

Performance Enhancement of Cellular Mobile Networks in Algeria Using Antenna Electrical Tilt

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Abstract:

This paper presents a structured radio network optimization methodology applied to a local operator in Algeria for different generations 2G, 3G, and 4G networks, integrating drive test measurements, ATOLL and Python radio coverage simulations, and electrical antenna tilt adjustments via Ericsson ENM/AMOS. Since the deployment of 5G in Algeria has been launched only in early 2026, field measurements related to the electrical tilt effect cannot be conducted at the time of this study. The methodology effectively mitigates overshooting cells while maintaining coverage continuity in the mentioned generations. Post-optimization evaluations, using drive test measurements and collected KPIs from Business Objects (SAP), demonstrate significant improvements in signal strength, quality of service, handover performance, and user throughput, alongside reduced interference. Outdoor 4G throughput increased by approximately 60%, while indoor throughput gains ranged from doubling to nine-fold across different zones. These enhancements are supported by improvements in RXLev, RSCP, RSRP, Rxqual, Ec/Io, and SINR, ensuring stronger cell dominance and a more stable user experience. The obtained results are validated through both simulation and field measurements. The proposed methodology provides a scalable framework for national deployment of mobile networks.

1. Introduction

The rapid growth of mobile communication services and data consumption has transformed modern telecommunications networks. High-speed internet, video streaming, online gaming, and cloud services demand reliable connectivity, high throughput, and consistent service quality, making network performance optimization a critical challenge. For more details about the growth of mobile market in Algeria, one can check the official web site of the Audiovisual Regulatory Authority [1]. In Algeria, mobile networks operate within a heterogeneous environment with multiple radio access technologies

(2G, 3G, 4G). While this multi-technology setup serves diverse devices and services, it introduces challenges in radio resource management, interference mitigation, and coverage optimization. A common issue is cell overshooting, where a cell's coverage extends beyond its intended area, causing inter-cell interference, inefficient handovers, increased signalling traffic and reduced user experience. Controlling radio coverage is therefore essential for maintaining network efficiency and high Quality of Service (QoS) and Quality of Experience (QoE). The authors address the overshooting problems for three different technologies of mobile networks [2]. Whatever the

mobile network generation, this problem can be solved by modifying antenna parameters at each base station in the area of interest. Among these parameters to be adjusted, one can cite electrical and mechanical tilt of the antenna [3, 4], and transmitted power [5, 6].

Previous studies have examined LTE network optimization through various methods. Larasati and Rizkiatna in [7] demonstrated the effectiveness of antenna re-azimuth, while subsequent studies by Rofiansyah et al. [8] and Laksana et al. [9] applied both electrical and mechanical tilt, reporting significant throughput improvements. The application of electrical tilt in dense urban environments was further validated by Laksana and Restu in [9]. Taruna and Mulyono [10] employed electrical tilt simulation at a site and demonstrated its effectiveness in improving network quality and throughput across multiple locations. More recently, Suprianto et al., in their paper [11], conducted a study using an antenna tilt adjustment method based on key performance indicator (KPI) results. Their research employed both mechanical and electrical tilt adjustments guided by KPI analysis, achieving substantial throughput gains. The present study investigates the implementation of electrical tilt optimization within a live 2G/3G/4G network environment. It proposes an integrated radio optimization framework combining simulation, parameter tuning and empirical validation through field measurements. Tools such as ATOLL, Ericsson ENM (AMOS) and SAP Business Objects were used for simulation, configuration, and KPI analysis. The study focused on areas with significant coverage overshooting. Targeted parameter adjustments were validated through real network measurements across 2G, 3G and 4G.

The main task of our study is to improve many KPIs such as throughput and enhance some quality of services, Reference Signal Received Power (RSRP), Signal-plus-Noise Ratio (SINR), while addressing the overshooting problem to improve mobile network performance.

2. Overview of mobile networks in algeria

The evolution of mobile networks from 2G to 4G demonstrates a gradual transformation in both services and architecture. 2G was designed primarily for voice and SMS, featuring a circuit-switched architecture and very limited data rates. With 3G, networks began integrating data transmission alongside voice, introducing packet switching while still supporting circuit-switched voice. This generation enabled access to the internet, video calling, and multimedia services. 4G represents a major shift, adopting an all-IP architecture focused on high-speed data with low latency, with voice

delivered as data through VoLTE. Each generation has progressively addressed increasing demands for capacity, bandwidth and quality of service. Looking ahead, 5G deployment in Algeria is expected to provide ultra-high-speed connectivity, extremely low latency, and support for emerging technologies such as IoT, autonomous systems and smart cities.

The spatial distribution of the local operator operational sites across Algeria was visualized in Google Earth, as shown in Fig. 1. The local operator mainly uses Ericsson technologies in its base stations, particularly the RBS 6000 series. To obtain realistic results, the radiation pattern of the commercial RRV4-65D-R6 antenna was considered, as illustrated in Fig. 2. The RRV4-65D-R6 is a 12-port multiband sectorial antenna operating in the range 694–960 MHz and 1695–2690 MHz bands. It has $\pm 45^\circ$ polarization, a horizontal beamwidth of 65° approximately, 15.8–18.3 dBi gain, and an electrical tilt ranging from 2° to 12° . It also supports remote electrical tilt (RET) using the 3GPP/AISG 2.0 protocol [12].



Figure 1. Projection in Google Earth (KMZ format) of the operational sites operated by local operator in Algeria.

Remote Electrical Tilt (RET) is a function that allows the antenna tilt angle to be changed remotely from a network management system. The present study considers electrical tilt as an alternative to conventional mechanical tilt for radio network optimization. By integrating the overshooting detection method based on high timing advance (TA) measurements with electrical tilt adjustment, it becomes possible to accurately identify and mitigate areas affected by excessive coverage without requiring physical intervention at the site level.

In contrast to mechanical tilt, which necessitates on-site operations involving engineer travel, logistical arrangements, and associated operational costs, electrical tilt modifications can be executed remotely through network management platforms such as Ericsson Network Manager (ENM) and AMOS (Advanced MOShell). This remote optimization capability reduces operational expenditures while enabling faster deployment of corrective actions.

Moreover, the near-real-time implementation of parameter adjustments enhances the responsiveness of the optimization process and improves radio coverage control and overall network performance. Therefore, the proposed approach offers practical

potential for large-scale deployment and supports the adoption of electrical tilt optimization as a standard practice in modern cellular network management.

