

4G/5G Radio Quality Evaluation at Brazilian University Campuses: A Case Study

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Abstract—This study examines 4G and 5G mobile network coverage and link quality on a Brazilian university campus. Empirical cumulative distribution functions of the reference signal received power (RSRP)/synchronization signal reference signal received power (SS-RSRP) and the signal-to-interference-plus-noise ratio (SINR) are employed to assess coverage and link quality in both indoor and outdoor environments. Measurement campaign results indicate that indoor areas remain insufficiently covered, while higher RSRP/SS-RSRP values in outdoor settings do not consistently yield proportional improvements in SINR, suggesting interference-limited operation. These results underscore the need to implement new strategies to enhance mobile network coverage and link quality on a university campus.

Keywords—Fifth-generation, fourth-generation, mobile network, coverage, link quality, university campus.

I. INTRODUCTION

Fourth generation (4G) and Fifth generation (5G) mobile networks constitute critical infrastructure for modern communications, enabling connectivity not only among people but also among machines, sensors, and devices in Internet of Things (IoT) and Industry 4.0 applications. As these technologies, referred to as Long Term Evolution (LTE) and New Radio (NR), respectively, continue to be deployed across increasingly diverse environments, evaluating their coverage and radio-link performance becomes essential to ensure service continuity, reliable connectivity, and satisfactory quality of experience.

The evaluation of coverage and link quality in 4G and 5G mobile networks relies on standardized key performance indicators (KPIs). The reference signal received power (RSRP) characterizes mobile coverage conditions by quantifying the received power of reference signals, whereas the signal-to-interference-plus-noise ratio (SINR) describes the effective link quality in the presence of interference and noise [1], [2]. The joint analysis of these KPIs enables the identification of coverage-limited and interference-limited regimes, which is fundamental for understanding mobile network performance and for supporting radio-network planning and optimization.

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Numerous radio-measurement studies have characterized 4G and 5G mobile-network coverage across urban, rural, and indoor environments; see [3] and references therein. With respect to university campuses, a few studies have also assessed mobile network performance on these campuses [4]–[6]; however, there remains a need for comprehensive measurement campaigns to characterize mobile coverage and link quality across multiple operators, technologies, and propagation scenarios.

To address this gap, this study analyzes the mobile coverage and link quality of 4G LTE and 5G NR networks operated by the existing mobile network operators on the Federal University of Juiz de Fora (UFJF) campus, in Juiz de Fora, Brazil. Based on a dedicated measurement campaign, RSRP, synchronization signal reference signal received power (SS-RSRP) and SINR measurements were collected in indoor and outdoor environments. Following a distribution-based analysis aligned with International Mobile Telecommunications (IMT) evaluation guidelines [7], the empirical cumulative distribution functions (ECDFs) [8] of the measured RSRP/SS-RSRP and SINR values are used to quantify coverage and link quality for 4G and 5G networks. The results show that indoor environments remain insufficiently covered, as indicated by the high probability of low RSRP/SS-RSRP values. In contrast, outdoor environments more often exhibit high received power levels; however, these coverage gains do not necessarily translate into proportional link-quality improvements, due to the persistent probability of low SINR values. Overall, the results indicate that coverage is mainly constrained indoors, whereas link quality requires further improvement outdoors.

II. FUNDAMENTALS OF RADIO QUALITY EVALUATION

Radio quality can be assessed by evaluating mobile coverage and link quality through specific KPIs related to received power and SINR. In both LTE and NR, these KPIs are derived from reference signals transmitted by the base station (BS). Since these signals are predefined and known by the user equipment, they enable standardized and comparable measurement procedures. In LTE, the cell-specific reference signal (CRS) supports channel estimation and power measurements, whereas in NR, the synchronization signal block (SSB) supports cell discovery, synchronization, and beam-based measurements [1], [2]. These reference signals are mapped onto orthogonal frequency-division multiplexing (OFDM) resource elements (REs), which represent the smallest time–frequency units in the resource grid, corresponding to one subcarrier over one OFDM symbol.

