# LTE Cell Load Analysis Using Live Network Data

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***Abstract*****—**The real throughput data is highly variable and depends on their user mobility, location in the active cell, servicing environment, cell load and "irregularities" from real-life cellular networks. In order to solve these problems, estimate the cell load, and cell throughput in a certain bandwidth and inter-cell distance is one of the preconditions for the operator for effective network planning. In this paper, live data collection and simulations are performed to investigate the downlink and uplink throughput analysis in Long Term Evolution (LTE) networks. This collected data reflects real-world usage of mobile service, allowing for deep insight into the nature of LTE networks in dense urban and urban area. The capacity model can be formulated by using theoretical planning concept and using real data both indoor and outdoor environment. The complete effect is being done for different cell load and bandwidth (such as 10 MHz, 15 MHz, and 20 MHz).Our results provide, a framework and numerical results of the cell throughput and cell load for different bands, as well as, inter-site distance that would benefit for operator end to end planning (i.e., minimizing rollout activities and maintenance procedures).

***Index Terms*****—**Cell load, cell throughput, LTE, SINR

## I. Introduction

According to the visual networking index revealed by Cisco, global cellular data traffic grew 2.5 exabytes per month in 2014 and would increase 10-fold in 2014-2019 [1]. To meet the traffic demand the development of wireless communication systems has been non-stop in the past decade.

As a step toward 4th Generation (4G) wireless mobile systems, the 3GPP group began its initial investigation of the LTE. This generation creates a new radio-access technology which will provide high data rates, a low latency and a greater spectral efficiency [2].

In order to consider methods of forecasting traffic and capacity dimensioning, the characteristics of traffic in LTE network access systems need first to be analyzed. Detail investigation of user behavior and live data assessment are one of the best approaches to determined capacity per cell, since users can communicate anytime and anywhere they want (i.e., not fixed), and traffic generation is heavily dependent on user behavior and radio condition. These the traffic in the radio access system is greatly affected by the characteristics of the users, since, user behavior generate unpredictable excessive traffic, in some case exceed the capacity of the network to handle it by more than an order of magnitude [3].

This paper addresses the cell load for LTE wireless networks. These networks contain different types of bandwidths in which each cell throughput may have a different value. In general, these cells are divided into dense urban and urban area, as well as, two environmental conditions such as indoor and outdoor. They provide the basic coverage to the target cluster hot spot area.

The objectives of this paper are to study the cell load of LTE network base on live data and to examine the validity of different downlink throughput and inter-site distance in a realistic LTE deployment. The ultimate goal is to support or make it suitable for the network planning and optimization of LTE.

Downlink and uplink are focused within the scope of this paper. To this end, a measurement campaign with drive test and system was conducted in dense urban and urban macro-cellular environment (both indoor and outdoor environments).The measurements were performed in the city center of Addis Ababa, Ethiopia. The rest of this paper is organized into five sections. Section II reviews related work, while the basic concepts are presented in section III. The simulation model for performance study is described in section IV, followed by results and analyses in section V. Finally, in the last section, conclusions are given in section VI.

## II. Related Work

There is a growing body of literature dedicated to directly analyzing cell load, throughput data rate for a cellular network. Although much of what exists is restricted to real data collected from different samples size and geographical location, as a result, we observed most studies conclude a vast variability in mobile network performance.

Several works are reported in the literature that focuses on analyzing strategy load decisions with receive level and quality targets, CQI, SINR and inter-cell distance. For the evaluation of the channel quality in LTE user equipment (UE), several Radio Resource Management (RRM) measurements are defined in [4], [5]. The studies consider Reference Signal Received Power (RSRP), Channel Quality Indicator (CQI), Reference Signal Received Quality (RSRQ) and Carrier Received Signal Strength Indicator (RSSI).Each user is assigned a portion of the spectrum depending on RSRP and RSRQ value in a

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different network environment. SINR is measured by UE on Resource Block (RB) and can be used to optimized RSRQ. Two major aspects considered in the references are the balance between resource efficiency and fairness, and quality of service awareness discusses in some authors, moreover, performance parameters such as SINR, RSRQ, etc have been investigated in [6],[7]. Authors in [8], [5] calculated the Reference Signal Received Quality (RSRQ) as follows.

$$\text{RSRQ}=10\log(N_{PRB}) + \text{RSRP}-\text{RSSI} \quad (1)$$

Basically, RSRQ is influenced by interference, data traffic and position of a user device.

