling	30%	4	0,01	0,01
Web Browsing	100%	0,4	0,76	3,03
File Transfer	20%	0,2	1,14	6,06
Email	10%	0,3	0,07	0,11
P2P file sharing	20%	0,3	6,06	18,19
TOTAL			**9,51**	**36,38**

III.3.3 Determination of the number of capacity eNodeBs

Table 4: Determination of the number of capacity eNodeBs [10]

ITEM	URBAN		Observations
	UL	DL	
Total User Number	700000	700000	20% of the population
Single user Throuhput (kbps)	**9,51**	**36,38**	
Total Network Throughput IP layer (Mbps)	6500,98	24869,14	
Total Network Throughput MAC layer (Mbps)	6630,94	25366,32	IP throughput/98,04%
Single cell Throuhput (Mpbs)	65,03	104,16	
eNodeB site count	102	244	
Number of capacity sites	244		Maximum of UL and DL eNodeB site count

III.4 - Evolution of LTE Planning of the city of Yaounde from 2019 to 2029

By using a similar method taking into account the population growth rate in Cameroon, where Yaounde stands at 2.8% per year [12] and with an LTE penetration rate of 20%, it shows the following site planning adjustments for the city of Yaounde.

Table 5: Evolution of the number of eNodeB per year for a constant penetration rate.

Year	Population (2,8% annual increase)	Population to be covered (20%) de la population	Number of eNodeBs
2019	3500000	700000	244
2020	3598000	719600	251
2021	3698744	739749	258
2022	3802309	760462	265
2023	3908773	781755	272
2024	4018219	803644	280
2025	4130729	826146	288
2026	4246390	849278	296
2027	4365289	873058	304
2028	4487517	897503	313
2029	4613167	922633	321

III.5 Simulation in the ATOLL Planning Software

We consider the map of the city of Yaounde in Figure 3 and we position in Figure 4 the 244 4G sites.
With the simulations done, the results on the maps 5, 7, 9 and 11 are obtained.

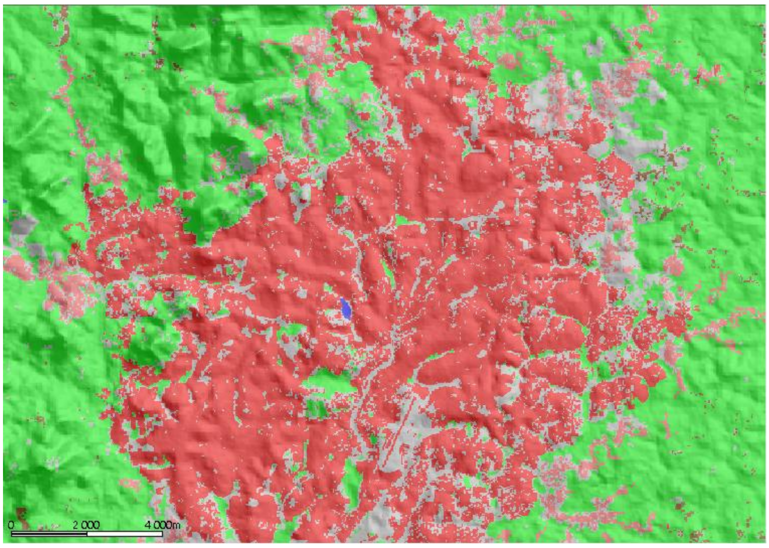

Fig. 3: Digital map of the city of Yaounde

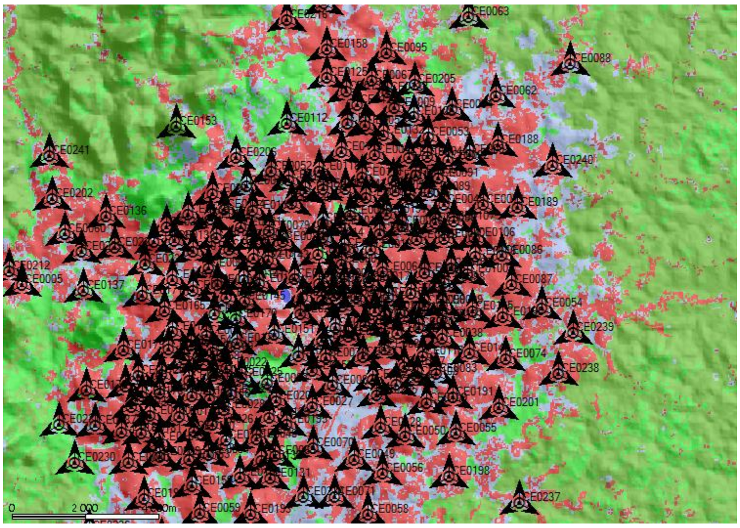

Fig. 4: Positioning of 244 4G sites with 207 existing (3G converted 4G) and 37 new 4G sites