Mobile coverage is evaluated from the received signal power, quantified by the RSRP. This KPI is fundamental for assessing signal availability, supporting cell selection, and characterizing network coverage. In both LTE and NR, RSRP/SS-RSRP¹ can be estimated as the average received power over the REs carrying reference signals [1], [2], [9]. Since RSRP is associated with specific reference signals, it is less sensitive to instantaneous traffic loading than wideband received-power KPIs, such as received signal strength indicator (RSSI). Therefore, it is widely used as a coverage indicator, reflecting large-scale propagation effects, including path loss, shadowing, and penetration loss.

Although RSRP/SS-RSRP characterizes the received signal power, it does not account for interference and noise. For this reason, link quality is evaluated through the SINR, defined as the ratio between the desired signal power and the combined interference-plus-noise power. In practice, SINR is estimated from reference-signal measurements and receiver processing, allowing the useful signal component to be assessed relative to interference and thermal noise. This KPI directly affects the efficiency with which the radio link supports data transmission and, consequently, the achievable throughput. It is also closely related to the selection of the modulation and coding scheme (MCS), which determines the spectral efficiency and data rate supported by the link. Thus, SINR reflects the effective link quality and the ability of 4G and 5G systems to sustain reliable data communication in the presence of interfering signals.

III. MEASUREMENT CAMPAIGN

To analyze the mobile coverage and link quality provided by existing 4G and 5G mobile network operators, a measurement setup was built to carry out the campaign on the UFJF campus in Juiz de Fora.

The measurement setup used in the campaign is illustrated in Fig. 1. It consists of a Global Positioning System (GPS) antenna, a receiver antenna, and a Rohde & Schwarz TSM-6B mobile network scanner [10]. The scanner measures the received signal and estimates its power and SINR KPIs by demodulating the aforementioned reference signals, while the collected data are post-processed using the SmartAnalytics software from Rohde & Schwarz [11]. All KPIs based on the power of received signals are obtained following the corresponding 3rd Generation Partnership Project (3GPP)/European Telecommunications Standards Institute (ETSI) physical-layer measurement definitions for LTE and NR [1], [2].



Fig. 1: Measurement setup: a GPS antenna, a TSM-6B mobile network scanner, a receiver antenna, and a laptop.

¹In NR, this KPI is commonly referred to as SS-RSRP, as it is derived from synchronization signal block resources.

The UFJF campus occupies approximately 1.3 km² and presents a heterogeneous propagation environment due to its irregular terrain and pronounced altitude variation between 880 and 960 m. Outdoor measurements covered the campus route shown in Fig. 2, where the black line represents the measurement path, while indoor measurements were conducted inside the Engineering School building. The campaign was carried out during the academic break, when the lower number of users led to mobile network traffic below typical levels and may have reduced inter-cell interference. Although RSRP is defined as the received power of the reference signal and does not explicitly account for interference and noise, the academic-break condition reduces randomness in its estimation process. In the indoor scenario, 14,149 LTE and 623 NR measurements were collected across three floors, capturing signal behavior under various structural conditions. In the outdoor scenario, 25,598 LTE and 2,130 NR measurements were collected over approximately 9.5 km of continuous traversal across diverse propagation scenarios and geographical areas within the campus.

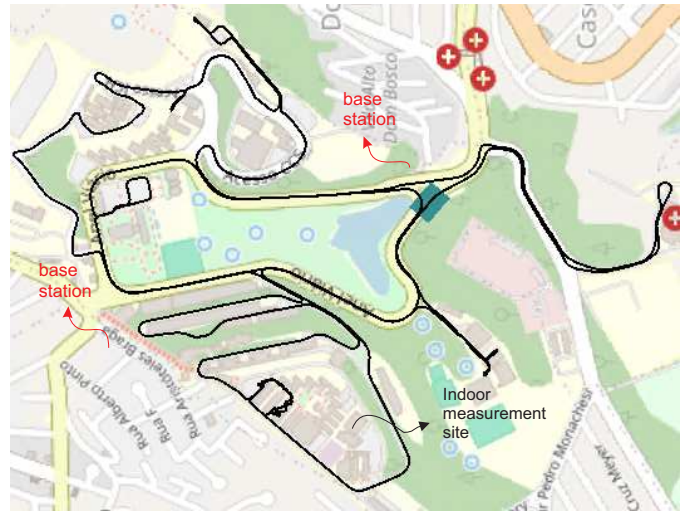


Fig. 2: The UFJF campus. The black lines indicate the routes used in the measurement campaign.