Authors in [9], presented the consideration of hidden cells and the optimal load redistribution can effectively overcome irrational load transferring and, hence, efficiently mitigate ping-pong effects.

In [10] proposed the capacity of LTE systems with scheduling, rate adaptation, and limited channel-state feedback Guaranteeing satisfactory level quality-of-service (QoS) experience for mobile end users becomes crucial [11]. In [12], illustrate unequal cell sizes result in unequal cell loads in a maximum SINR cell association, by assuming a relatively uniform mobile user distribution in a specific radio condition.

The work in [13] and [14] contains an in-depth study of LTE networks, using a large dataset collected by a telecom operator. In this study they discover that TCP connections routinely under-utilized the capacity of LTE connections, highlighting the importance of understanding and exploring the unique features of LTE for performance analysis. In [15], analyze a grouping of measurements to enable estimating the quality of connectivity in an area. The study shows the correlation between signal strength and TCP good put in graphs and geographical maps, and the behavior depending on the time of the day. In [16], the author's investigate and measure the characteristics of the cellular data networks using experiments in the laboratory as well as with crowd-sourced data from real mobile subscribers. Authors [17] develop a physically motivated model for the traffic at some point in a network based on observations.

The focus of our research is slightly different; we are concerned with examining and explaining the dependence of cell load, uplink and downlink throughput on a number of factors, including, but not limited to, inter-cell distance, RSRP, SINR and cell edge throughput.

## III. Basic Concept

### A. Channel Model

Path Loss (PL), which dictates the Radio Frequency (RF) coverage distance (i.e., cell size) for wireless systems employing is based on a generic format that is relevant to the practical scenario such as dense urban and urban areas. The path loss is calculated by:

$$L(c) = L_d(c) + L_{sh} + L_p(c)\ [dB] \quad (2)$$

where c=1,.....,C is the carrier index. Ld (based on Okumura Hata model), $L_{sh}$, and $L_p$ are the distance dependent path losses, the shadowing losses and the frequency-dependent penetration losses [18], [19].

### B. SINR Coverage

LTE throughput depends on physical resource blocks (PRB), Signal to Noise Ratio (SINR), inter-site distance, etc [20]. The SINR coverage probability Pc(T) is defined as the probability that the received SINR is larger than some threshold T > 0, i.e., Pc(T) = P(SINR > T). There are two classes of target functions: capacity-based targets would optimize figures such as cell throughput, cell edge throughput, number of satisfied users, etc.; energy-based targets would optimize power consumption of BSs and UEs. At least the capacity-based targets will be based on the signal-to-interference and noise ratio of every user. Based on the system model, the SINR can be expressed as

$$SINR_u = \frac{P_{x(u)} \cdot L_c(\vec{q_u}, \Theta_c)}{N + \sum_{c \neq X(u)} \rho_c \cdot P_c \cdot L_c(\vec{q_u}, \Theta_c)} \quad (3)$$

where: A particular issue in this equation is the interaction of cell load $\rho_c$ with service requirements, scheduler design, and SINR distribution within the cell. $\rho_c$ is defined as the fraction of used PRBs in cell c ( Refer (8)). In general, the UE closer to the eNodeB experience better interference limited regime and SINR as compared to the UE in the cell edge. At the cell edge, users experience very low SNR due to the high path losses and fading. In addition to this, the SINR is largely determined by the relative base station density, which is the ratio of the base station density to the blockage density [21], [22]. The distribution of the coverage number of the typical user defined as the number of strongest BSs (base stations) that the typical user can be connected to at the SINR level T, mathematically [23], [24].

$$N(T) = \sum_{x \in x} 1[SINR(x) > 1] \quad (4)$$

The k-coverage probabilities correspond to the marginal distributions of the SINR process and the probability of the typical user being covered by at least k base station, which we call k-coverage probability, defined as

$$P_c^{(k)}(T) = \mathrm{P}\{N(T) \geq k\} \quad (5)$$

The predicted probability of coverage is also exactly the complementary cumulative distribution function of SINR over the entire network since the CDF gives P[SINR ≤ $T$ ].