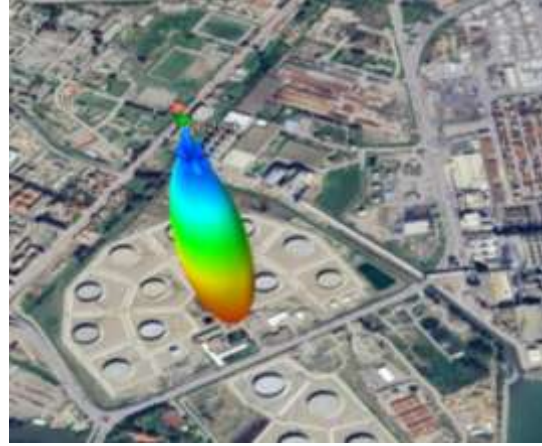


Figure 2. Electrical tilt configuration of the RRV4-65D-R6 antenna.

3. Radio optimization based on kpi analysis and drive test

Optimization in mobile networks plays an important role, since multiple parameters must be optimized to enhance quality of service and ensure that network performance meets the predefined KPI thresholds or target values set by the operator [13]. This section presents an optimization approach based on KPI analysis, field validation, and antenna tilt adjustment for different generations of mobile networks (2G, 3G, 4G). The obtained parameters are expected to reduce overshooting, improve signal quality, and enhance mobility and overall network performance. The validation process is carried out in two phases: (i) field measurements obtained through drive tests conducted before and after optimization, assessing parameters such as RxLev and RxQual for 2G, RSCP and Ec/Io for 3G and RSRP, RSRQ, SINR and throughput for 4G; and (ii) simulation-based analysis using Python to evaluate the impact of antenna tilt and Atoll to analyze cell dominance, interference and coverage at the network cluster level. Simultaneously, cross-validation is performed between simulation results, planning predictions and field measurements to ensure the consistency and reliability of the obtained results. Performance is subsequently evaluated by comparing KPIs before and after optimization, demonstrating improvements in coverage, signal quality, throughput, handover stability and interference reduction.

3.1 Radio optimization methodology

The adopted radio optimization methodology combines KPI analysis, drive test measurements, simulation, electrical tilt adjustment, and post-optimization validation. Fig. 4 and Fig. 5 illustrate the main steps of the KPI-based optimization process.

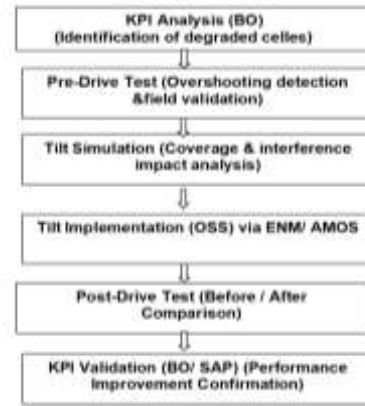


Figure 3. Radio optimization methodology Flowchart.

The process begins with KPI analysis to identify performance degradation at the cell level. Drive tests are then conducted to detect cells affected by overshooting. Based on these measurements, tilt simulations are performed to determine the optimal electrical tilt settings. Once the optimal tilt adjustments are implemented, additional drive tests are conducted to verify the post-optimization improvements. Finally, the results are validated and consolidated using SAP BusinessObjects tools, confirming the overall enhancement in network performance.

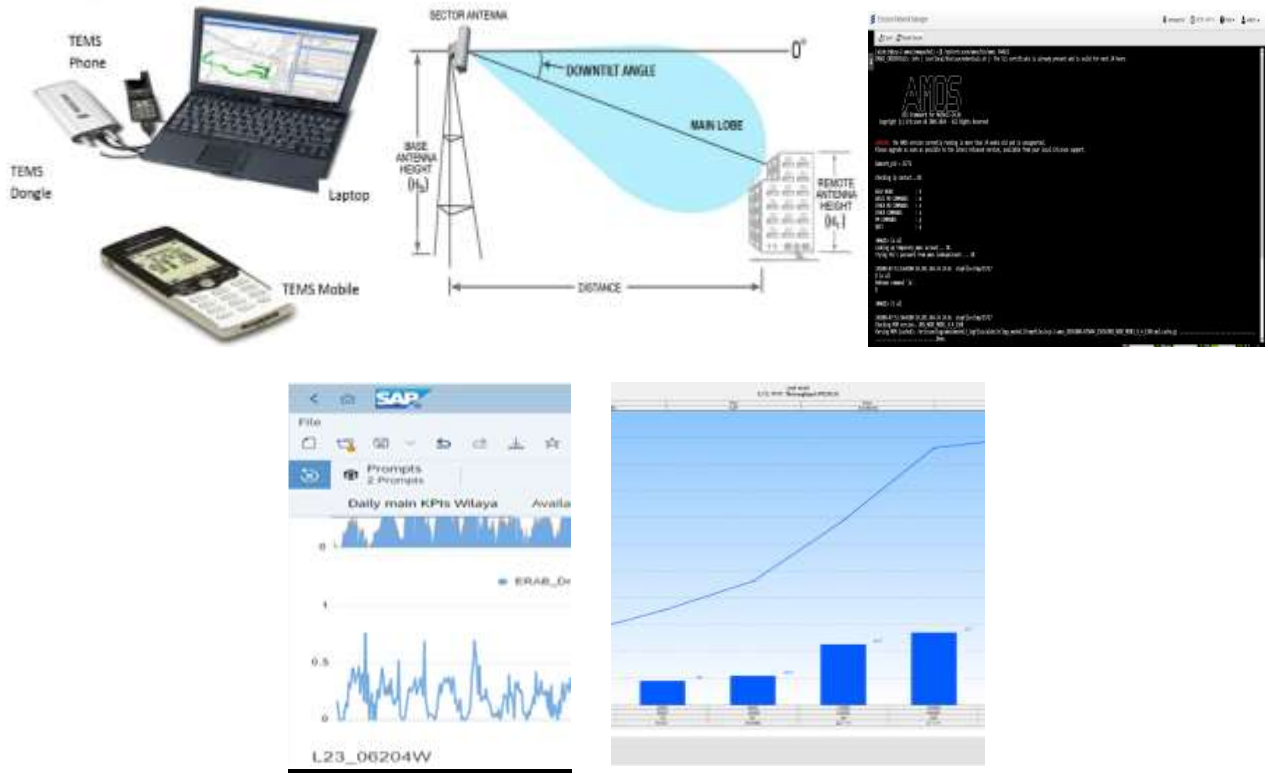


Figure 4. Main Steps of the radio-optimization process.

3.2 Antenna tilt

Antenna tilt is an important network parameter in wireless communication systems that significantly influences system performance and capacity. By adjusting the tilt angle, the radiation pattern of the antenna can be steered vertically, allowing the radiated energy to be redistributed toward a desired coverage region. This improves the efficiency of coverage control and helps in reducing interference in cellular networks. Antenna tilt is defined as the

angle of the main beam of the antenna with respect to the horizontal plane, where positive and negative values correspond to downtilt and uptilt, respectively. Antenna downtilt can be achieved using either mechanical or electrical methods. While mechanical tilt is achieved through physical adjustment of the antenna's mounting angle, electrical tilt is realized by adjusting the antenna phase shifter to modify the vertical radiation pattern of the main beam [13], enabling uniform beam steering in all azimuth directions without any physical intervention, as illustrated in Fig. 6.

