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Original

Optimization of an LTE network in the province of Santa Elena using the Atoll Simulation Tool for the study of packet scheduling strategies: Round robin and Proportional Fair

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Abstract: The optimization of an LTE cellular network deployed across the province of Santa Elena in Ecuador aims to enhance the performance of the communication system by applying different scheduling strategies. This improvement is intended to deliver a superior packet transmission quality to network users. The optimization involves the implementation of packet scheduling strategies: Round robin and Proportional Fair. For the successful application of these strategies, it is crucial to have accurate network planning. Utilizing the meticulously studied and defined parameters with the Atoll simulation software, various tests are conducted to analyze network coverage through downlink and uplink links, employing each packet scheduling strategy. The test results determine that the Proportional Fair strategy achieves better results, improving download speeds by 17% and upload speeds by 5% compared to the round robin strategy. Additionally, the need to develop strategies for interference management was found due to the low signal quality detected.

Keywords: Optimization, LTE, packet scheduling, simulation, coverage

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1. Introduction

The implementation of modern technologies within the field of telecommunications in the province of Santa Elena, Ecuador has propelled and enhanced the service performance of LTE networks deployed in this region.

The LTE service is integrated into the array of services offered by the National Telecommunications Corporation Álvarez Paredes (2018). In the provincial context, areas with deficient coverage have been identified, characterized by signal levels below -120 dBm, which does not ensure adequate data service provision. The only viable alternative in these cases involves configuring equipment with 3G technology Evolución de la red de comunicación móvil, del 1G al 5G | VIU, (2023). These challenges have spurred the investigation and development of packet scheduling strategies known as round robin and Proportional Fair, aiming to optimize the LTE network implemented in the province of Santa Elena.

The simulation development, with the terminal equipment correctly configured using the Atoll simulation software, provides a comprehensive insight into the current state of the network Proaño Calderón (2016). This allows us to recognize and characterize the environment, considering factors such as interferences and coverage overlap that may arise.

The analysis of coverage performance results, especially when simulating packet transmission in downlink and uplink links, plays a crucial role in identifying the most suitable strategy for implementation in the LTE network system Muñoz (2016). This thorough evaluation provides the necessary information to determine which of the two strategies is more efficient, significantly contributing to achieving the main objective: The optimization of the LTE network system to meet the needs of users utilizing the network.

1.1. Round robin strategy

The purpose of this scheduler strategy is to allocate resources to each user consecutively within the same time interval for each user. This means that the allocation is performed in order, user by user, sequentially, without considering channel conditions (Yagual & Ernesto, 2018).

The round robin (RR) strategy is considered an equitable strategy because each user will receive the same portion of allocated resources Alonso Sánchez et al. (2014). However, it simultaneously exhibits disadvantages, as a user with poor channel conditions will experience lower throughput compared to a user with more favorable conditions.

The process conducted by the simulator is illustrated in Figure 1, depicting the segmentation of resource quantities for users in the uplink and downlink procedures of the mobile terminal.

