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Optimization of QoS key parameters in LTE network by using central composite design (CCD)

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Abstract

The quality of service is always desirable and challenging factor from generation to generation. In this research work "optimization of QoS key parameters in LTE network using central composite design", different approach has been adapted to optimize quality of service. The motto of selecting this research work was for achieving better quality of service with limited power consumption. In addition, very few researches have been done in optimization and this can be gateway and matter of research for 5G too for focusing on optimizing network parameter for gaining better QoS. In this module, Central Composite Design is considered as fixed method for optimization among many other optimizations approaches available. In this module, both simulation and observation are considered as a system result. It is found that antennae height, antennae gain is impacting quality of service. Along with those antennae parameter other parameter is also taken in consideration. It is considered that these control parameters are impacting coverage, signal level, service area analysis and this research methodology try to check performance of the system on the basis of same performance parameters. The optimum value of azimuth angle, mechanical tilt, antennae gain and antennae height was achieved 8.7-degree, 0 degree, 20 dBi and 27.5m respectively. Performance test and validation of system was done using those optimum value by running simulation on Atoll and compare those result with existing network simulation result. The total coverage area was increased from 92.2% to 99.6% after optimization which was based on LTE band 3, 1800 MHz frequency. The average best signal coverage all over the computational region has risen from -78.56 dBm to -76.31 dBm and service area analysis based on modulation scheme also get enhanced. similarly, poor signal zone reduced from 4% to 0.27% after optimization.

Keywords: Central composite design (CCD), long term evolution (LTE), quality of service (QoS), modulation, optimization.

Introduction

The standard for LTE is developed by the 3rd generation partnership project (3GPP) and is designated in its Released eight document series, with some improvement explained. LTE supports various transmission bandwidth 1.4MHz, 3MHz, 5MHz, 10MHz, 15MHz and 20 MHz LTE has total of 31 band for Frequency Division Duplexing (FDD). Response Surface Methodology (RSM) has a long history and nowadays has many applications in the field of engineering and in structural reliability. RSM is mainly used in combination with finite element models. Response surface methodology investigate relationship among various input parameters and response parameters. The process was developed George E.P. Box and K.B. Wilson in 1951. The introduction of RSM is to use sequence of designed experiment to get and optimal response.

Central Composite Design (CCD) is an experimental design, important in RSM, for creating second order model for the response variable. LTE has engaged the attentiveness of various service provider and investors throughout the globe in the late years and optimization is still a big challenge in it[1,3]. There is a relation of some parameter such as antennae gain, antennae height, azimuth angle with coverage area but it is still unknown about what type of relation they contain, these relations can be used to determine optimal response to achieve maximum quality of service. In addition, it is assumed some input variable hast strong influence and some has weak impact on response variable because every explanatory variable doesn't have equal strong influence on output. So, this study can be strong factor to know the behavior of different input parameter in terms of response. Optimization of network is very useful in providing best service rather than providing good service which can be done by adjusting values of few parameters. These optimal range of explanatory variables helps to get better advantage in terms of better service from same devices just by adjusting their values. It is expected 5G will be implemented soon and network optimization is one of the important fields in 5G too.

This research on LTE can be gateway and matter of research for 5G to focused on optimizing network parameter for gaining better grade of service. This optimization helps to achieve better quality of service with limited power consumption and is cost effective too. The main motto of RF planning is to make overall LTE system efficient because LTE is expensive and time consuming to be implemented. Network planning is based on simulation, optimization, estimation etc.

The main aim of our work is to find optimal value of Antennae parameter which will enhance coverage area, signal level-based coverage, service area analysis based on modulation scheme etc. In this research work LTE planning will be based on real data provided by network operator. 1800-megahertz frequency and 5-megahertz frequency will be used for planning the LTE network. Several factors like river, forest and its associated loss are to be considered. For optimization technique, CCD technique is implemented to calculate optimal value of input variables with a smaller number of experiments. In this research work, coverage area, overlapping zone, signal level-based coverage, dead zone, service area analysis based on modulation scheme etc. will be focused and comparison between previous network and newly optimized network to be performed. Here, benefit of tuned network on new coverage zone, signal level and so on will be studied and analyzed. After obtaining optimum value, system is again redesigned to get new cell radius which will be used as input in Atoll for achieving new results. CCD main objective is to minimize variation in overall system by finding best suitable value for input parameters. Parameters require for simulation are discussed in chapter 2 while chapter 3 shows the results and discussion. Finally, chapter 4 presents the conclusion part.

Methodology

Radio Network optimization is an important component for successful design, implementation of cellular network. Efficient planning is obtained through several process of examination. Appropriate Network optimization is most required to achieve highest availability and performance for all user. To obtain a good network optimization, at first phase papers and journal related to Network optimization should be studied and focus on optimization methods and their pros and cons. Furthermore, details about band, bandwidth, frequency, service support, duplex mode of LTE used in Nepal is to be collected. Then Antennae parameter such as azimuth angle, mechanical tilt, antennae height and antennae gain are chosen as a design variable. Based on the input variable or factors number of requirements of axial points, center points to be calculated. By knowing all above mentioned elements, number of experiments to be done in our CCD approach is determined. Coverage planning of LTE network requires various parameters out of which link budget analysis is an important one. Link budget analysis gives Maximum Allowable Path Loss (MAPL) which assists to determine cell radius thereby using appropriate propagation model.

The main part of optimization of LTE network is defining the optimal range of controlled variable. Mathematical modeling of the system is required to provide optimal value of design variable. After knowing the optimal range, intensity of relationship between design variable and response variable is to be determined. In addition, simulation of LTE network is done in Atoll. After achieving the optimal value of the design variable, those optimum value are used to test the performance of LTE system. All those optimal values are used for simulation in Atoll and interpret the outcome based on new prediction on Atoll. Performance test will be based on coverage area, overlapping zone, signal level-based coverage, dead zone, service area analysis based on modulation scheme etc.