### C. Cell Load

The cell load factor is the ratio between the required bandwidth and the maximum total bandwidth available in the cell which is the resources allocated to the cell

$$\delta_{b,s} = \frac{w_{b,s}^{s}}{w} \tag{6}$$

where, $w_{b,s}^{s}$ in the total allocated bandwidth to the base station $b$ in the reference scenario $s$, $w$ is its maximum available bandwidth

The load $k_u$ of the user u is interpreted as the percentage of occupied PRBs per frame needed to make user satisfied.

The load of the cell c is denoted by:

$$\rho_c = \sum_{u|X(u)=c} k_u \geq 0 \tag{7}$$

A simple model capturing the cell loads of a network with discrete customers and connection bandwidths can be evaluate using a modified Shannon capacity formula [25]. Under these conditions, the amount of expected PRBs for user u can be written as (Du/R(SINRu)) [26], where Du is the constant data rate requirement of each user u ( load) and R(SINRu) the data rate per PRB. In general, Load can be defined as

$$\rho_c = \frac{\sum_{u|X(u)=c} N_u}{N_{tot}} \tag{8}$$

where $N_u$ the amount of resources occupied by user u and $N_{tot}$ total number of resource [27], [28].

Authors in [29] suggested that the downlink cell load for a stable network should not exceed 70%.

## IV. Simulation Scenario and Parameters Assumption

In the present LTE network, the management of the radio resource to connect users and cell edge, cell load and cell throughput in the networks is an important issue for this study. In order to solve these problems, this paper proposes a method of forecasting traffic systematically based on the user's behavior, real data and information about the environment.

In order to create the traffic model, two frameworks have been built (we use firstly the estimation of the RSRP and secondly the estimation of the cell load) followed other LTE coverage and capacity parameters. Monte Carlo simulation based planning tools are used to present the effect of different uplink and downlink throughput, CQI, and coverage in LTE based outdoor and indoor environment. In addition to this data have been collocated in application layer using drive test tools.

We compute the downlink and uplink throughput by considering the outdoor and indoor environment, and finally, we do the computation RSRQ / SINR which is linked to the cell load. Our computation uses the real measured data to model the cell throughput in the main city in Ethiopia from one cluster of LTE network.

The setup considers s network configuration, path loss data, cluster data, height data, traffic data, and mobility data, etc, (see Table I).

TABLE I: BASIC PARAMETERS OF THE SIMULATION MODEL

| **Parameters** | Value |
|---|---|
| Layout | 65 sites and 3 sectors/site |
| eNB heights range | [25m,45m] |
| Antenna gain | 18 dBi |
| Propagation scenario | Macro |
| UE speed | 5 km/hr |
| UE height | 1.5m |
| Number of PDCCH Symbol per sub-fram | 3 PDCCH symbol |
| Scheduler | channel unaware scheduler |
| Duplex mode | FDD |
| Propagation model | Hata |
| Antenna configuration | 2Tx -2 Rx |
| Frequency | 2600/1800 MHz |
| RRH | No |
| Total number of PRBs per TTI | 50 |

## V. Analysis and Result

### A. Analysis Real Data Measured Data

We have collected traffic and coverage real data (path loss, SINR, RSQI and CQI) in the same cluster network into account for traffic models as shown in Fig. 1 and Fig. 2.

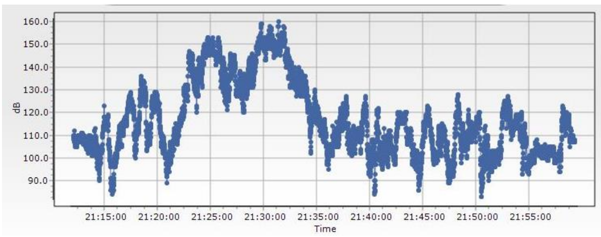


Fig. 1. Path Loss with different time

The mean value of LTE UE path loss is 120 dB (see Fig. 1). In addition to this, the drive test result also provides the value of other LTE parameters such as -8dB, -87dBm and -58 dBm for RSRQ, RSRP, and RSSI respectively. These values are important for the next simulation activity (throughput and cell load analysis).