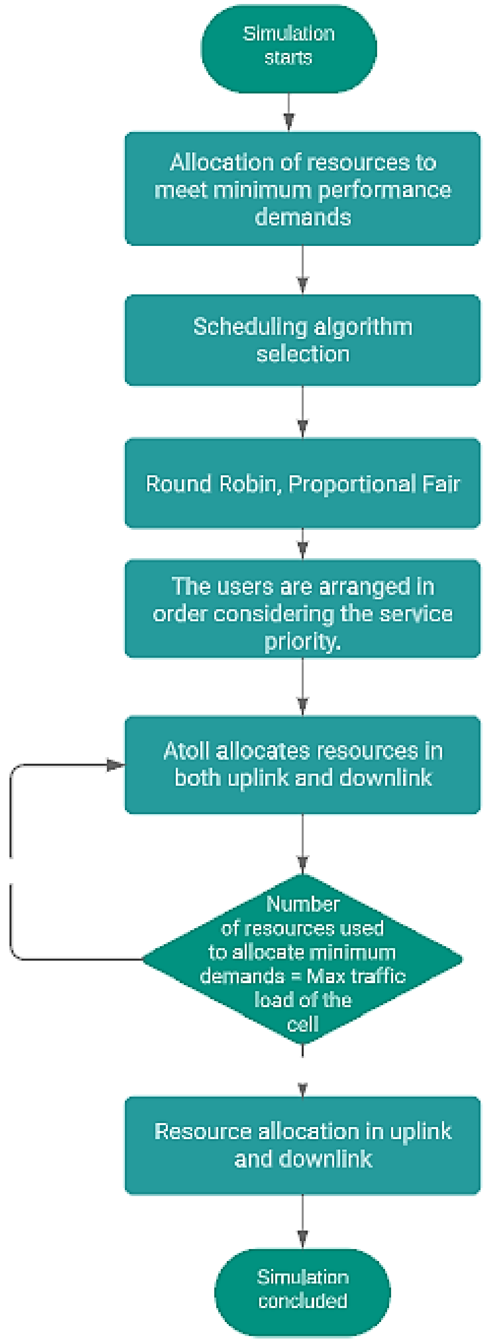

Figure 1. Block diagram in meeting minimum performance demands.

1.2. Proportional Fair strategy

Proportional Fair (PF) combines an efficient radio channel with an equal distribution of resources among users. The objective is to ensure that no user is left without the opportunity to access resources. Through this procedure, a balanced distribution is achieved, combining adaptive strategy and throughput optimization for each user (Sesia et al., 2011).

In the simulator, PF must similarly adhere to the fair distribution of resources among all users to maximize individual performance (Guinand Salas, 2012). This is resolved at a specific moment in time, and its process is also illustrated in Figure 1, with PF selected.

As depicted too in Figure 1, the resource allocation must meet "minimum performance demands." This refers to the minimum data rates required within a service to achieve efficient results. If the packet scheduling strategy fails to allocate the necessary resources to satisfy the minimum performance demands of a user's service, the consequence is receiving no resources at all.

The representations described in Table 1 correspond to the characteristics of "Equation 1" and "Equation 2" for the round robin scheduler, while for the Proportional Fair scheduler, we have "Equation 3" and "Equation 4."

Table 1. Representation of equations.

$CTP_{P-DL}^{M_i^{Sel}}$	Peak channel throughput in downlink
$CTP_{P-UL}^{M_i^{Sel}}$	Peak channel throughput in uplink
$R_{DL}^{TX_i}$ y $R_{UL}^{TX_i}$	Total resources allocation in data upload and download for each cell
$TX_i, \eta_{B_{DL}}^{M_i}$ y $\eta_{B_{UL}}^{M_i}$	Spectral efficiency of the radio bearer
D_{Frame}	LTE frame duration
$G_{MUG-DL}^{TX_i}$ y $G_{MUG-UL}^{TX_i}$	Multi-user diversity gain assigned to user Mi based on the number of connected users in the downlink and uplink of cell TXi

$$CTP_{P-DL}^{M_i^{Sel}} = \frac{R_{DL}^{TX_i} \times \eta_{B_{DL}}^{M_i}}{D_{Frame}} \quad (1)$$

$$CTP_{P-UL}^{M_i^{Sel}} = \frac{R_{UL}^{TX_i} \times \eta_{B_{UL}}^{M_i}}{D_{Frame}} \quad (2)$$

$$CTP_{P-DL}^{M_i^{Sel}} = \frac{R_{DL}^{TX_i} \times \eta_{B_{DL}}^{M_i}}{D_{Frame}} \times G_{MUG-DL}^{TX_i} \quad (3)$$

$$CTP_{P-UL}^{M_i^{Sel}} = \frac{R_{UL}^{TX_i} \times \eta_{B_{UL}}^{M_i}}{D_{Frame}} \times G_{MUG-UL}^{TX_i} \quad (4)$$

Hence, the algorithms executed by the program in resource allocation depend on the mathematical models associated with each selected packet scheduling strategy for that process.

2. Materials and methods

This research employs the quantitative method since its development involves the study of performance coverage concerning speeds in Kbps relative to the coverage area of the transmitting station. This analysis includes both downlink and uplink packet transmission, represented through statistical bars for the two packet scheduling strategies.

Atoll is a widely used radio planning tool in the wireless telecommunications industry. Developed by the company Forsk, Atoll provides a comprehensive environment for planning, optimizing, and simulating mobile communication networks. Its intuitive user interface and versatile set of tools make it an excellent choice for RF planning (Forsk, 2024). In this research, version 3.3 of the Atoll software is used.