In CCD design, main motto is to determine loss function which will be used as objective function for optimization. Experiment is conducted based on star, corner and center point and obtain the coverage for every experiment by running a simulation in Atoll. The principal goal of CCD is to exploit the quadratic model approximating the nonlinear relationship of product parameter and the performance characteristics. Initially second order polynomial function is used to approximate mean for the system and then Taylor series expansion is used to obtain estimated variance for the response variable. Afterward sequential lease square programming technique is used for optimization. CCD is classic five level design and has great statistics properties. Star points, center points and two level full/ fractional factorial are elements in CCD. In any 2-level factorial design, with two points only a straight line can be made but curvature effect cannot be tested. The way it is done is one center point is added, two axial point are added for each variable. Star or axial points help to know performance of system beyond the range of control variable[1-7]. Typically, in the center points replication is 4 whereas replication in axial and corner point are unity. Center point helps to know pure measure mental error in the system. The rotatability is 2 for 4 design variable and this helps to give value for axial point of design variable[8].

Number of star points=2*K*Ns (1)

Number of axial point=Nc*2^ (k) (2)

K=Number of variables, Ns=Number of replications for star points, Nc=Number of replications for corner. Ns=Nc=1.

There are altogether 28 experiments for four design variable which consist of 16 factorial point, 8 axial point and 4 center point[2]. Every experiment is run in Atoll to get response as coverage area. Azimuth angle, antennae gain, mechanical tilt and antennae height is selected as design variable and their unit are expressed in degree, dBi, degree and meter respectively. Here center point for these parameters are 20degree, 1 degree, 18dBi and 22.5 meter respectively. Factorial and star point value is shown in the Table-1.

Table-1: Star and factorial value for experiment in CCD.

Star and factorial value	Factorial point (-1)	Star point (-a)	Factorial point (+1)	Star point (+a)
Azimuth angle	0	-20	40	60
Mechanical tilt	0	0	2	3
Antennae gain	16	14	20	22
Antennae height	17.5	12.5	27.5	32.5

Mathematical modeling in CCD is required to obtain the objective and constrain function which will be further used by sequential least square programming to determine optimal value of antennae parameter. Finally, after obtaining estimated variance for the response variable nonlinear programming optimization technique has been used to determine optimal value for azimuth angle, mechanical tilt, antennae height and antennae gain for achieving maximum coverage area. In our model nonlinear objective function and constrain are required for optimization. Here variance function is objective and second order equation is constrain. Initial guesses to the variable are given after defining objective and constrain. After initial guess then upper and lower limit are been assign for each control variable. Sequential least square programming technique has been used for optimization Objective function helps to approximate mean for the system whereas, constrain function used minimize variation to achieve target value[8-10]. The equation 3 and 4 is objective and constrain equation where x1, x2, x3, x4 represents azimuth angle, mechanical tilt, antennae gain and antennae height respectively. Sequential least square programming use both constrain and objective function to give optimal value of antennae parameter that maximize coverage or reduce loss[2].

Obj function=σ1[(B1+2*B11*x1+B12*x2+B13*x3+B14*x4)] ^(2) + σ2[(B2+2*B12* x1+B22*x2+B23*x3 + B24*x4)] ^(2)+ σ3[(B3+2*B13* x1+B23*x2+B33*x3+B34*x4)]^(2)+ σ4 [(B4+2*B14* x1+B24*x2+B34*x3+B44*x4)]^(2) (3)

Const fucn=B0+B1*x1+B2*x2+B3*x3+B4*x4+B11*x1*x1+B12*x1 *x2+ B13*x1*x3+B14*x1*x4+B22*x2*x2+B23*x 2* x3+ B33*x3*x3+B34*x3*x4+B44*x4*x4+B24*x2*x4 (4)

Coverage planning start with calculation of maximum allowable path loss (MAPL) by the support of link budget calculation. MAPL is been for both uplink and downlink scenario and the data needed for MAPL is provided by telecom operator of Nepal and from the paper on RF planning. This helps in determining the cell radius for downlink and uplink using appropriate path loss model. After that site area and cell area been focused on for calculating number of site sufficient for coverage[7]. Link budget is essential for RF planning. Initially and gain associated with channel, device, environment etc. are taken into account. Then we go for calculation for cell radius by using Cost 231 Hata propagation model and maximum allowable path loss. MAPL provides amount of power which can be played with for determining cell radius. 3 sector sites are assumed and site area is determined and then by the help of site area and total coverage area, number of sites to be determined. Finally, these number of sites is used for analysis of performance parameter in Atoll in a given computational zone. LTE template is selected to work with. The projection used for Nepal is WGS 84/ UMT zone 45N. Digital map imported in Atoll. Digital map consists of data related to clutter class, clutter height, altitude, places information, vector map. Network parameter like LTE band, area type, transmitter, antennae, cell radius, propagation model etc. has been selected[11-14]. Afterward site configuration is been imported then calculation is done such as path loss matrices, noise figures etc. Now Automatic frequency planning is performed by updating the event. This Automatic Frequency planning helps in providing cell number, cell id, frequency allocation to our network. Finally, new prediction has been created such as coverage, service area analysis based on modulation scheme, dead zone and coverage by signal level, for analyzing the result for LTE scenario. Table-2 gives information about different loss and gain associated with the system and environment for link budget calculation for uplink.

Table-2: Link budget calculation for uplink[7].

Transmitter- UE	
Maximum transmitter power *	26 dBm
Transmitter antenna gain	0 dBi
Body loss	0 dB
EIRP	26 dBm
Receiver- BTS/NodeB/eNode B	
Cable loss	2 dB
Interference margin	3 dB
Receiver sensitivity	-115.40 dBm
Receiver noise floor	-116.00 dBm
SINR	-7 dB
Node B noise figure	2 dB
Receiver antenna gain *	18 dBi
Thermal noise	-105.00 dBm
MHA gain	2 dB
Penetration loss	18 dB
Diversity gain	3 dB
Maximum allowable path loss	141.40 dB

Table-3 provides information about different loss and gain associated with the system and environment for link budget calculation for downlink. MAPL is calculated for both uplink and downlink scenario. Maximum allowable path for uplink and downlink are 141. 40 dB and 144.50 dB respectively.