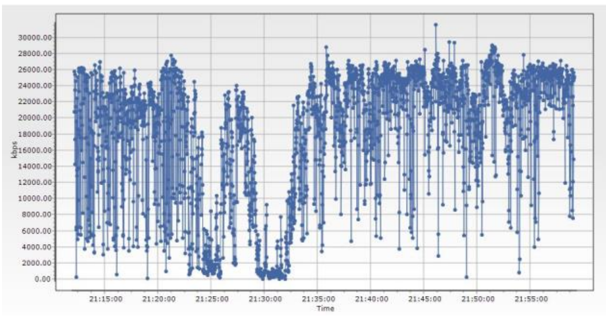


Fig. 2. Realistic Scenario, downlink throughput verse time

In cellular networks, the sources of LTE communication traffic are not fixed, either in terms of time or location due to user movement and the radio situation in the ambient surroundings, as shown Fig. 2. Different points on these plots correspond to different hours of some given day (some busy hr, idel, average etc.). The maximum and average downlink throughput recorded 31Mbps and 18 Mbps.

Following the simulation assumptions quoted above (see Table I). a simulation setup with 65 sites in a non-regular hexagonal grid, 3 sectors per site and 195 cells are defined in one cluster. We run (iterate) the Monte Carlo simulation based planning tools about seven times to get stable results; the result is shown partly in Fig. 3 and Fig. 4.

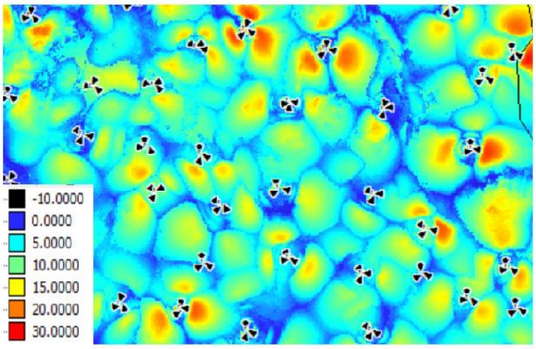


Fig. 3. Signal to Interference and Noise Ratio (SINR) measurements

Fig. 3 presents the site locations (black three sector dots) and the RF coverage simulation results for the LTE cells in the selected dense urban area. The figure shows the real-life situations of the overlapping signal regions among the best, second-best, etc., near the cell edges. From the drive test and this simulation result, the average downlink SINR is 15 dB. This approach provides to predict Resource Blocks (RB) data rate by combining different category (cat) and antenna configuration. For example, using the same average SINR in cat4 and 2x2 MIMO, we found 695 kbps, 688 kbps and 687 kbps for 10MHz, 15 MHz and 20 MHz bandwidth respectively.

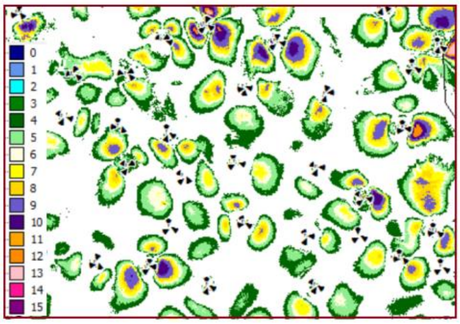


Fig. 4. Channel Quality Indicator (CQI) measurements

From the simulation (as shown Fig. 4) result, we obtain 85 % of the total area covered CQI 5 to 11. Moreover the maximum and average CQI value become 15 and 10 respectively. The duration of the simulation is specified by the Transmission Time Interval (TTI). We set the total number of PRBs per TTI 50, 75, 100 for the selected bandwidth 10 MHz 15 MHz and 20 MHz respectively.

In the simulation scenario, we compare the performance of the throughput when implementing the real data in traffic modeling (scenario two: RSRP=-87dBm, average data rate by served subscriber 1300 kpbs, PL=120dB) and when not invoking the real data (scenario one: RSRP=-94dBm, average data rate by served subscriber 1000kpbs, PL=126dB), as shown in Fig. 5 and Fig. 6 (both indoor and outdoor environment). In scenario two, the downlink throughputs obtained were higher than scenario one. This is because of the lower value of RSRP and higher average data rate by the served subscriber. This throughput represented the acceptable threshold for network coverage and user experience.