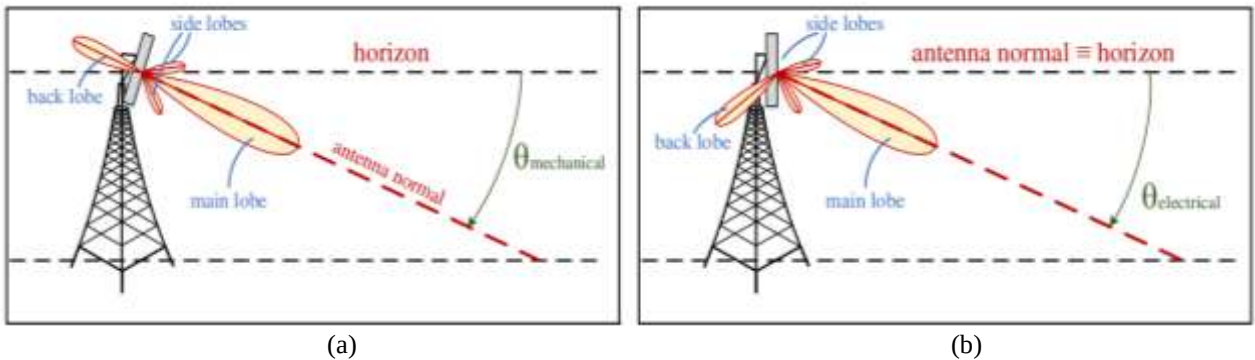


Figure 5. Mechanical downtilt in (a) and electrical downtilt in (b) [14].

The antenna radiation pattern can be obtained using two-dimensional (2D) horizontal and vertical pattern approximations. The horizontal (azimuth) and vertical (elevation) patterns are given by [12].

$$B_H(\phi) = -\min \left\{ \xi, 12. \left(\frac{\phi - \phi_0}{\Phi_{3dB}} \right)^2 \right\} \quad (\text{Azimuth}) \quad (1)$$

$$B_V(\theta) = -\min \left\{ \xi, 12. \left(\frac{\theta - \theta_t}{\Theta_{3dB}} \right)^2 \right\} \quad (\text{Elevation}) \quad (2)$$

The combined three-dimensional (3D) antenna pattern is expressed as:

$$B_{3D}(\phi, \theta) = -\min \{ [\xi, -(B_H(\phi) B_V(\theta))] \} \quad (3)$$

In (1) and (2), Φ_{3dB} and Θ_{3dB} are the half-power (3 dB) beamwidths of the main lobe in the horizontal and vertical planes, respectively, Φ_o is the azimuth offset, Θ_t is the electrical tilt angle, and ξ is the backward attenuation factor, which varies depending on the clutter type of the considered environment.

The electrical tilt angle can be expressed based on the geometric relationship between the base station and the mobile station as:

$$\theta = \arctan\left(\frac{h_{ant} - h_{mob}}{d}\right) \quad (4)$$

where, θ represents the electrical tilt in degree, h_{ant} denotes the antenna height, h_{mob} denotes the mobile station height and d is the distance between the mobile station and the BTS.

$$SINR(dB) = 10 \times \log_{10}\left(\frac{P_{signal}}{(P_{interference} + P_{noise})}\right) \quad (5)$$

Increasing down tilt concentrates energy closer to the base station, which can improve SINR by reducing interference but may reduce coverage at the cell edge. Conversely, reducing tilt extends coverage range but may lead to overshooting, where the signal propagates beyond the intended coverage area, increasing interference to neighboring cells and potentially lowering SINR. Therefore, antenna tilt introduces a trade-off between coverage and SINR performance, as changes in tilt affect both signal distribution and interference levels. SINR (Signal-to-Interference-plus-Noise Ratio) measures signal quality relative to interference and noise, where higher values indicate better throughput.

4. Effect of antenna configurations at the covered area

Electrical tilt and antenna height affect the coverage area, as illustrated in the following simulated cases, where the coverage extent is represented by the distance d .

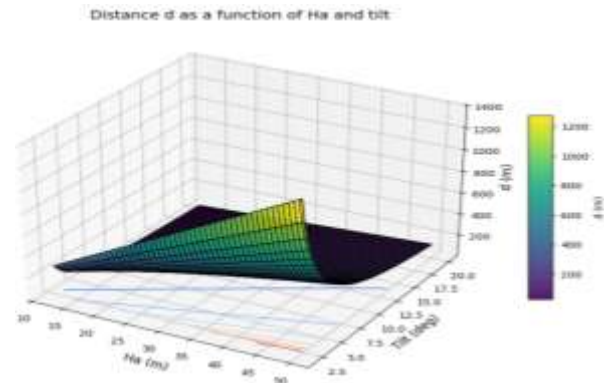


Figure 6. Effect of Antenna tilt and Antenna height on the distance of covered area (Tilt: 2 to 12 and H_a : 10 & 60 m).

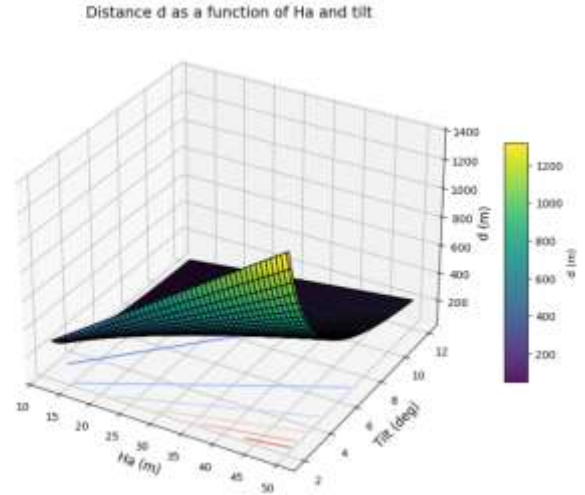


Figure 7. Effect of antenna tilt and antenna height on the distance of covered area (Tilt: 2 to 12 and H_a : 10 & 50 m).