After that maximum allowable path loss value is used for further calculation of cell range using COST Hata model[7].

Table-3: Link budget calculation for downlink[7].

Downlink	
Transmitter- BTS/NodeB/eNode B	
Maximum transmitter power *	43 dBm
Transmitter antenna gain	18 dBi
Cable loss	2 dB
EIRP	59 dBm
Receiver- UE	
Control channel overhead	1 dB
Receiver antenna gain	0.00 dBi
Diversity gain	3 dB
Node B noise figure	7 dB
Receiver sensitivity	-105.5 dBm
Interference margin	4 dB
Penetration loss	18 dB
Body loss	0 dB
Receiver noise floor	-98.50 dBm
SINR	-7 dB
Thermal noise	-105.50 dBm
Maximum allowable pathloss	144.50 dB

The Cost-Hata model for sub urban is formulated as[1]

$$L=46.3-13.82 \log hB + [44.9-6.55 \log hB]*\log d+33.9 \log f-a(hR) \quad (5)$$

Antennae height correction factor

$$a(hR)=(1.1 \log f -0.7)\, hR - (1.56 \log f - 0.8) \quad (6)$$

where, L= path loss, hB= height of base station in meter, hR = height of the terminal antennae, f = frequency in megahertz, d= distance between base station and terminal in kilometer.

This radio frequency planning was performed in Gaighat region of Udayapur district. The computational region compromises of 13919 population with area of 3.65 square kilometer. According to rough estimated data provided by operator, 5219 are total user and 3131 are LTE user which is roughly sixty percent of total user. Similarly, there are 1565 busy hour user or it can be described as number of maximum active subscriber at a time[15]. Now, uplink and downlink cell range has been calculated using equation 5 and 6 and chose the minimum value.

Now uplink cell distance is determined by using propagation model has been which came to be 1.30 km and it is known range is half of the cell distance which is 0.65 km. Cell distance (downlink) by using propagation model is been calculated which came to be 1.591 km and it is known cell range is half of the cell distance which is 0.795 km. Uplink cell range value has been selected for input to Atoll since its value is minimum.

$$\text{Area of site} = 1.95 * R^2 \quad (7)$$

$$\text{Number of site} = (\text{Computational zone area})/(\text{Area of each site}) \quad (8)$$

Equation 7 provides area of single site when 3 sector area is assumed. By the help of below mention equation 8, total number of sector site required for coverage planning is four.

Cell capacity plays a crucial role in maintaining quality of service to the number of customers. Capacity of cell also decide the number of subscribers supported by the system. Capacity of cell is dependent on various factor such as resource block, MIMO, modulation scheme etc[16]. Cell capacity is calculated assuming 5-megahertz bandwidth is used which consist of 25 resource blocks. 64 QAM and 16QAM are considered for downlink and uplink with coding rate of 0.92 and 0.6 respectively. 2*2 MIMO antennae has been considered for capacity planning as used by our service provider. Cell capacity for downlink and uplink is determined by the equation mentioned below[7].

$$DL\ CAP+CRC= (168-36-12) *C_B*C_R*K*1000*N_{RB} \quad (9)$$

$$UL\ CAP+CRC= (168-24-12) *C_B*C_R*K*1000*N_{RB} \quad (10)$$

CRC: Cyclic Redundancy Rate, DL CAP: Downlink Capacity, UL CAP: Uplink Capacity, N_{RB}: Number of Resource Block, C_R: Coding Rate of Given Channel, C_B: Number of Bits Modulated

$$DL\ Cap + 24 =(168 - 36 - 12) \times 25\times 6\times 0.92\times 2\times 1000 = 33\ \text{Mbps}$$

$$UL\ Cap + 24 =(168-24-12) \times 25\times 4 \times 0.6\times 2\times 1000 = 15.84\ \text{Mbps}$$

Cell capacity for downlink was found to be 33 Mbps and for uplink was found to be 15.84 Mbps. Modulation scheme for uplink and downlink are SC-FDMA and OFDMA respectively due to PAPR[6]. Capacity planning initiate with calculation of cell capacity and then single user throughput to be determined. Then number of active users is to be estimated which helps to calculate network throughput.

Table-4: Experiment for response variable using CCD.

Azimuth	MT	Gain	Height	Coverage
0	0	16	17.5	95.2
40	0	16	17.5	96.6
0	2	0	17.5	95.2
40	2	0	17.5	96.6
0	0	16	17.5	81.5
40	0	16	17.5	83.1
0	2	16	17.5	81.5
40	2	16	17.5	83.1
0	0	20	27.5	99.8
40	0	20	27.5	100
0	2	20	27.5	99.8
40	2	20	27.5	100
0	0	16	27.5	90
40	0	16	27.5	90
0	2	16	27.5	90
40	2	16	27.5	90
-20	1	18	22.5	92.7
60	1	18	22.5	92.7
20	-1	18	22.5	92.7
20	3	18	22.5	92.7
20	1	14	22.5	78.2
20	1	22	22.5	100
20	1	18	12.5	79.9
20	1	18	32.5	99.3
20	1	18	22.5	92.7
20	1	18	22.5	92.7
20	1	18	22.5	92.7
20	1	18	22.5	92.7

After that throughput density and cell area are estimated for calculating number of site sufficient for capacity planning. From capacity planning number of sites required came out to be four in our case. Now, simulation part is done in Atoll at general setting and 28 experiment are performed for achieving different coverage with changing antennae parameters. For every experiment new cell radius is calculated and new value is substitute on Atoll for gaining new result in term of coverage.