2.1. Recognition and characterization

The province of Santa Elena is geographically located on the Ecuadorian coast. It borders to the north with the Puerto López canton, to the south with the Pacific Ocean and the Playas canton, to the east with the cantons Pedro Carbo, Isidro Ayora, and Guayaquil, and to the west with the cantons La Libertad, Salinas, and the Pacific Ocean (EcuRed, 2019).

2.2. Bandwidth and frequency bands

The telecommunications service provider CNT is assigned the frequency bands AWS 1700/2100 MHz and APT in 700 MHz (Arcotel, 2023).

For the simulation, Band 4 is utilized, which is the band used by CNT to provide LTE technology services.

2.3. Propagation model

Propagation models are highly valuable in the design of telecommunications networks as they assist in analyzing the behavior of radio waves during data transmission (Quiñonez, 2016).

The chosen model for the simulation analysis of this network is the Cost Hata model. It is selected for its alignment with the characteristics of the chosen frequency band. Additionally, it considers the height range of CNT transmitters, which varies from 4 to 50 meters. The formula utilized by this model is described in "Equation 5."

$$L = 46{,}3 + 33{,}9\log(f) - 13{,}82\log(hb) - Ahm + (44{,}9 - 6{,}55\log(hb))\log(d) + Cm \quad (5)$$

The following variables are indicated in the expression of Cost Hata: Path loss (L), frequency (F), height antenna (hb), distance between transmitter and receiver (d), constant between 0 and 3 in metropolitan areas (Cm), and correction value for mobile antenna height (Ahm).

Among the materials employed, it was necessary to use the Global Mapper software for extracting the relief map of the province of Santa Elena. This was done to consider elevations with respect to the Earth's surface. Mobile applications, such as G-NetTrack and SpeedTest by Ookla, were utilized in the initial phase of the research work simulation to relate the obtained results to prediction maps. Finally, the Atoll software was used for network design, simulation of coverage and performance predictions, and result interpretation to choose the best-applied scheduler.

In the simulator, a general LTE template configuration is necessary within the parameter layer in radio network settings. Parameters such as downtilt, transmitter height, propagation model, transmission power, RSRP, and traffic loads for both downlink and uplink are configured in a general manner (Logroño Llumiquinga, 2014). These parameters configured in the software are divided into four categories called: General, transmitter, LTE and neighbors which are shown in Table 2.

Table 2. LTE parameters configured in Atoll.

	Parameter	Value
General	Hexagon radius	500 m
	Mechanical downtilt	0°
	Height above ground	25 m
	Transmission	2
	Reception	2
	Propagation model	Cost-Hata
	Principal radius	7,000 m
	Main resolution	100 m
Transmitter	TMA	Default TMA equipment
	Feeder	1/2" at 2100 MHz
	Transmitter	Default
	Feeder length/transmission	5 m
	Feeder length/reception	5 m
	Miscellaneous losses/transmission	0 dB
	Miscellaneous losses/reception	0 dB
LTE	Max power	46 dBm
	Frequency band	E-UTRA Band 4 – 10 MHz
	LTE equipment	Default cell equipment
	Cell type	LTE
	Min RSRP	-140 dBm
	DL traffic load	100%
	UL traffic load	100%
	DL max traffic load	100%
	UL max traffic load	100%
	UL noise rise	0 Db
Neighbors	Intra-technology	16
	Inter-technology	16

2.4. eNB establishment

The geographical locations of the transmitting towers are configured with the latitude and longitude data Serra Jiménez and Marante Rizo (2013). This data was officially collected to verify where the National Telecommunications Corporation locates the transmitting base station.

For a specific analysis, some stations were selected: La Libertad, Autódromo, and Noreste. The La Libertad station is located at latitude -2.22023 and longitude -80.90746, with an elevation of 30 meters. The Autódromo station is situated at latitude -2.2382 and longitude -80.8877, also with an elevation of 30 meters. Finally, Noreste station has a latitude of -2.22604, a longitude of -80.90584, and an elevation of 23 meters.

3. Results and discussion

In this section the initial simulation tests are planned, initiating the design of the LTE network system. To obtain speed values, simulation groups were conducted for each base station. In these simulations, Atoll assigns a random number of users connected to the network to execute the simulation and deliver the desired values.