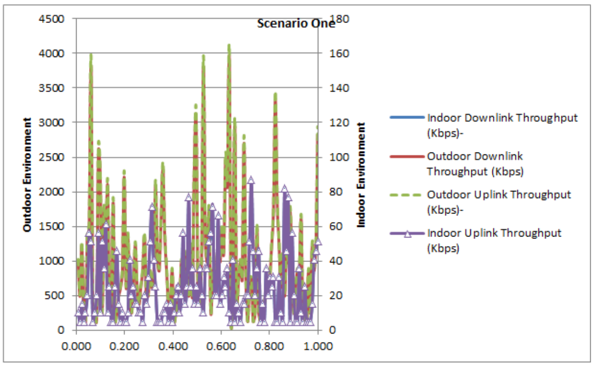


Fig. 5. Throughput vs CDF for scenario one

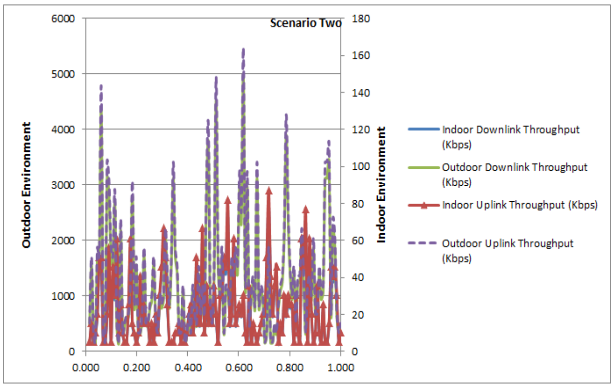


Fig. 6. Throughput vs CDF for scenario two

### *B. Cell Load Analysis*

All the results presented so far were obtained considering separately. The following simulations present the case with cell throughput, cell load, and inter-site distance.

For downlink performance evaluation, it was chosen a scenario with RSRP (dbm)= -107,-94 and -87 having downlink neighboring cells load 50% (i.e., these few neighbor cells contribute sufficient cell interference ). Fig. 7 shows the evolution of downlink throughput with the cell load (experiencing the same radio conditions as in both scenarios). For most case, the planning activity consider 70% cell load [29], as a result, the achievable downlink throughput become 9 Mbps, 12 Mbps, and 27 Mbps when RSRP=-107 dBm, RSRP=-94 dBm, and RSRP=-87 dBm respectively.

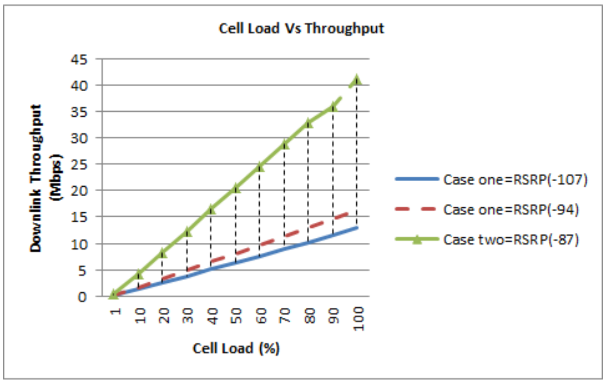


Fig. 7. Cell Load Vs Downlink throughput

One can see from Fig. 2, that the average downlink throughput reach 18 Mbps. Combing the result obtained from Fig. 7 the corresponding cell load reaches near 50 %, so the operator can be plan between 50% to 70 % for optimal CapEx and OpEx. Moreover, the spectral efficiency of the cell edge users has captured two simulation results 0.74 b/s/Hz and 1.04 b/s/ Hz, for cell load of 50 % and 70% respectively.

Now let us see, the average cell throughput corresponding to the solutions to the cell load. Mathematically, the average cell throughput is defined as the sum of the experienced throughput of all UEs (Ci) in cell i divided to the number of cells (N), i.e.

$$Cell\_Average\_Througput = \frac{1}{N}\sum_{i=1}^{N} C_i \tag{9}$$

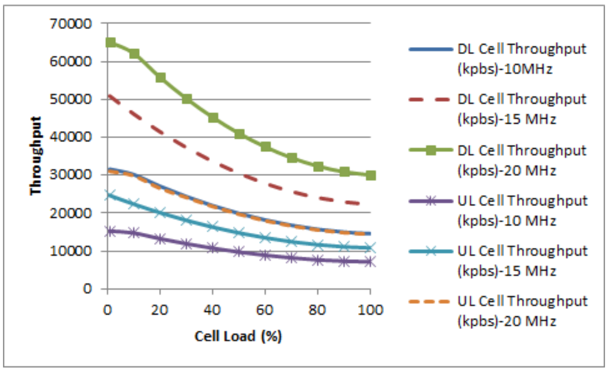


Fig. 8. DL cell throughput in the dense urban network versus cell load in the 50% neighbor site interference