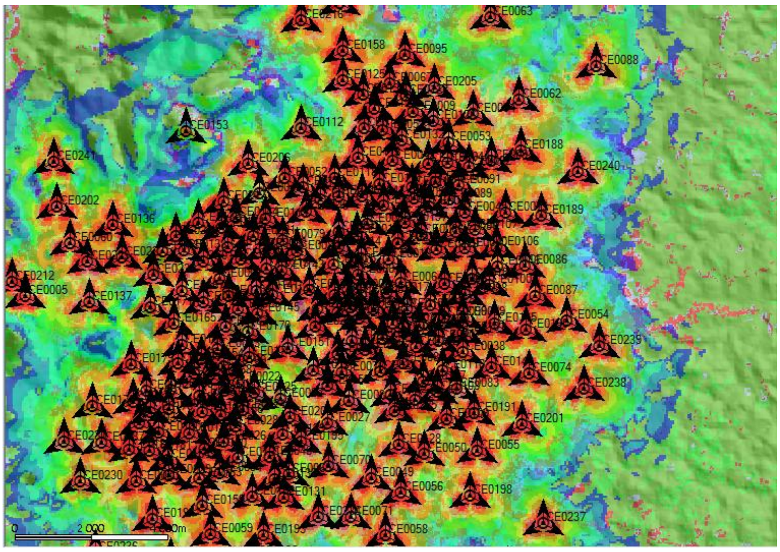

Fig. 5: Prediction of LTE network coverage of downlink transmitters

Display type: Value intervals

Field: Best Signal Level (dBm)

		Min	Max	Legend
1		-70		Best Signal Level (dBm) >=-70
2		-75		Best Signal Level (dBm) >=-75
3		-80		Best Signal Level (dBm) >=-80
4		-85		Best Signal Level (dBm) >=-85
5		-90		Best Signal Level (dBm) >=-90
6		-95		Best Signal Level (dBm) >=-95
7		-100		Best Signal Level (dBm) >=-100
8		-105		Best Signal Level (dBm) >=-105

Fig. 6: Legend of downlink signal levels

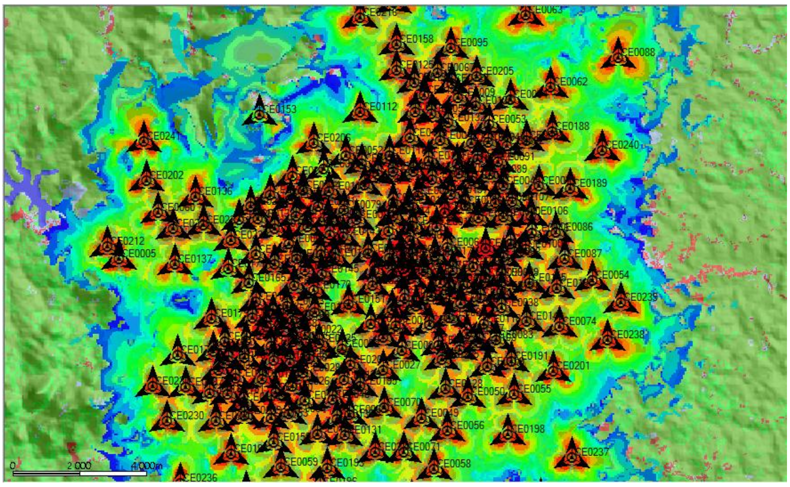

Fig. 7: Prediction of LTE network coverage of downlink signal levels downlink transmitter DL

Display type: Value intervals

Field: PDSCH C/(I+N) Level (DL) (dB)

		Min	Max	Legend
1		30		PDSCH C/(I+N) Level (DL) (dB) >=30
2		29		PDSCH C/(I+N) Level (DL) (dB) >=29
3		28		PDSCH C/(I+N) Level (DL) (dB) >=28
4		27		PDSCH C/(I+N) Level (DL) (dB) >=27
5		26		PDSCH C/(I+N) Level (DL) (dB) >=26
6		25		PDSCH C/(I+N) Level (DL) (dB) >=25
7		24		PDSCH C/(I+N) Level (DL) (dB) >=24
8		23		PDSCH C/(I+N) Level (DL) (dB) >=23
9		22		PDSCH C/(I+N) Level (DL) (dB) >=22
10		21		PDSCH C/(I+N) Level (DL) (dB) >=21
11		20		PDSCH C/(I+N) Level (DL) (dB) >=20
12		19		PDSCH C/(I+N) Level (DL) (dB) >=19
13		18		PDSCH C/(I+N) Level (DL) (dB) >=18
14		17		PDSCH C/(I+N) Level (DL) (dB) >=17
15		16		PDSCH C/(I+N) Level (DL) (dB) >=16
16		15		PDSCH C/(I+N) Level (DL) (dB) >=15
17		14		PDSCH C/(I+N) Level (DL) (dB) >=14
18		13		PDSCH C/(I+N) Level (DL) (dB) >=13
19		12		PDSCH C/(I+N) Level (DL) (dB) >=12
20		11		PDSCH C/(I+N) Level (DL) (dB) >=11
21		10		PDSCH C/(I+N) Level (DL) (dB) >=10
22		9		PDSCH C/(I+N) Level (DL) (dB) >=9
23		8		PDSCH C/(I+N) Level (DL) (dB) >=8
24		7		PDSCH C/(I+N) Level (DL) (dB) >=7
25		6		PDSCH C/(I+N) Level (DL) (dB) >=6
26		5		PDSCH C/(I+N) Level (DL) (dB) >=5
27		4		PDSCH C/(I+N) Level (DL) (dB) >=4
28		3		PDSCH C/(I+N) Level (DL) (dB) >=3
29		2		PDSCH C/(I+N) Level (DL) (dB) >=2