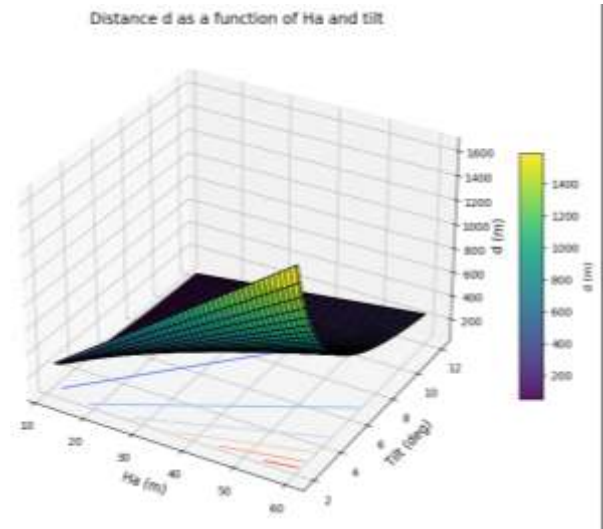


Figure 8. Effect of Antenna tilt and Antenna height on the distance of covered area (Tilt: 2 to 12 and H_a : 10 & 60 m).

Fig. 7, Fig. 8, and Fig. 9 present the results of a Python-based simulation illustrating the effect of electrical tilt as a function of distance d and antenna height H_a for different mobile network radio configurations. Fig. (7) depicts antennas with heights ranging from 10 m to 50 m and tilt angles between 2° and 20° , achieving a coverage radius of up to 1400 m. Figure 7 shows the impact of tilt angles ranging from 2° to 12° on signal distribution. Figure 8 highlights the influence of antenna heights up to 60 m under specific configurations, achieving a coverage radius of up to 1600 m. These results help to identify the optimal tilt settings for maximizing coverage and ensuring proper orientation of the antenna's main lobe, thereby improving energy efficiency and quality of service.

5. Drive test measurements

A drive test was first conducted to identify cells affected by overshooting and to evaluate radio performance across different technologies. The assessed parameters included RxLev and RxQual for GSM/2G, RSCP and Ec/No for UMTS/3G, and RSRP, RSRQ, SINR, and throughput for LTE/4G. As shown in Fig. 9, the measured GSM/2G Timing Advance (TA) value reached 22, corresponding to an estimated coverage distance of approximately 12.1 km ($TA \times 550 \text{ m} \approx 12100 \text{ m}$). In an urban environment, where the typical cell coverage radius is generally 2–3 km, a TA value of 22 is exceptionally high and clearly indicates overshooting. As shown in Fig. 9, some cells extend well beyond their theoretical service areas, leading to increased inter-cell interference, degraded radio quality and suboptimal handovers, which negatively impact the user experience. After analyzing logs, KPIs and field measurements, and considering prior tilt simulations, electrical tilt adjustments are implemented on the affected cells. These

adjustments aim to reduce excessive coverage, refocus signal strength within the intended area, improve cell dominance, and minimize interference. This optimization enhances voice and data performance across 2G, 3G, and 4G networks, achieving a better balance between coverage, quality, and capacity while improving the overall network stability. The Timing advance represents the distance between a MS and BTS. This is one of the most important parameters estimated by the network during a communication. The TA takes scaled values from 0 to 62 (62 is the maximum value, it corresponds to 35 Km). In Fig. 10, a drive test snapshot illustrates a Timing advance of 22, which corresponds to a distance of 12 Km in 2G technology. This value means that we have an overshooting in the area of interest. For that the RxQual is 18.10, which is highlighted in red color. An electrical tilt must be done in the BTS to avoid this phenomenon.

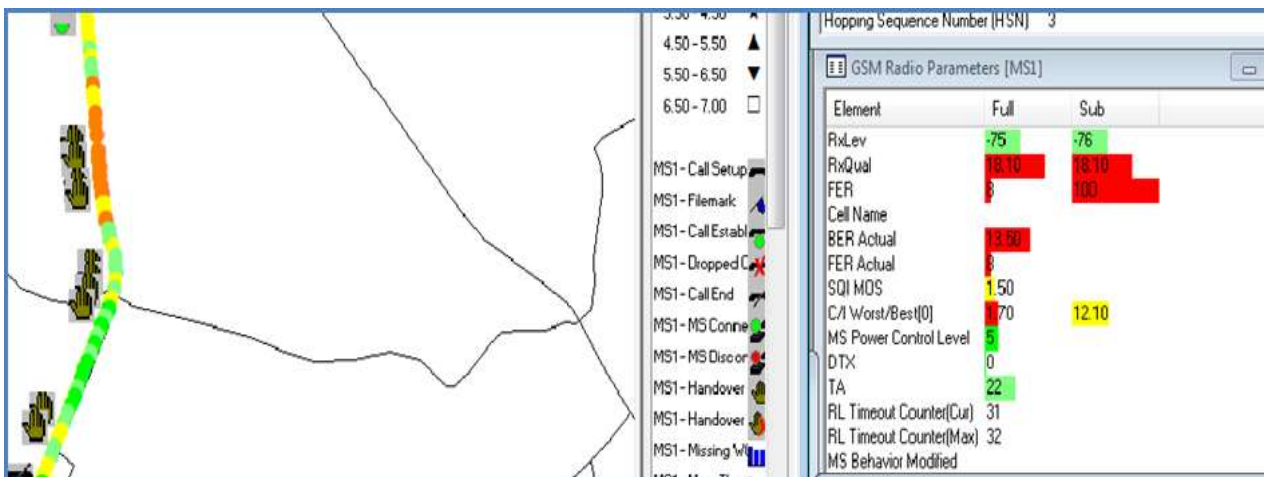


Figure 9. GSM/2G TA timing advance measurements.

5.1. Drive test in a given area

The drive test and practical optimization process were conducted in the wilaya of Bejaia shown in Fig.11, located in northeastern Algeria. These operations were carried out to assess network performance under real field conditions and to implement targeted optimization measures aimed at improving coverage quality, signal strength, and overall service reliability. As a result, a significant improvement in throughput was achieved, ensuring higher data rates, better user experience, and more stable connectivity across the region.

Scenario:

- MS1: 2G Long Call
- MS2: 3G Long Call
- MS3: 4G DATA

- MS4: Free DATA
- **6. TA of the serving cell before and after tilt**
- In this study, Atoll was used for mobile radio network planning and simulation. It enables accurate modeling of radio wave propagation, allowing evaluation of base station coverage within a specific geographic area. The tool allows configuration of various site parameters, including supported technologies (2G, 3G, and 4G), antenna types, and key radio parameters such as transmit power, azimuth, and antenna tilt. The tool also supports different radio configurations, including horizontal beamwidth antenna (HBA) setups.