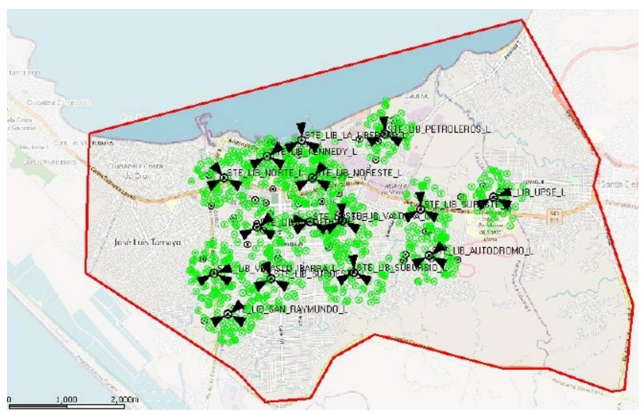

Figure 2. Network planning.

The figure 2 illustrates the simulation of eNB locations and proceeds to calculate mobile internet access. As a result of this initial analysis, Table 3 reveals that downlink transmission covers values above 20 Mbps, while uplink varies between 5 to 15 Mbps. These values are based on the peak transfer of packet data units (PDU) managed by radio link control (RLC). Three base stations are taken as samples.

As mentioned earlier, in the LTE template, it is necessary to complete some radio parameters. Some of these parameters, such as RSRP, RSRQ including RSRI, are crucial for network coverage. These parameters can also be obtained through the G-NetTrack application by conducting field measurements. Table 3 also summarizes the measurements.

Table 3. Data collected by G-NetTrack and download values without optimization.

Station	Cell ID	F DL	F UL
La Libertad	51625-2	2120,0 MHz	1720,0 MHz
Autódromo	51626-1	2120,0 MHz	1720,0 MHz
Noreste	51612-3	2120,0 MHz	1720,0 MHz

Station	RSRP	RSRQ	RSSI
La Libertad	-84 dBm	-13 dB	-55 dBm
Autódromo	-100 dBm	-13 dB	-69 dBm
Noreste	-92 dBm	-13 dB	-55 dBm

Station	Cell ID	DL (Peak RLC)	UL (Peak RLC)
La Libertad	51625-2	15.52 Mbps	15.33 Mbps
Autódromo	51626-1	21 Mbps	10.24 Mbps
Noreste	51612-3	12.95 Mbps	11.22 Mbps

Figure 3 gathers screenshots of measurements taken at a maximum distance of 10 m between eNB and the user equipment.

Figure 3. G-NetTrack data. Top: La Libertad, middle: Autódromo, bottom: Noreste.

Similarly, transfer speeds for the sending of information in uplink and downlink links are compared using data collected by the SpeedTest by Ookla application. The collected data are shown in Figure 4.

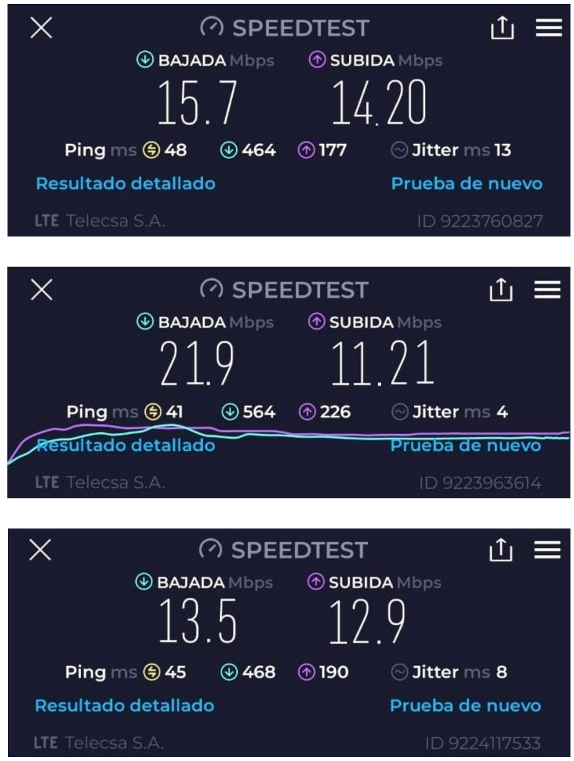

Figure 4. Ookla data. Top: La Libertad, middle: Autódromo, bottom: Noreste.