Fig. 8: Legend of downlink Signal to noise and interference ratio levels

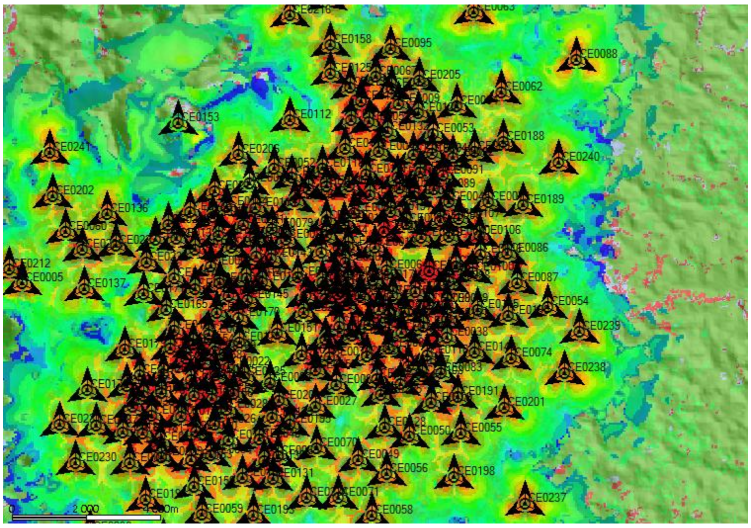

Fig. 9: Prediction of LTE network coverage of downlink Signal to noise and interference ratio

Display type: Value intervals
Field: Peak RLC Channel Throughput (DL) (kbps)