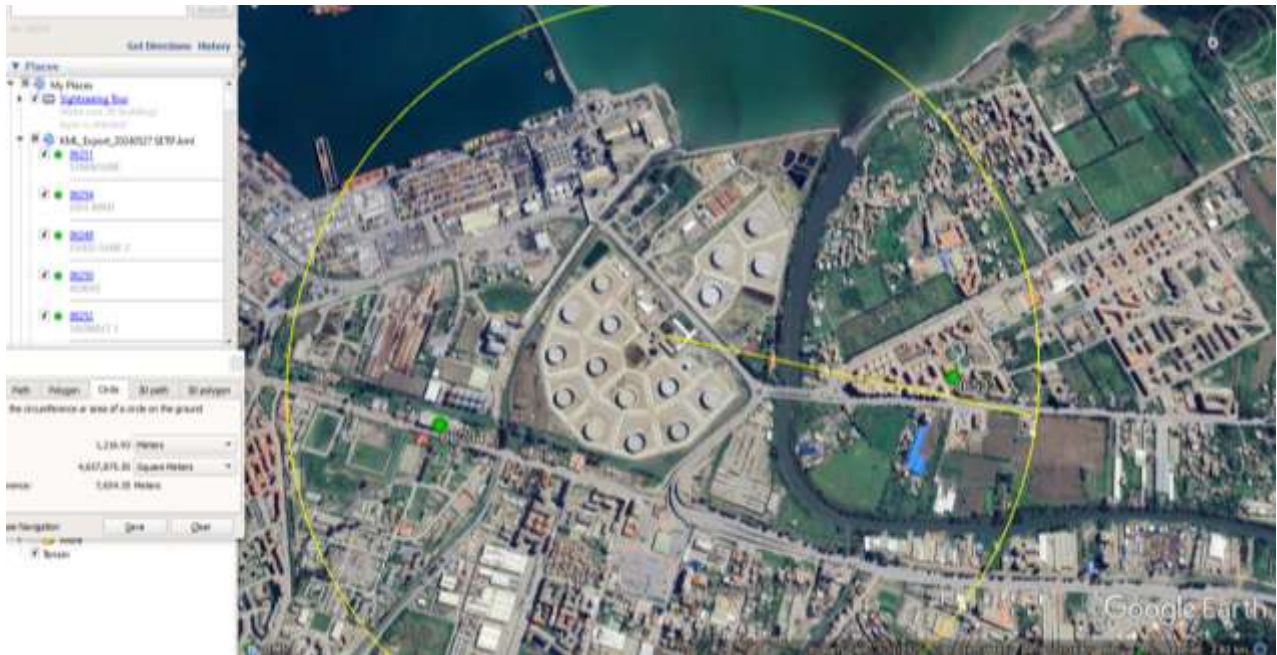


Figure 10. Area of interest for drive test measurements.

In the practical case study, the optimization targeted at the area of interest. The radio configurations of the main sites, 06204 and 06533, were integrated into the Atoll simulation environment, as illustrated in Fig. 12.

This simulation complements a preliminary analysis conducted in Python, which focused on optimizing the electrical tilt. Together, these two approaches contribute to more accurate optimization through better selection of radio parameters, particularly tilt adjustments. To further assess the optimization outcome, drive test measurements and KPIs collected before and after optimization are evaluated.

As shown in Table 1, the maximum TA value decreased after tilt optimization, particularly for cell 06102, where it was reduced from 22 to 6. This

reduction indicates improved coverage control and confirms the effectiveness of electrical tilt adjustment in mitigating cell overshooting.

Table 1 - Maximum TA Before and After Tilt Optimization.

Table 1. Maximum TA Before and After Electrical Tilt Optimization.

Cell serving	Max TA (before)	Max TA (after)
06102	22	6
06533	4	2
06664	8	4
061002	10	2
06204	4	2

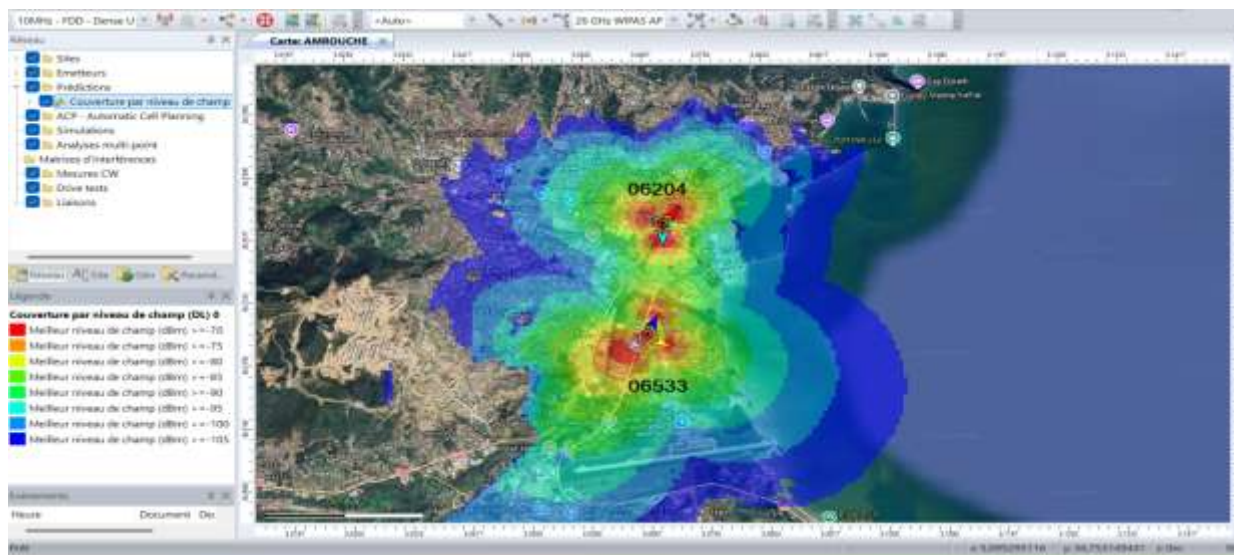


Figure 11. Simulation with ATOLL of the dominant sites in the coverage area, mainly 06204 and 06533.

7. Drive test measurements before and after tilt

7.1. Drive tests for different gene-rations

Fig. 13, Fig. 14, and Fig. 15 present the drive test results before and after the application of electrical tilt for 2G, 3G, and 4G networks, respectively. These

results indicate improvements in coverage, signal strength, and signal quality after applying the optimal tilt values. The optimization also reduced cell overshooting, improved handover (HO) performance between neighboring cells, and mitigated the ping-pong effect in the optimized area.



(a): Before Tilt.



(b): After Tit.

Figure 12. Drive test 2G call Before and after Antenna Tilt.



(a): Before Tilt.



(b): After Tilt.

Figure 13. Drive test for 3G call Before and After Antenna Tilt.



(a): Before Tilt.



(b): After Tilt.

Figure 14. Drive test for 4G call Before and After Antenna Tilt.