The Table-4 gives data about variation of result on coverage area when different sort of data taken as input for azimuth, mechanical tilt, antennae height and antennae gain based on central composite 5 level design. These all 28 experiments are run in Atoll. First sixteen are the factorial data points and 17-24 are the star or axial data points and last four are center points. In case of 3 factor, there are 8 factorial point and 6 axial point[17]. It is considered different factor has influenced on output but cannot say what is their relation on output and actual relationship will be provided by CCD. To successfully carry out any designed experiment, the region of operability must encompass the region of interest[18].

Equation-3 is used to approximate mean for the system which mean relation of coverage area with different antennae parameter and then Taylor series expansion is used to obtain estimated variance for the response variable[9]. Afterward sequential lease square programming technique is used for optimization by using boundary and initial value of antennae parameter as described in Table-5.

After obtaining optimal value using sequential least square programming, new cell radius is calculated and then run simulation on Atoll by using optimum value of antennae parameter. Afterward Prediction of Atoll was re focused on coverage area, overlapping zone, signal level-based coverage, dead zone, service area analysis based on modulation scheme etc. and then compare these performance parameters with existing network before optimization.

Table-5: Initial guess and boundary for optimization.

	Initial guess	Upper boundary	Lower boundary
Azimuth angle (degree)	20	40	0
Mechanical tilt (degree)	1	2	0
Antennae gain (dBi)	18	20	16
Antennae height (meter)	22.5	27.5	17.5

Results and discussion

In this chapter, Let's discuss result obtained while design framework for optimization of QoS key parameters in LTE network by using central composite design. The simulation of LTE network on Atoll was performed on general setting and by taking all the parameter in account. Prediction of Atoll was focused on coverage area, overlapping zone, signal level-based coverage, dead zone, service area analysis based on modulation scheme etc.

All the programming part was done in python. Different statistical parameter is used to obtain objective and constrain function which helps to ease the process of optimization. The adj R square value 0.976 and standard error 2.78 suggest that the model has nicely predicted the mean value of product performance characters tics. Also, 15 coefficients were obtained from second order polynomial equation which is used to provide an approximate equation of coverage area in terms of four explanatory variable.

Finally, by the help of nonlinear objective function and constrain function the optimum setting for the azimuth angle, mechanical tilt, antennae gain and antennae height was obtained 8.7 degree, 0 degree, 18dBi and 27.5 meter respectively. This optimization model can be used for any area urban, suburban and best result can be obtained.

For a new site only, certain experiment is to be performed on Atoll and same model can provide optimum value for Antennae parameter for achieving desired quality of service.

```
coefficients: 15
[-8.56395833e+01  7.54166667e-02  -3.33333333e-01  1.15479167e+01
  3.54333333e+00  4.16666667e-04  -2.99066327e-15  -1.26287869e-15
 -3.50000000e-03  1.66666667e-01  -5.27919722e-15  -3.47551848e-15
 -1.83333333e-01  -9.25000000e-02  -2.43333333e-02]
<class 'numpy.ndarray'>
```

Figure-1: Coefficient determination and mean approximation for coverage area.

The coefficients obtained from second order polynomial equation and shown in figure one is used to provide an approximate equation of coverage area in terms of four explanatory variable.

Figure-2 describes about the actual versus predicted coverage percentage. The dot one shows actual coverage area whereas solid line shows predicted coverage by the help of fifteen coefficient.

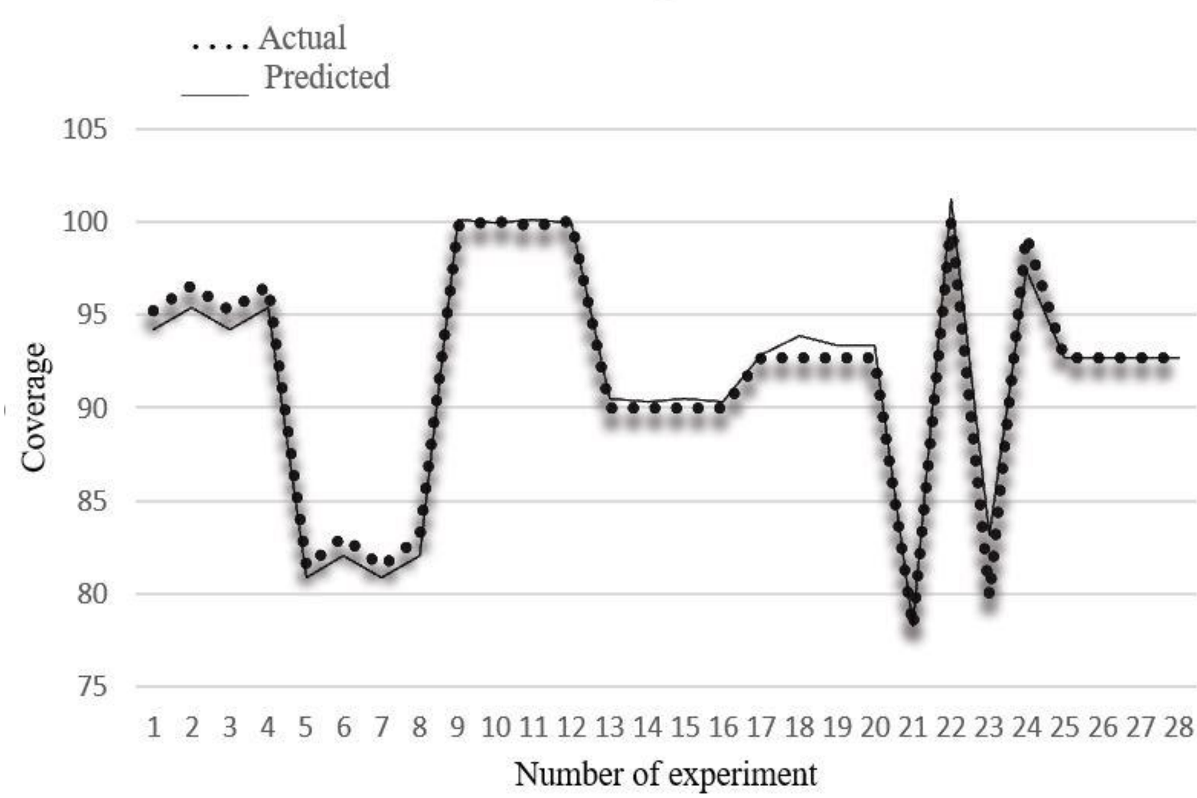
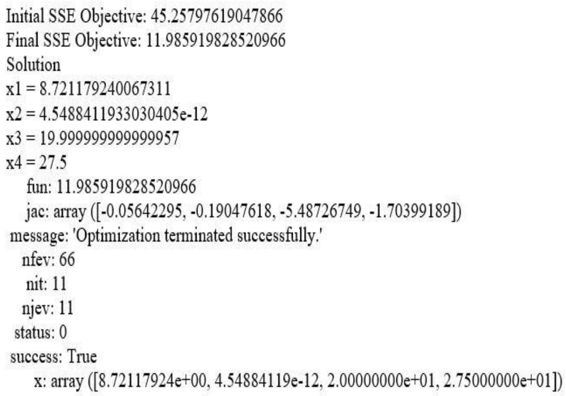