		Min	Max	Legend
1		50 000		Peak RLC Channel Throughput (DL) (kbps) >=50 000
2		49 000		Peak RLC Channel Throughput (DL) (kbps) >=49 000
3		48 000		Peak RLC Channel Throughput (DL) (kbps) >=48 000
4		47 000		Peak RLC Channel Throughput (DL) (kbps) >=47 000
5		46 000		Peak RLC Channel Throughput (DL) (kbps) >=46 000
6		45 000		Peak RLC Channel Throughput (DL) (kbps) >=45 000
7		44 000		Peak RLC Channel Throughput (DL) (kbps) >=44 000
8		43 000		Peak RLC Channel Throughput (DL) (kbps) >=43 000
9		42 000		Peak RLC Channel Throughput (DL) (kbps) >=42 000
10		41 000		Peak RLC Channel Throughput (DL) (kbps) >=41 000
11		40 000		Peak RLC Channel Throughput (DL) (kbps) >=40 000
12		39 000		Peak RLC Channel Throughput (DL) (kbps) >=39 000
13		38 000		Peak RLC Channel Throughput (DL) (kbps) >=38 000
14		37 000		Peak RLC Channel Throughput (DL) (kbps) >=37 000
15		36 000		Peak RLC Channel Throughput (DL) (kbps) >=36 000
16		35 000		Peak RLC Channel Throughput (DL) (kbps) >=35 000
17		34 000		Peak RLC Channel Throughput (DL) (kbps) >=34 000
18		33 000		Peak RLC Channel Throughput (DL) (kbps) >=33 000
19		32 000		Peak RLC Channel Throughput (DL) (kbps) >=32 000
20		31 000		Peak RLC Channel Throughput (DL) (kbps) >=31 000
21		30 000		Peak RLC Channel Throughput (DL) (kbps) >=30 000
22		29 000		Peak RLC Channel Throughput (DL) (kbps) >=29 000
23		28 000		Peak RLC Channel Throughput (DL) (kbps) >=28 000
24		27 000		Peak RLC Channel Throughput (DL) (kbps) >=27 000
25		26 000		Peak RLC Channel Throughput (DL) (kbps) >=26 000
26		25 000		Peak RLC Channel Throughput (DL) (kbps) >=25 000
27		24 000		Peak RLC Channel Throughput (DL) (kbps) >=24 000
28		23 000		Peak RLC Channel Throughput (DL) (kbps) >=23 000
29		22 000		Peak RLC Channel Throughput (DL) (kbps) >=22 000
30		21 000		Peak RLC Channel Throughput (DL) (kbps) >=21 000
31		20 000		Peak RLC Channel Throughput (DL) (kbps) >=20 000
32		19 000		Peak RLC Channel Throughput (DL) (kbps) >=19 000
33		18 000		Peak RLC Channel Throughput (DL) (kbps) >=18 000
34		17 000		Peak RLC Channel Throughput (DL) (kbps) >=17 000
35		16 000		Peak RLC Channel Throughput (DL) (kbps) >=16 000
36		15 000		Peak RLC Channel Throughput (DL) (kbps) >=15 000
37		14 000		Peak RLC Channel Throughput (DL) (kbps) >=14 000
38		13 000		Peak RLC Channel Throughput (DL) (kbps) >=13 000
39		12 000		Peak RLC Channel Throughput (DL) (kbps) >=12 000
40		11 000		Peak RLC Channel Throughput (DL) (kbps) >=11 000
41		10 000		Peak RLC Channel Throughput (DL) (kbps) >=10 000
42		9 000		Peak RLC Channel Throughput (DL) (kbps) >=9 000
43		8 000		Peak RLC Channel Throughput (DL) (kbps) >=8 000
44		7 000		Peak RLC Channel Throughput (DL) (kbps) >=7 000
45		6 000		Peak RLC Channel Throughput (DL) (kbps) >=6 000
46		5 000		Peak RLC Channel Throughput (DL) (kbps) >=5 000
47		4 000		Peak RLC Channel Throughput (DL) (kbps) >=4 000
48		3 000		Peak RLC Channel Throughput (DL) (kbps) >=3 000
49		2 000		Peak RLC Channel Throughput (DL) (kbps) >=2 000
50		1 000		Peak RLC Channel Throughput (DL) (kbps) >=1 000
51		0		Peak RLC Channel Throughput (DL) (kbps) >=0

Fig. 10 : Legend downlink channel throughputs

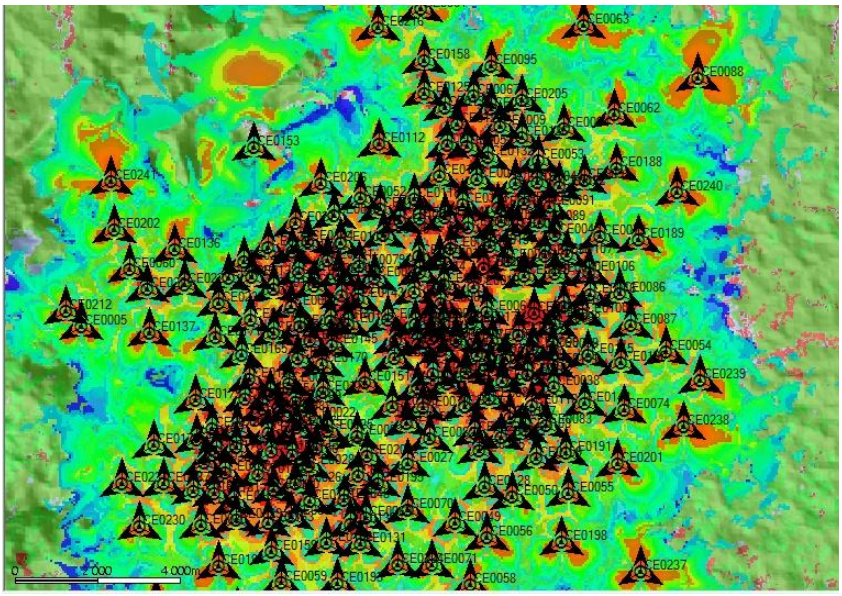

Fig. 11: Prediction of LTE network coverage of downlink channel throughput

IV. Conclusion

The purpose of an LTE radio network planning is to provide the relevant models for determining the number of elements in the radio network. In this context, an appropriate approach of using existing sites was developed taking the case of an operator in the city of Yaounde in possession of an existing 3G network and projecting for a migration to the 4G network. It results from calculations that 244 sites are needed and the operator will have to deploy 37 additional sites by capitalizing the existing 207 sites. The simulations carried out made it possible to predict a total traffic coverage of the zone of interest and a better signal-to-noise and interference ratio, thus a good quality of service.

As perspective we envisage to simulate the coverage and quality of service produce by the location of eNodeB during each year of the period 2019 and 2029 considering the same penetration rate.

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