3.1. Comparative analysis of simulations and mea surements

For the initial comparative analysis of upload and download values, the coverage by throughput prediction is selected to display data according to DL and UL in relation to the RLC layer, which reliably sends packets between the eNodeB and the user equipment. Atoll initiates a simulation where a maximum list of users is automatically grouped, connected, and disconnected from the network. The results, with a randomly selected number of 28 users connected to the LTE network, are presented in terms of upload and download based on the RLC layer in comparative Table 4.

The RSRP level or reference signal received power level has a value of -100 dBm as shown in the data collected by G-NetTrack. The simulation results display an RSRP level ranging from -140 dBm to -85.2 dBm, as shown in Figure 5. Similar analysis aligns with the variables of RSRQ and RSRI. Field measurements fall within the range obtained by the simulation.

Table 4. Comparative data Autódromo station.

	Autódromo station
	Atoll data
DL	Peak RLC cumulated throughput: 21 Mbps, effective RLC cumulated throughput: 20.92 Mbps, cumulated application throughput: 19.88 Mbps
UL	Peak RLC cumulated throughput: 10.24 Mbps, effective RLC cumulated throughput: 10.23 Mbps, cumulated application throughput: 9.71 Mbps
	Ookla data
DL	21.9 Mbps
UL	11.21 Mbps

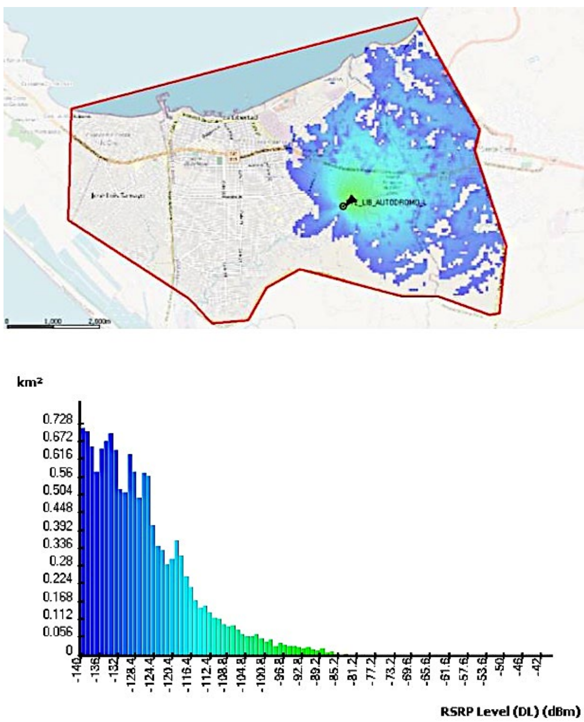

Figure 5. RSRP level and histogram Autódromo station.

In the previous case, the comparative analysis was conducted individually for each node, allowing us to verify that the simulated data closely aligns with the measurements from the current network deployed by the CNT. For the following analyses, simulations are conducted considering the complete set of eNBs defined in Table 2.

3.2. Comparative analysis of packet scheduling strategies without optimization

In this analysis, the packet scheduling strategies round robin and Proportional Fair are applied to analyze their impact on the LTE network coverage. As mentioned earlier, all eNBs are considered with their current configuration, meaning that network optimization is not yet considered. This implies that the simulation does not modify: Physical cell ID, frequency planning, neighbor assignments, traffic maps, and environmental densities.

Figure 6 corresponds to the prediction analysis for downlink coverage where traffic resources are utilized at 100%. This overall result indicates that there are many areas with poor coverage performance, and the acceptable peak performance of 50,000 kbps only covers an area of approximately 3.50 km^2. This analysis is corroborated by the histogram.