7.2. Optimization kpis for different generations

The results presented in Table 2 indicate an overall improvement in network performance across 2G,

3G, and 4G technologies after the application of electrical tilt. In 2G, the outdoor signal level (RxLev) improved from -82.31 dBm to -78.13 dBm, while the signal quality (RxQual) showed a

significant enhancement from 1.65 to 0.7. In 3G, the outdoor signal strength (RSRP) increased from -86.54 dBm to -83.37 dBm, accompanied by an improvement in quality (Ec/Io) from -15.99 dB to -14.34 dB. In 4G, notable enhancements were observed, with RSRP improving from -102.88 dBm to -99.18 dBm, RSRQ from -19.86 dB to -18.77 dB, and SINR from -2.79 dB to -1.25 dB, indicating clear improvement in radio conditions. Consequently, the downlink throughput (DL throughput) increased significantly, rising from 10,220.88 Kbps to 16,269.87 Kbps in outdoor scenarios.

Indoors, several areas also showed considerable improvements were observed, particularly in 4G throughput, which reached up to 11,307.09 Kbps compared to 1,218.32 Kbps before optimization in certain locations. Additionally, the results indicate a shift toward 4G utilization reaching up to 100%, indicating better radio resource management and reduced dependence on legacy technologies. Nevertheless, slight performance degradation was observed in some indoor areas, which can be attributed to the intentional reduction of cell overshooting resulting from the applied electrical tilt.

Table 2. Measurement and improvement of 2G, 3G and 4G KPIs before and after electrical tilt implementation in outdoor and indoor areas.

KPIs	Outdoor KPIs Before	Outdoor KPIs After	1 st area Indoor 1 Before	1 st area Indoor 1 After	1 st area Indoor 2 Before	1 st area Indoor 2 After	1 st area Indoor 3 Before	1 st area Indoor 3 After
2G Long Call Average RxLev	-82.31	-78.13	-89.33	-87.57	-80.22	-88.08	-84.27	-78.37
2G Long Call Average RxQual	1.65	0.7	3.1	0.77	0.12	0.37	0.62	1.55
3G Long Call Average RSCP	-86.54	-83.37	-94.2	-99.79	-99.16	-94.43	-107.41	-97.94
3G Long Call Average Ec/Io	-15.99	-14.34	-13.62	-16.37	-19.18	-15.31	-18.55	-16.19
4G Data Average RSRP	-102.88	-99.18	-116.11	-115.09	-112.95	-115.18	-120.37	-112.13
4G Data Average RSRQ	-19.86	-18.77	-18.14	-20.1	-21.77	-19.4	-23.39	-23.28
4G Data Average SINR	-2.79	-1.25	-4.3	-4.93	-7.59	-3.26	-7.11	-6.28
4G Data DL Throughput Average (Kbps)	10220.88	16269.87	1044.97	2040.78	1218.32	11307.09	1704.86	6384.28
Free Data DL Throughput Average (Kbps)	4G (95.34%) 9584.55	4G (100%) 14154.14	4G (100%) 1211.42	4G (100%) 1323.86	4G (100%) 2445.79	4G (100%) 1687.61	2G (100%) 39.75	4G (100%) 2918.83

Overall, the optimization process has effectively enhanced network coverage, improved quality of service, and delivered a better user experience. The results presented in Table 3, corresponding to the second indoor area, indicate mixed performance variations after the application of electrical tilt. In 2G, the signal level (RxLev) improved in both zones, increasing from -83.78 dBm to -80.75 dBm in Indoor Area 1 and from -90.63 dBm to -86.64 dBm in Indoor Area 2. However, the quality (RxQual) showed contrasting behavior, with a degradation in Indoor Area 1 (from 2 to 3.69) and a significant improvement in Indoor Area 2 (from 1.47 to 0.38). In 3G, the signal strength (RSCP) improved in Indoor Area 1 from -97.28 dBm to -93.62 dBm, while it degraded in Indoor Area 2 from -99 dBm to -105.9 dBm. Nevertheless, the quality indicator

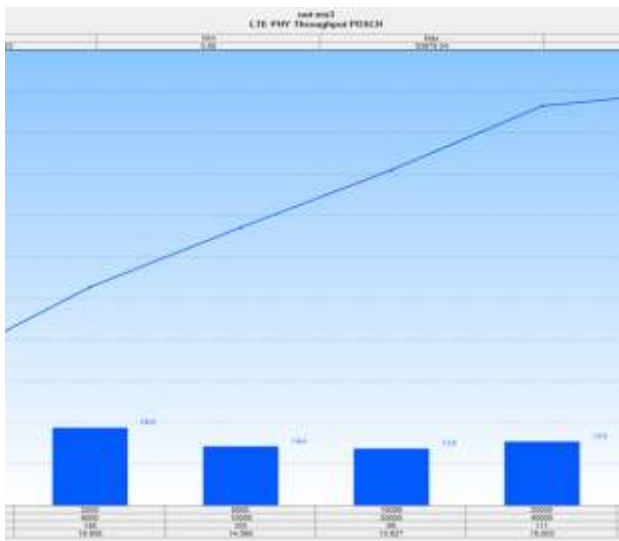
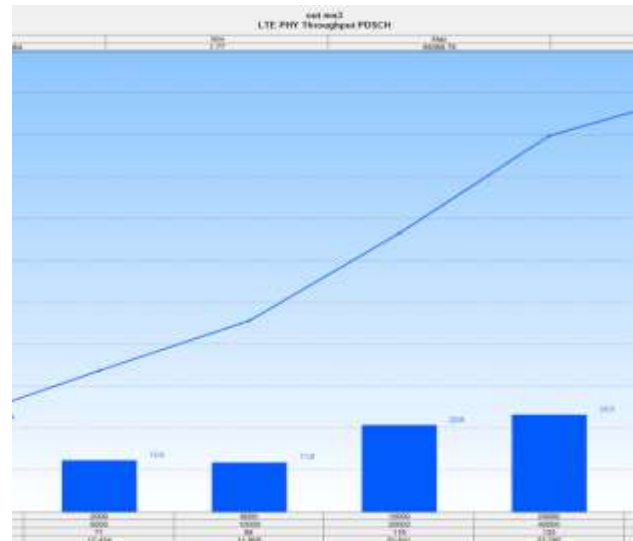
(Ec/Io) improved in both areas, from -21.21 dB to -19.11 dB and from -18.85 dB to -17.99 dB, respectively. In 4G, the results indicate improvements in certain key indicators, particularly in Indoor Area 2, where RSRP improved from -111.33 dBm to -108.65 dBm, RSRQ from -20.49 dB to -17.85 dB, and SINR significantly increased from -3.62 dB to -0.99 dB. However, Indoor Area 2 experienced degradation in RSRP (from -108.22 dBm to -119.95 dBm) and RSRQ (from -19.02 dB to -21.16 dB), although SINR improved from -5.1 dB to -2.21 dB. In terms of throughput, Indoor Area 1 recorded a decrease from 5498.71 Kbps to 2789.03 Kbps, whereas Indoor Area 2 showed a clear improvement from 778.54 Kbps to 1777.37 Kbps. Furthermore, the analysis confirms that 4G remains the dominant technology with 100% utilization in