Figure-2: Actual versus predicted coverage percentage.



```
Initial SSE Objective: 45.25797619047866
Final SSE Objective: 11.985919828520966
Solution
x1 = 8.721179240067311
x2 = 4.5488411933030405e-12
x3 = 19.999999999999957
x4 = 27.5
   fun: 11.985919828520966
   jac: array ([-0.05642295, -0.19047618, -5.48726749, -1.70399189])
 message: 'Optimization terminated successfully.'
   nfev: 66
    nit: 11
   njev: 11
 status: 0
 success: True
      x: array ([8.72117924e+00, 4.54884119e-12, 2.00000000e+01, 2.75000000e+01])
```

Figure-3: Optimum value of antennae parameter.

Figure-3 provides optimum value for azimuth angle, mechanical tilt, antennae gain and antennae height and they are 8.7degree, 0 degree, 20 dBi and 27.5m respectively for gaining better quality of service.

Table-6: Antennae parameter value.

	Before optimization	After optimization
Azimuth angle (degree)	0	8.7
Mechanical tilt (degree)	0	0
Antennae height (meter)	25	27.5
Antennae gain (dBi)	18	20

Similarly, table six gives information about value of different antennae parameter before and after optimization. Based on the value of antennae parameter simulation was performed in Atoll for analysis of coverage area, overlapping zone, signal level-based coverage, dead zone, service area analysis based on modulation scheme and know the level of optimization.

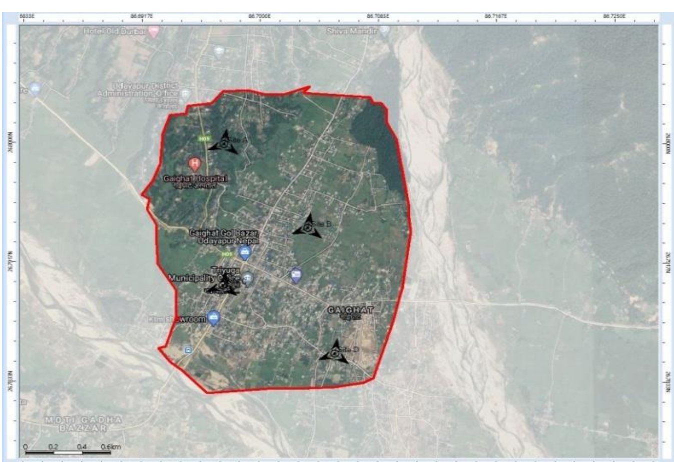


Figure-4: Planning area with site and transmitter.

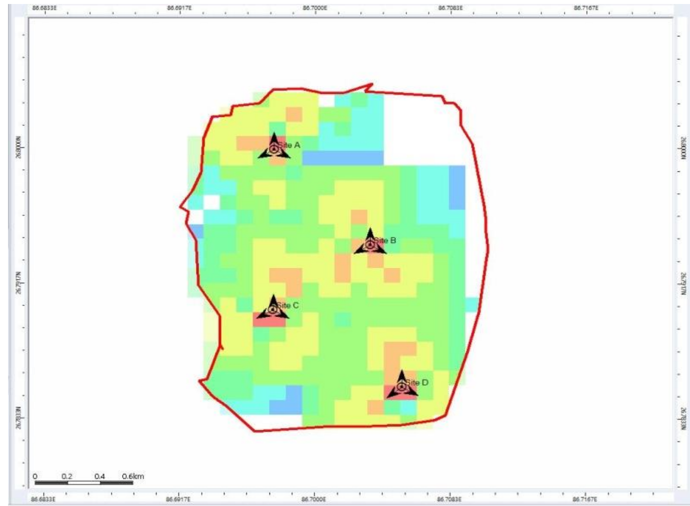


Figure-5: Coverage area of LTE (Before optimization).

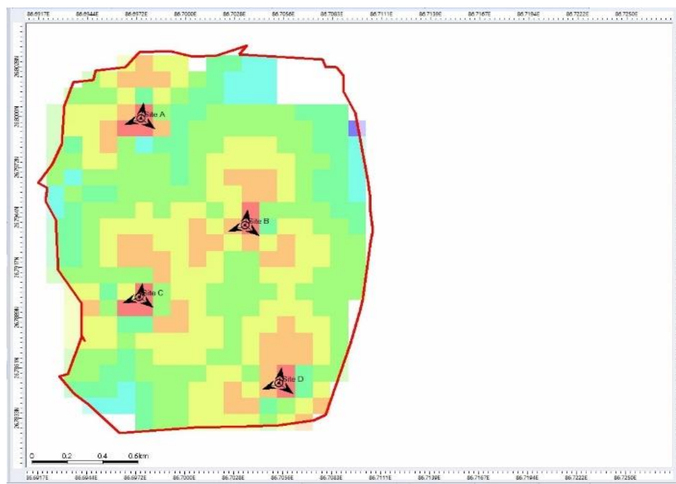


Figure-6: Coverage area of LTE (After optimization).