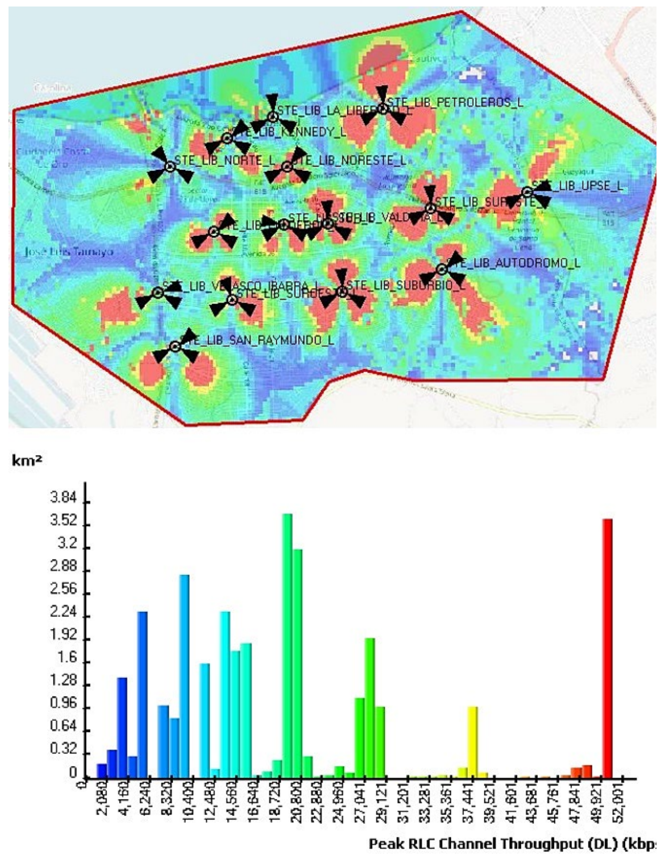

Figure 6. Downlink coverage and histogram performance – PF.

For the analysis in uplink, the process in the software is similar regarding the configuration of radio parameters.

Then, the downlink coverage simulation is performed, corresponding to the application of the round robin strategy with traffic resources at 100%, obtaining the following results shown in Figure 7. The results of applying the round robin strategy show that, in general, the acceptable quality of 50,000 kbps only covers an area of 1.40 km^2. This result is also observed in the histogram.

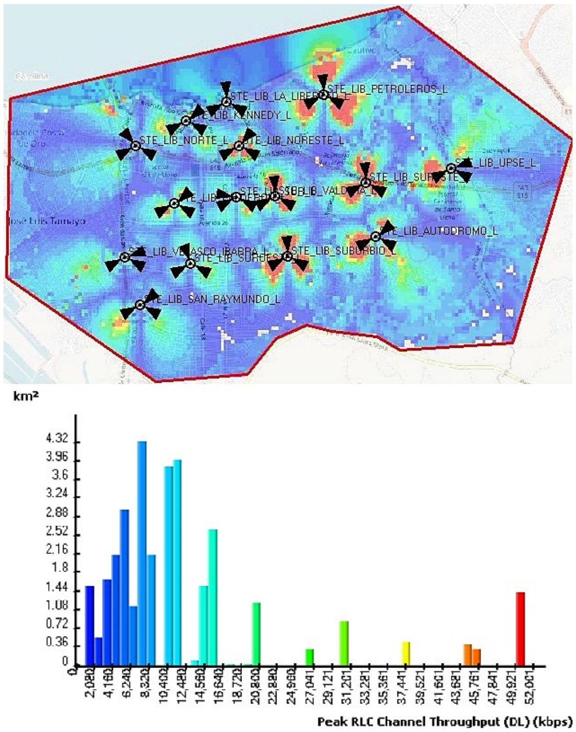

Figure 7. Downlink coverage and histogram performance – RR.

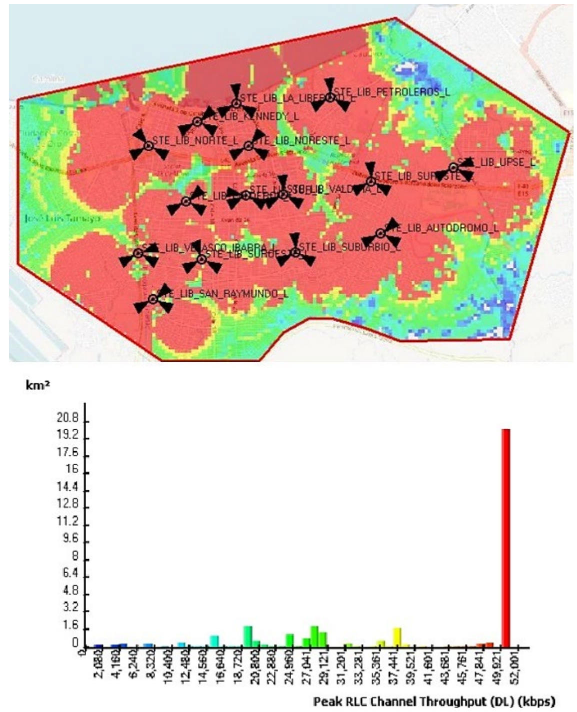

Figure 8. Downlink coverage and histogram performance – PF – optimized.