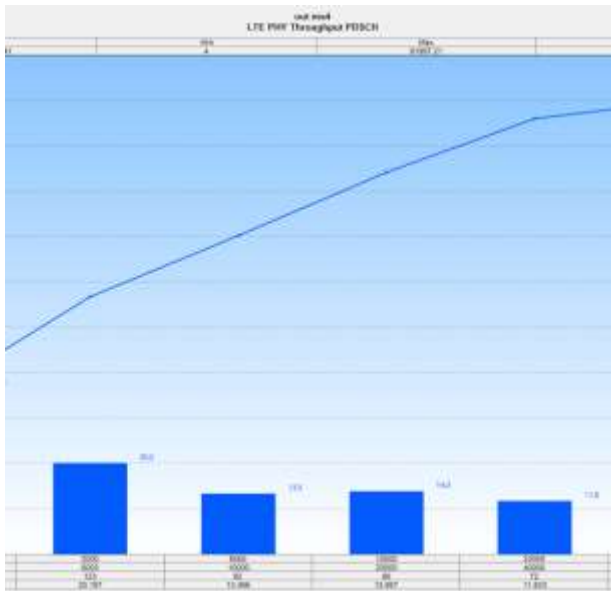
Table 3. Measurement and improvement of 2G, 3G and 4G KPIs before and after electrical tilt implementation in indoor areas.

KPIs	2 nd area Indoor 1 Before	2 nd area Indoor 1 After	2 nd area Indoor 2 Before	2 nd area Indoor 2 After
2G Long Call Average RxLev	-83.78	-80.75	-90.63	-86.64
2G Long Call Average RxQual	2	3.69	1.47	0.38
3G Long Call Average RSCP	-97.28	-93.62	-99	-105.9
3G Long Call Average Ec/Io	-21.21	-19.11	-18.85	-17.99
4G Data Average RSRP	-111.33	-108.65	-108.22	-119.95
4G Data Average RSRQ	-20.49	-17.85	-19.02	-21.16
4G Data Average SINR	-3.62	-0.99	-5.1	-2.21
4G Data DL Throughput Average (Kbps)	5498.71	2789.03	778.54	1777.37
Free Data DL Throughput Average (Kbps)	4G (100%) 3718.05	4G (100%) 1630.86	4G (100%) 2487.9	4G (100%) 1246.42

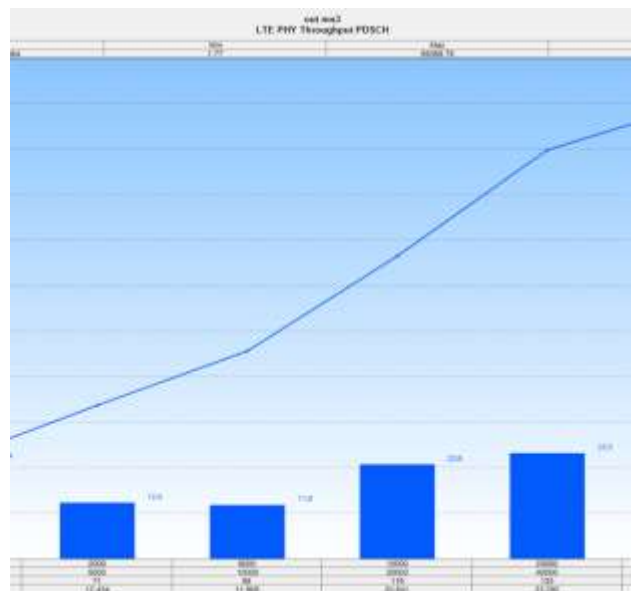
both areas, reflecting consistent LTE prioritization. Overall, the applied electrical tilt led to performance improvements in several KPIs, especially in signal quality (Ec/Io, SINR). However, some localized degradations in signal strength and throughput were observed, which can be attributed to coverage reshaping and cell overshooting reduction.

To show the effect of electrical tilt, LTE throughput statistics are given before and after the optimization process and also in outdoor (Fig. 16) and indoor tests. In the same manner, a good enhancement in free data DL Throughput is also recorded as demonstrated in Fig. 17.

**(a):** Before optimization (averaging 10.22 Mbps).**(b):** After optimization (averaging 16.26 Mbps).**Figure 15.** LTE Throughput Before and After optimization (outdoor test).



(a): Before optimization (averaging 9.58 Mbps).



(b): After optimization (averaging 14.15 Mbps).

Figure 16. Free data DL Throughput Before and After optimization (in Mbps).

7.3. Validation kpi after optimiza-tion with sap

The snapshot below (presented in Fig. 18) illustrates the used methodology for extracting and analyzing the optimized KPIs following to the application of

electrical tilt adjustments. The resulting performance indicators enable the assessment of the effectiveness of the implemented optimization actions and validate their compliance with the methodology as described previously in Fig. 4 & Fig. 5.



Figure 17. Methodology for KPI Extraction, Analysis, and Optimization in SAP.

Figure 19 illustrates the improvement of the main KPIs after the implementation of the electrical tilt optimization on Sites of interest (06533 and 06204), as summarized in the attached table (highlighted in black). The results show good enhancements across several performance indicators, including accessibility, traffic handling, and handover (HO)

success rate. A notable improvement is also observed in both downlink (DL) and uplink (UL) throughput, which confirming the effectiveness of the optimization actions performed on the serving site covering the area of interest (Sites 06533 and 06204).