IV. NUMERICAL RESULTS

This section presents the numerical results from the measurement campaign carried out to collect data on 4G and 5G technologies used by mobile network operators. In this sense, measured values of RSRP and SINR for LTE and NR systems from existing mobile network operators were analyzed using ECDFs, with separate assessments for indoor and outdoor environments. Table I presents the RSRP and SINR thresholds used to classify channel as “Poor”, “Moderate”, “Good”, or “Excellent”, following the ECDF interpretation available in [12]. Also, percentile-based analysis is considered because it is consistent with 3GPP/ETSI performance evaluation practice [13].

A. The Channel Inventory

The channel inventory of LTE and NR bands was first conducted to identify active carriers and existing mobile

TABLE I LIMIT VALUES OF RSRP AND SINR FOR RF CHANNEL QUALITY CLASSIFICATION.

RF Conditions	RSRP (dBm)	SINR (dB)	Percentile
Excellent	> -80	> 20	90th/95th (P_{90}/P_{95})
Good	-80 to -90	13 to 20	50th (P_{50})
Moderate	-90 to -100	0 to 13	10th (P_{10})
Poor	< -100	< 0	5th (P_5)

network operators on the UFJF campus. The inventory in Fig. 3 shows that there are three mobile network operators (VIVO, TIM, and CLARO), each with LTE deployments in LTE bands 1, 3, 7, 28/5, and 40, as well as in the NR band. This plot shows spectral fragmentation, characterized by non-contiguous frequency allocations among mobile network operators, reflecting the use of implicit guard bands to reduce adjacent-channel interference. Also, this plot reveals that in the NR n78 band, adjacent channel interference (ACI) was detected, attributed to adjacent allocations of CLARO and VIVO. The interference between them in the range between 3.365 GHz and 3.395 GHz, corresponding to a bandwidth overlap of ≈ 30 MHz. This phenomenon was systematically captured and recorded by the measurement equipment during the outdoor campaign. However, additional spectrum measurements are required to distinguish adjacent-channel interference to confirm its impact on SINR.

B. 4G/LTE Analysis

The coverage and link quality results for 4G/LTE systems are discussed as follows:

1) *Coverage Performance*: The LTE coverage performance is analyzed using the ECDFs of the measured RSRP values, as shown in Fig. 4. The indoor results in Fig. 4a exhibit strong operator- and band-dependent dispersion, indicating that building penetration loss and local propagation conditions significantly affect indoor coverage. For the low-frequency bands 28/5, which are commonly used for wide-area coverage, VIVO achieves the best indoor performance, with $P_{50} \approx -90.5$ dBm and $P_5 \approx -108.8$ dBm. Therefore, the median coverage is close to the “Good”/“Moderate” boundary, although the lower tail remains in the “Poor” region and “Excellent” coverage is rarely observed. For outdoor environments, the corresponding ECDFs shift toward higher received-power values, consistent with lower propagation losses in open environments. VIVO reaches $P_{50} \approx -96.0$ dBm and $P_5 \approx -109$ dBm, indicating that the median coverage is classified as “Moderate”.

Note that TIM exhibits the lowest performance in bands 28/5. In the indoor environment, its distribution is shifted far to the left, with $P_{50} \approx -115.3$ dBm and $P_5 \approx -120.8$ dBm. In the outdoor environment, TIM improves but remains mostly in the “Poor” condition, with $P_{50} \approx -109.5$ dBm and $P_5 \approx -119$ dBm. CLARO shows intermediate indoor coverage, with $P_{50} \approx -111.6$ dBm and $P_5 \approx -125.0$ dBm. Considering outdoor uses, CLARO improves to approximately $P_{50} \approx -99.2$ dBm and $P_5 \approx -114.3$ dBm, placing its median close to the “Poor”/“Moderate” boundary.