Figure-4 provides information regarding position of transmitter with in coverage zone of 3.65 square kilometer. The total computational zone covered by the LTE network before and after optimization are 92.2% and 99.6% respectively which is shown in figure 5 and 6. This shows that coverage area can be enhanced with same site number and same transmitter power by using optimal value of Antennae parameter.

Figure-7 and 8 describes about signal level provided by LTE network all over the region before and after optimization and their best mean signal are -78.56 dBm and -76.31 dBm respectively. This newly plan network average signal level is increase by 2.25 dBm in compare to previous network. In addition, LTE planning covers almost 70% of computational zone with signal greater or equal to -85dBm whereas now it covers nearly 80% which is an effective result. This shows newly plan network after optimization provide good signal strength to end user and can maintain quality of service. In addition, poor signal zone reduced from 4% to 0.27% after optimization.

Figure-9 and 10 provides information about area covered by different number of servers before and after optimization. In case of overlapping zone, previous network single server cover almost 70% of total coverage area and percentage of overlap Zone by three or more servers is 2% whereas newly plan network single server covers 67.3% of total coverage area and percentage of overlap Zone by three or more servers is 4%.

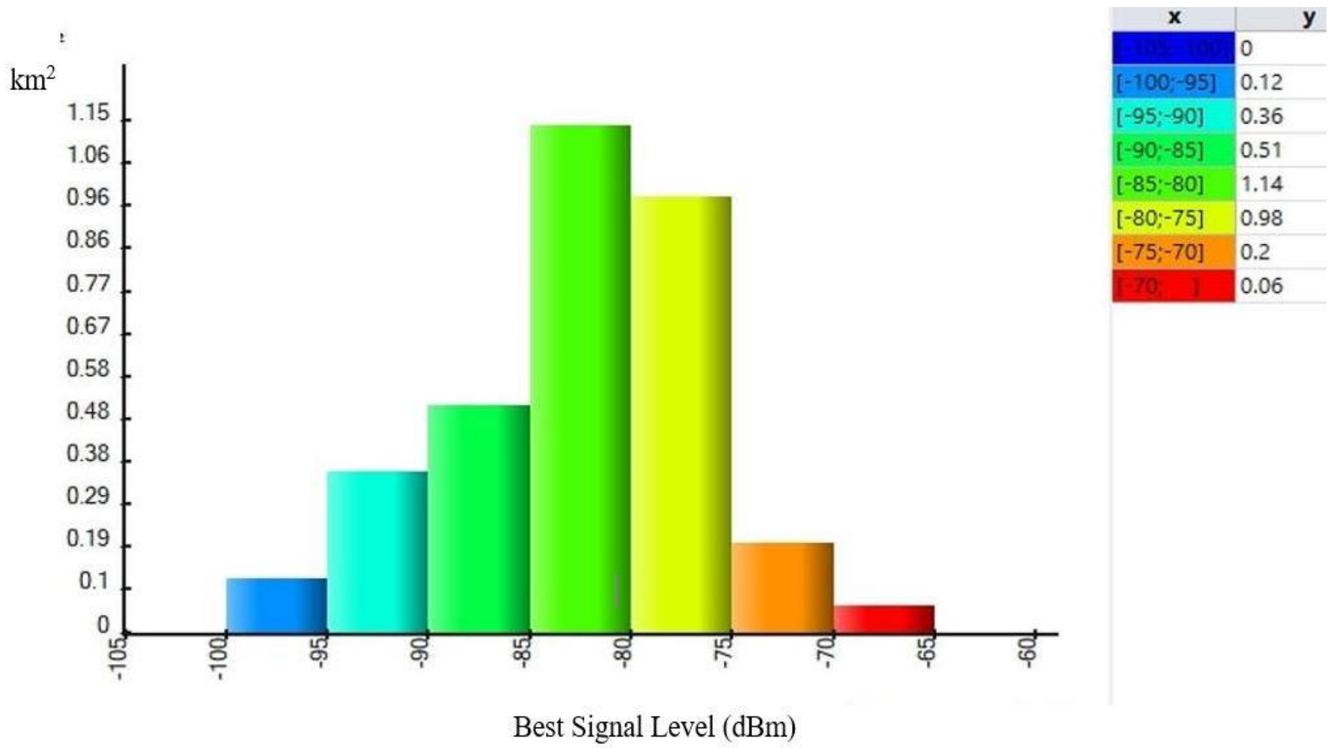


Figure-7: Best signal level versus area (before optimization).