3.3. Comparative analysis of packet scheduling strategies with optimization

Within this analysis, optimization of the physical cell ID, frequencies, and neighbors is employed to provide better performance to the designed LTE network. This is made possible through the functionalities embedded in the Atoll software, such as automatic neighbors' allocation.

Next, the results of the Proportional Fair strategy are presented, corresponding to the analysis of downlink coverage performance. It is clearly observable that the coverage radio of the transmitters has increased, as seen in the red color in Figure 8. The red color indicates that the best quality of 50,000 kbps covers an area of 19.5 km^2 entirely, and there is no low-performance peak. This result is also comparable with the histogram.

The analysis with the application of the round robin strategy shows satisfactory results, where the best quality of 50,000 kbps covers an area of 13.5 km^2. However, it is observed that there are few areas where the coverage performance is not as acceptable, as shown in Figure 9. This is noticeable as coverage gaps are observed, reflected in the statistics of the histogram presented, where higher coverage percentages are observed at lower speeds around 15,000 Kbps.

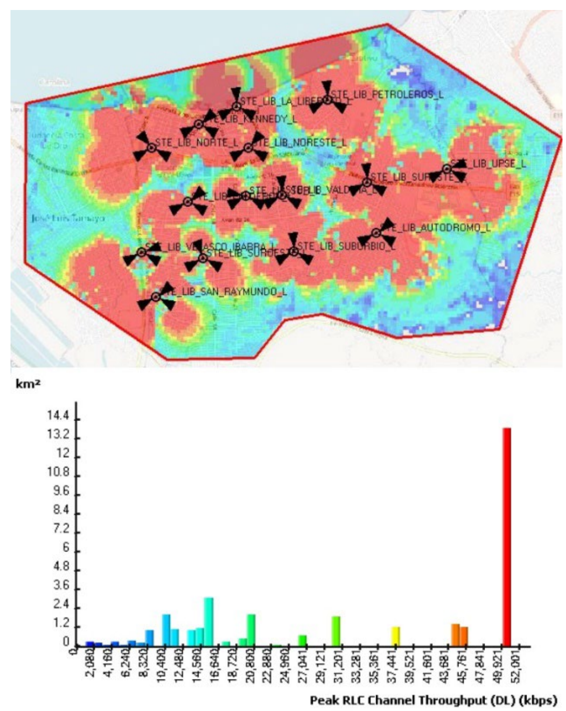

Figure 9. Downlink coverage and histogram performance RR strategy – optimized.

3.4. Selected scheduler and LTE network optimization

Once all performance results are obtained for both downlink and uplink, the histograms and coverage maps on the province's terrain are analyzed. The information from both strategies is collected in Table 5, and it can be highlighted that the Proportional Fair strategy achieves better performance and results in downlink coverage. However, in uplink, these results are less prominent due to the demand where users prefer to download information more than uploading it.

Table 5. Optimized load and download values.

Transmitter	Scheduler	Downlink	Uplink
La Libertad	PF	59.69 Mbps	29.31 Mbps
	RR	57.69 Mbps	28.18 Mbps
Autódromo	PF	68.25 Mbps	19.12 Mbps
	RR	56.52 Mbps	18.72 Mbps
Noreste	PF	70.02 Mbps	17.61 Mbps
	RR	59.61 Mbps	31.08 Mbps

The results in the LTE network, in the context of downlink and uplink, highlight exceptional performance in coverage, demonstrating a highly efficient state for users connecting within the specifically planned area for the province of Santa Elena.

From an advanced technological perspective, the figures accurately illustrate how the enhancements implemented in the LTE network have significantly optimized service quality. In the downlink, a distribution of spectral resources ensuring optimal transmission speed for users is observed, as shown in the upper Figure 10, while in the uplink, the data transmission capacity from mobile devices to the network has been maximized, thus contributing to a superior user experience.