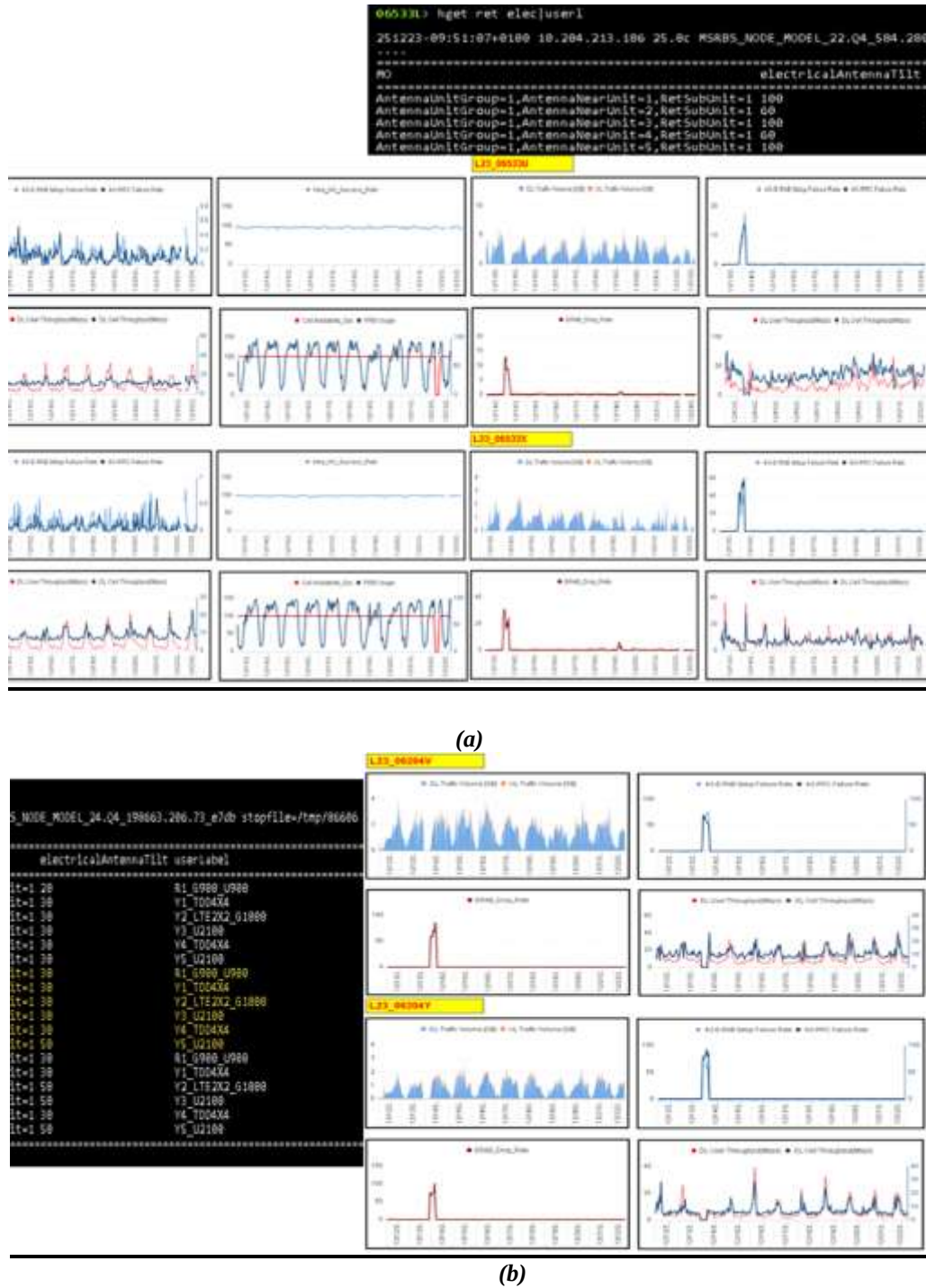


Figure 18. Optimization of KPI in SAP with Applied Electrical Tilt in sites of interest, (a): Site 06533 and (b): Site 06204

The drive test was conducted in the city of BEJAIA, Algeria, to evaluate radio network performance before and after optimization. Following the identification of overshooting cells, an optimization process based on radio simulation (Business Objects/SAP) and electrical tilt adjustment was applied across the three technologies: 2G, 3G, and 4G. The comparative KPI analysis highlights a significant overall improvement. In outdoor conditions, the average 4G throughput increased from approximately 10.2 Mbps to 16.3 Mbps,

representing a gain of about 60%, accompanied by an improvement in RSRP ($\approx +3.7$ dB) and SINR, reflecting reduced interference and enhanced spectral efficiency. Indoors, the gains in 4G throughput were even more substantial: in Zone 1, throughput doubled (≈ 1 Mbps to 2 Mbps); in Zone 2, it increased by nearly nine times (≈ 1.2 Mbps to 11.3 Mbps); and in Zone 3, it improved by approximately 3.7 times (≈ 1.7 Mbps to 6.4 Mbps). These improvements are closely linked to the optimization of radio coverage and quality

parameters, including increases in RXLev, RSCP, and RSRP, as well as enhancements in Rxqual, Ec/Io, and SINR, which are essential for ensuring stronger cell dominance, reduced inter-cell interference, and a more stable user experience. This optimization methodology, successfully implemented across 2G, 3G, and 4G networks, has been generalized to other areas and can be adapted for future 5G network optimization. Furthermore, this research is based on both a theoretical approach using radio simulation and practical validation through real drive test measurements conducted before and after optimization. The results were also validated using Business Objects SAP KPIs, thereby strengthening the scientific and operational credibility of the study.

8. Conclusion

This paper presented a structured radio network optimization methodology applied to a local operator in Algeria for three mobile network generations (2G, 3G, and 4G), which allowed to evaluate performance before and after optimization. The approach integrates drive test measurements, radio coverage simulations using the ATOLL planning tool, and controlled electrical antenna tilt adjustments implemented through Ericsson ENM/AMOS. After identifying overshooting cells, an optimization process based on radio simulation and electrical tilt reconfiguration was applied across all three technologies, effectively mitigating overshooting while maintaining coverage continuity. Post-optimization evaluations, based on drive test measurements and key performance indicators from Business Objects SAP, demonstrated significant improvements in signal strength, signal quality, handover performance, and user throughput, along with reduced interference. Outdoor 4G throughput increased from approximately 10.2 Mbps to 16.3 Mbps ($\approx 60\%$ gain), accompanied by an improvement in RSRP ($\approx +3.7$ dB) and SINR, reflecting reduced interference and better spectral efficiency. Indoor performance gains were even more pronounced: Zone 1 throughput doubled (≈ 1 Mbps $\rightarrow$ 2 Mbps), Zone 2 increased nearly nine-fold (≈ 1.2 Mbps $\rightarrow$ 11.3 Mbps), and Zone 3 improved by ≈ 3.7 times (≈ 1.7 Mbps $\rightarrow$ 6.4 Mbps). These enhancements are linked to improvements in RXLev, RSCP, RSRP, Rxqual, Ec/Io, and SINR, ensuring stronger cell dominance, lower inter-cell interference, and a more stable user experience. The methodology, validated both theoretically through simulation and practically via drive tests, demonstrates high operational reliability. Applied successfully across 2G, 3G, and 4G networks, it provides a scalable framework for

national deployment. Future work will extend this methodology to 5G NR networks, considering their propagation characteristics, massive MIMO configurations, and beamforming techniques, ensuring continued quality of service in next-generation networks.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
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