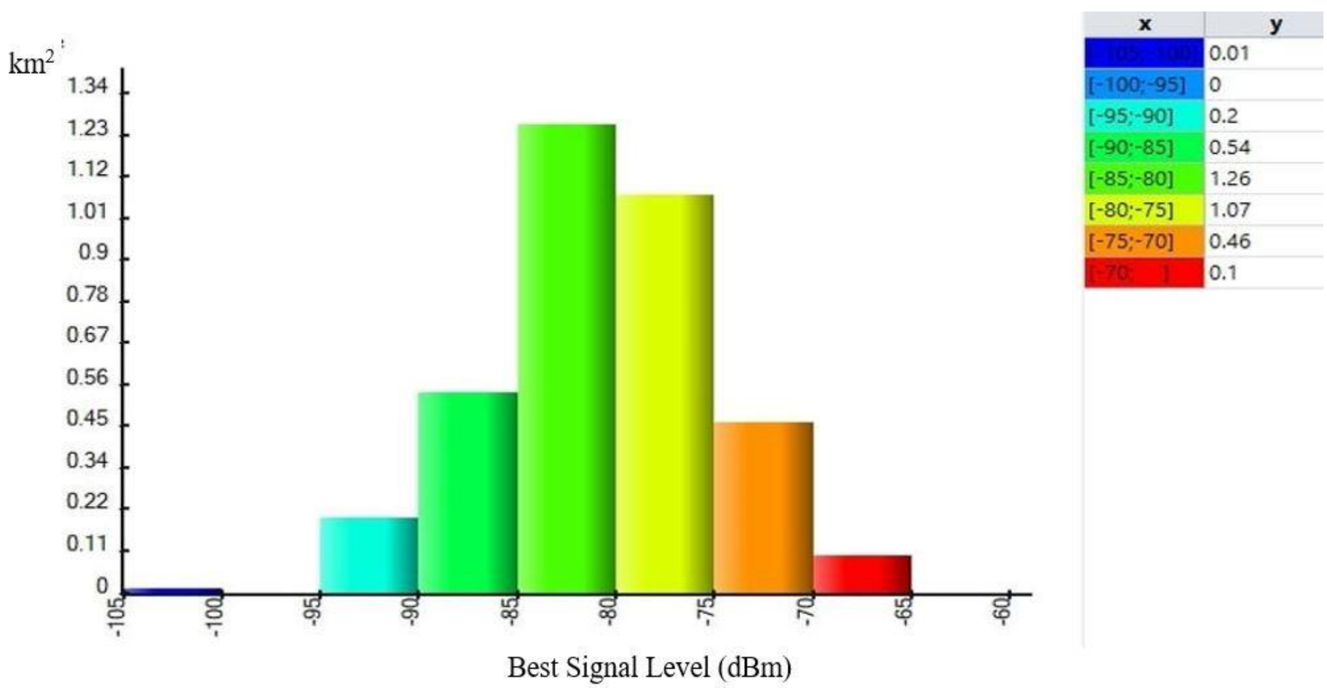


Figure-8: Best signal level versus area (after optimization).

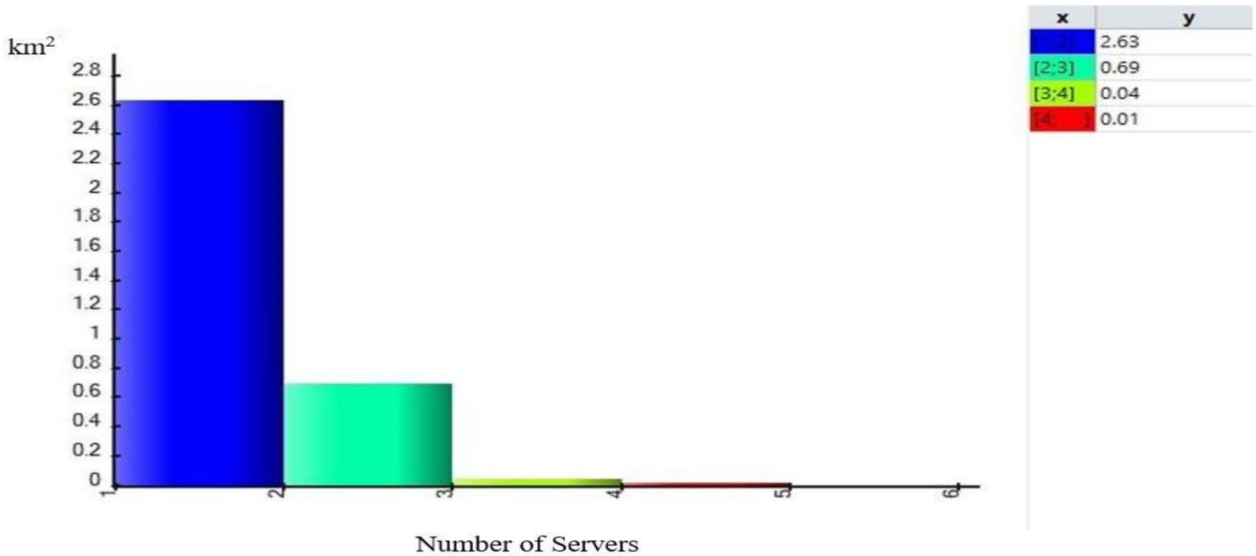


Figure-9: Server number v/s area (Before optimization).

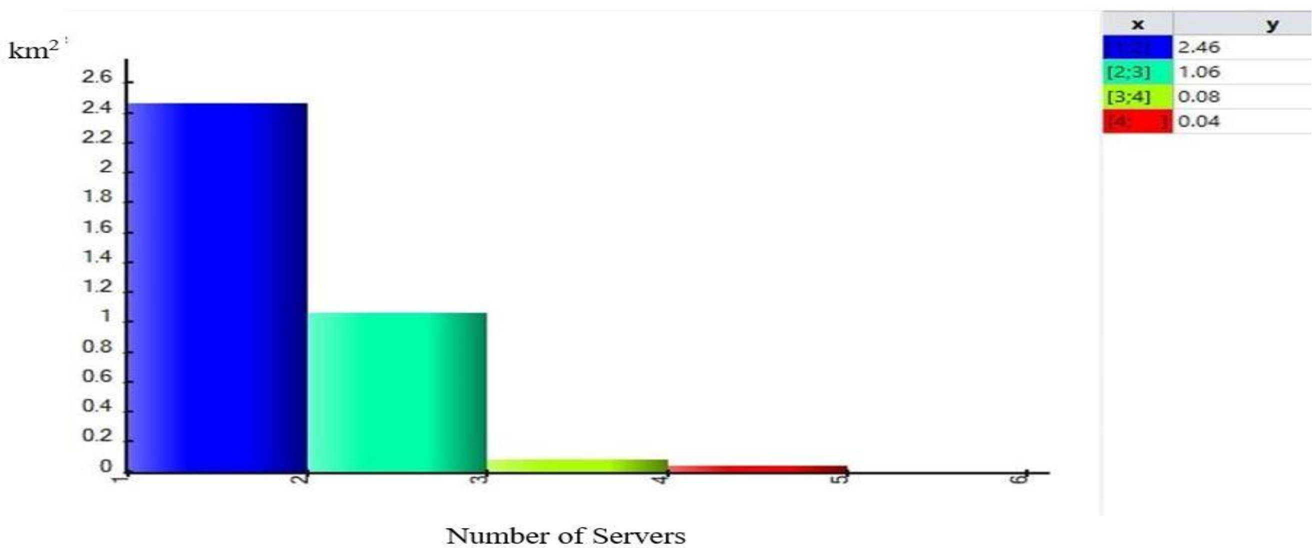


Figure-10: Server number v/s area (After optimization).