The uplink coverage map is shown in down Figure 10, and acceptable performance is observed near the transmitting station. In distant areas, the coverage performance is not as acceptable, but this is because in real life, users are closer to the transmitting station downloading information rather than uploading information.

These results reflect the success of the strategic implementation of packet scheduling, which has strengthened spectral efficiency and the ability to manage multiple simultaneous connections. Consequently, robust coverage and enhanced network capacity are achieved in the province of Santa Elena.

The effectiveness of scheduling algorithms such as RR and PF depends on the conditions of the radio channel. Since the study was conducted in the coastal area of Santa Elena, there are buildings, ships, and a large water surface that can cause reflections and diffractions affecting the signal quality. Additionally, there may be interference caused by other maritime and terrestrial communication systems, further degrading the signal quality. Therefore, if the channel conditions are not uniform or if some users experience significantly worse signal quality than others, an algorithm that prioritizes and adapts resource allocation according to these conditions, such as PF, achieves superior results.

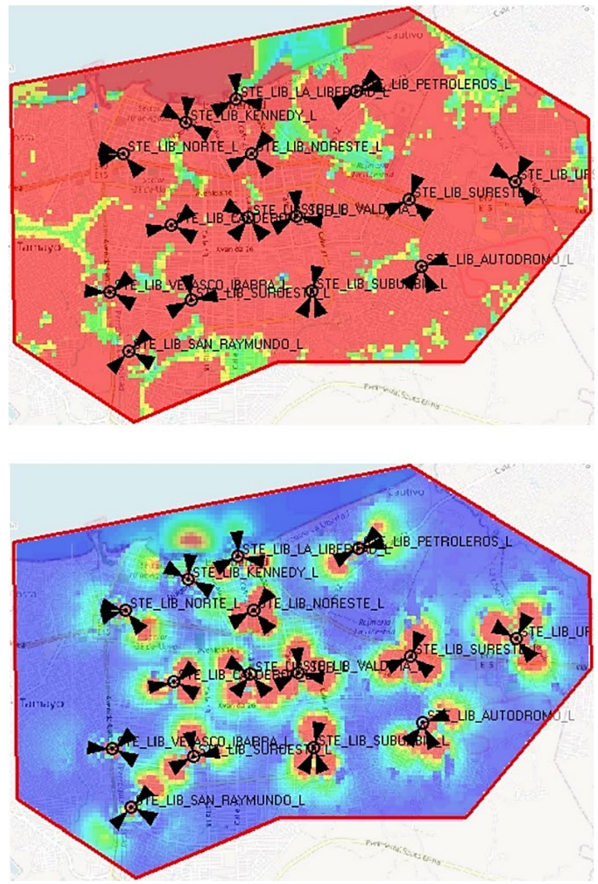

Figure 10. Optimized downlink and uplink coverage map.

4. Conclusions

The packet scheduling techniques efficiently improve the quality of service in the LTE network across various sectors of the established transmitting base stations in the province of Santa Elena.

Through the analysis of downlink coverage by performance, with the optimized system and traffic resources at 100%, it is observed that the Proportional Fair strategy at its maximum of 50,000 kbps covers an area of 19.5 km^2 in its entirety, while for the round robin strategy, the maximum of 50,000 kbps is only represented in an area of 13.5 km^2.

In conclusion, it can be deduced that applying both packet scheduling strategies improves the LTE network performance. Still, it is determined that the Proportional Fair strategy achieves better results. In the downlink, 68.25 Mbps was achieved compared to 56.52 Mbps when applying the round robin strategy. Meanwhile, for uplink, the values vary from 1 to 14 Mbps. Based on these findings and prioritizing the downlink service the Proportional Fair strategy is the better option for system optimization and configuration of each base station's parameters.

For future research, it is suggested to explore further scheduling algorithms that consider dynamic variations of the channel and interference, as well as to develop new models that can predict and mitigate the negative effects of these factors in various topographies and environments.

Specific strategies can be developed for interference management and coverage optimization in the province of Santa Elena, where significantly lower signal quality was detected.

Conflict of interest

The authors do not have any type of conflict of interest to declare.

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