From the simulation result, the average cell throughput becomes 14.1 Mbps and 19.8 Mbps for 50 % and 70% respectively. Fig. 8 and Fig. 9 present both uplink and downlink cell throughput in Dense Urban and Urban, respectively. These figures illustrate the relationship between the data rate and cell load in LTE. In Fig. 9, 70% cell load provides the downlink data rate of 16.4 Mbps.25.3 Mbps, and 34 Mbps in the urban area at 10 MHz, 15 MHz and 20 MHz channel bandwidth respectively. The throughput is more when comparing in the dense urban area (see Fig. 8). When cell load 50 %, 20 Mbps, 30.5 Mbps, 41 Mbps in the dense urban area obtained in 10 MHz, 15 MHz and 20 MHz channel bandwidth respectively. The maximum allowed cell load usage depends on the required user throughput, meaning there is no single maximum acceptable value which is correct for all operators to maintain some targeted user data throughput. The curve also depends on the neighboring cells load, radio condition, antenna configuration, modulation, and coding scheme. The data rate would be lower in case of a lower bandwidth and higher interference, for example in this study the data rate would be lower with 10MHz in uplink-downlink both dense and urban area.

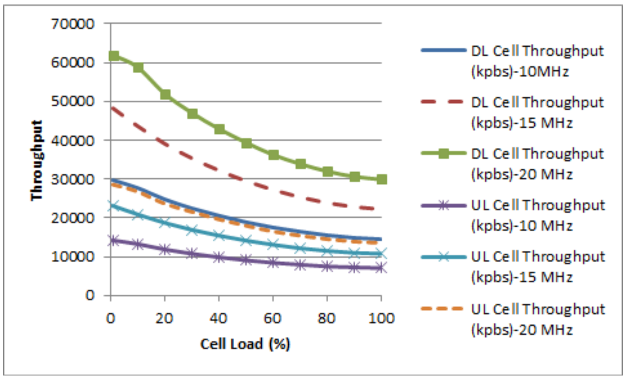


Fig. 9. DL cell throughput in the urban network versus cell load in the 50% neighbor site interference

In general, for both scenarios, we can observe that, when cell load increases, cell throughput decrease. If we wish to provide high user data rates and cell throughput in this condition, the capacity enhancement needs to be planned for at a low cell load.

### C. Inter Site Distance

Fig. 10 displays the inter-sites distance in the urban and dense urban area with different bands. We have two remarks. For the traffic demand smaller than 50 % or greater than 70% cell load (see Fig. 2), both thresholds predict the number of active users per cell, Cell Throughput, Throughput per eNB and a total number of sites. For this scenario (for which we present the measurements), beyond this value of the traffic demand per cell the estimators become not optimal or in some case, the operator cannot meet user demand. In 20 MHz, the maximum distance of dense urban reach 431 and 410 meters in 50% and 70 % cell load respectively. Similarly, 667 meters and 644 meters in urban 20 MHz for 50% and 70 % cell load respectively.

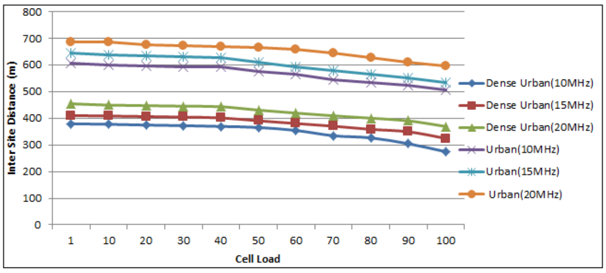


Fig. 10. Load performance versus inter site distance

## VI. CONCLUSION

This paper, is attempt to tackle the complexity of LTE capacity modeling the interplay between this real network and theoretical concept and to obtain a realistic evaluation of the throughput performance at the cell level. The methods, which are based on real data, are trained to obtain the relevant parameters such as SINR, PL, CQI, RSRP, and RSRQ and then tested on scenarios (using planning tools and Mento Carlo simulation) with different environmental conditions and LTE bands. The study analysis, cell throughput and cell load with some parameter assumption. We also intend to incorporate correlation between inter-site distance and cell load both dense urban and urban area.

Proper cell load threshold selection is important for dimensioning the LTE system and configuring the optimal set of radio parameters and resource allocation. In this paper, for both scenarios, the results show clearly that the throughput and cell load has an inverse relationship, and we also observe that 50% to 70% cell load is the optimal value for the selected scenarios.

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