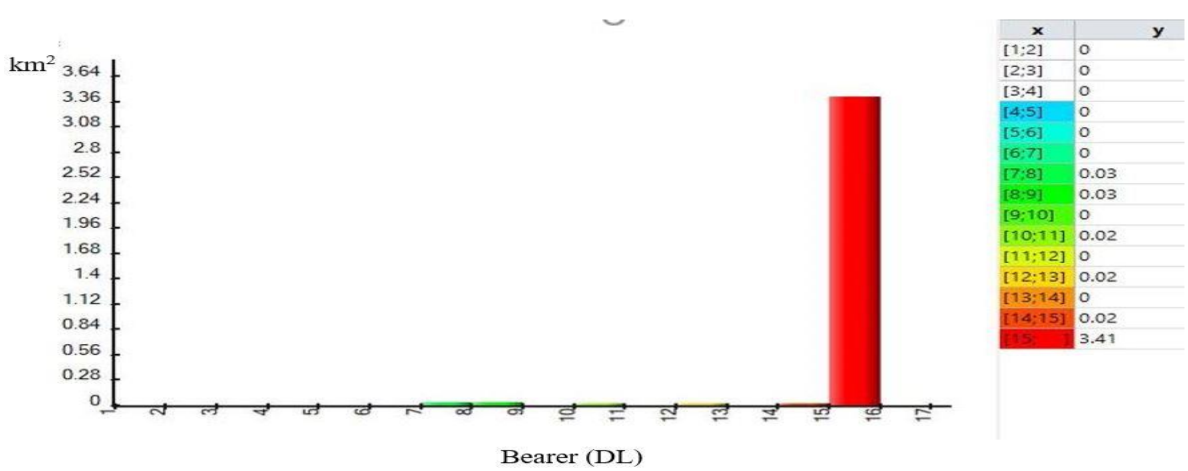


Figure-11: Bearer (DL) v/s area (Before optimization).

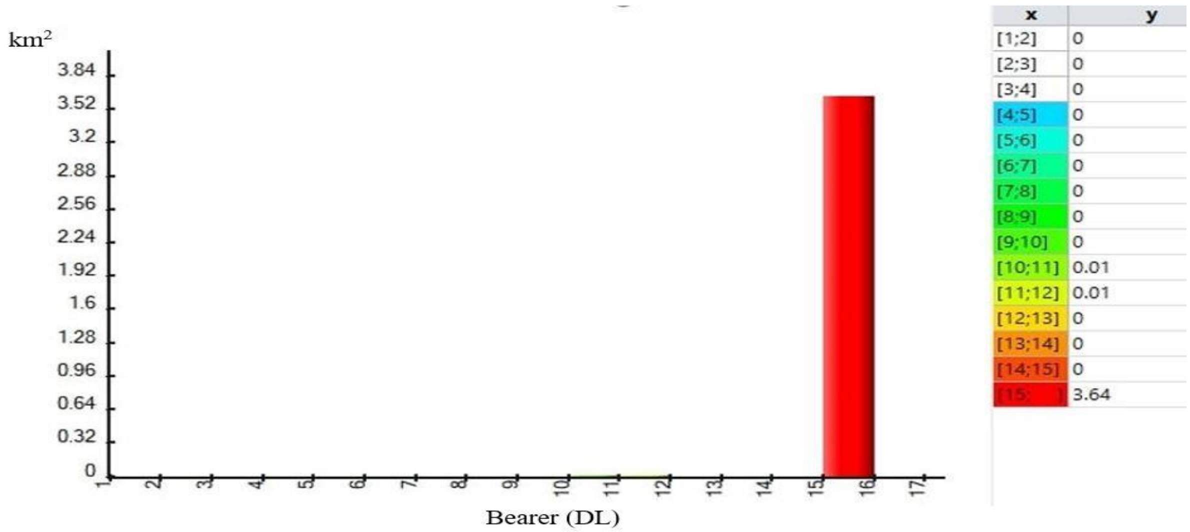


Figure-12: Bearer (DL) v/s area (after optimization).

Figure-11 and 12 gives information area covered by different modulation scheme. The bearer DL has mean of 14.82 and standard deviation of 1.06 for existing network whereas newly plan network has mean of 14.98 and standard deviation of 0.33 which is a good result.

Conclusion

The main aim of the CCD in LTE network is to find optimum value of Antennae parameter. The basic model supports in calculating new value of azimuth angle, mechanical tilt, antennae gain and antennae height. The optimum value of azimuth angle, mechanical tilt, antennae gain and antennae height was obtained to be 8.7 degree, 0 degree, 20 dBi and 27.5 meter. The total coverage area was increased from 92.2 % to 99.6% after optimization which was based on LTE band 3, 1800 MHz frequency. Similarly, the average best signal coverage all over the computational region has risen from -78.56 dBm to -76.31 dBm and poor signal zone reduced from 4% to 0.27% after optimization. In addition, mean of bearer DL was increased from 14.82 to 14.98 after optimization. Furthermore, capacity of cell for downlink and uplink was obtained 33 Mbps and 15.84 Mbps respectively.

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