The higher-frequency LTE bands 1, 3, 7, and 40 are typically associated with capacity-oriented deployments, depending on

bandwidth availability and network planning. Band 40 is detected only in the outdoor scenario. In the indoor scenario, VIVO achieves median values of $P_{50} \approx -112$ to -116 dBm, with Band 1 providing the strongest coverage among the bands. In the outdoor scenario, VIVO improves substantially, reaching $P_{50} \approx -101.0$ dBm in Band 1 and $P_{50} \approx -95.0$ dBm in Band 7, with $P_5 \approx -109$ to -115 dBm across the bands. This places a relevant fraction of outdoor samples in the “Moderate” condition.

CLARO again exhibits intermediate indoor coverage in the higher-frequency bands, with $P_{50} \approx -118.6$ to -110.0 dBm and $P_5 \approx -130.0$ to -120.0 dBm. For outdoor scenario, its coverage generally improves, with median values ranging from “Poor” to “Moderate”, depending on the band. TIM shows the worst indoor coverage, especially in Band 7, where $P_{50} \approx -135.3$ dBm and $P_5 \approx -141.8$ dBm. Its other indoor bands remain around $P_{50} \approx -113$ to -118.5 dBm and $P_5 \approx -117.0$ to -125.0 dBm. For outdoor uses, TIM exhibits the largest band-dependent spread: Band 7 reaches $P_{50} \approx -107.0$ dBm and $P_5 \approx -115.0$ dBm, Bands 1/3 cluster near $P_{50} \approx -106.0$ dBm and $P_5 \approx -119.0$ dBm, and Band 40 presents the worst outdoor coverage, with $P_{50} \approx -110.0$ dBm and $P_5 \approx -125.0$ dBm.

2) *Link Quality Performance*: The LTE link quality is analyzed using the ECDFs of the measured SINR values, as shown in Fig. 5. The indoor results in Fig. 5a show pronounced operator- and band-dependent separation, indicating strong variability in indoor SINR conditions.

Note that CLARO provides the best indoor link quality among LTE Bands 1/3/7, with median values between $P_{50} = 3.6$ and 5.8 dB and lower-percentile values between $P_5 = -6.0$ and -3.1 dB. However, its performance in Bands 28/5 degrades to $P_{50} = 0.8$ dB and $P_5 = -7.1$ dB. VIVO exhibits lower medians, with $P_{50} = 2.0$ dB in Bands 1/3, $P_{50} = 3.1$ dB in Band 7, and $P_{50} = 0.0$ dB with $P_5 = -6.2$ dB in Bands 28/5. TIM presents the most degraded indoor conditions, with $P_{50} = -0.1$ dB in Bands 1 and 3, $P_{50} = -8.6$ dB in Band 7, and $P_{50} = -5.9$ dB with $P_5 = -14.8$ dB in Bands 28/5. These results indicate that, although Bands 28/5 may provide higher RSRP, they do not necessarily provide higher SINR.

In the outdoor scenario, Fig. 5b shows higher SINR values than indoors. TIM reaches the highest upper-tail values, represented by P_{95} , but the median values of the operators and bands are relatively close, around $P_{50} \approx 6.0$ dB. CLARO and VIVO present P_5 values approximately between -2.5 and 2.5 dB, whereas TIM remains more limited in Bands 1, 3, 7, and 28/5, with P_5 below -5 dB. Overall, the outdoor measurements contain a larger fraction of samples in the “Moderate” and “Good” classes. Nevertheless, several bands still exhibit low-percentile SINR values near or below 0 dB, indicating that improved coverage does not necessarily translate into proportional link-quality gains and suggesting interference-limited behavior.

C. 5G/NR Analysis

Mobile coverage and link quality for 5G NR networks operating in band n78 are analyzed using the ECDFs shown in

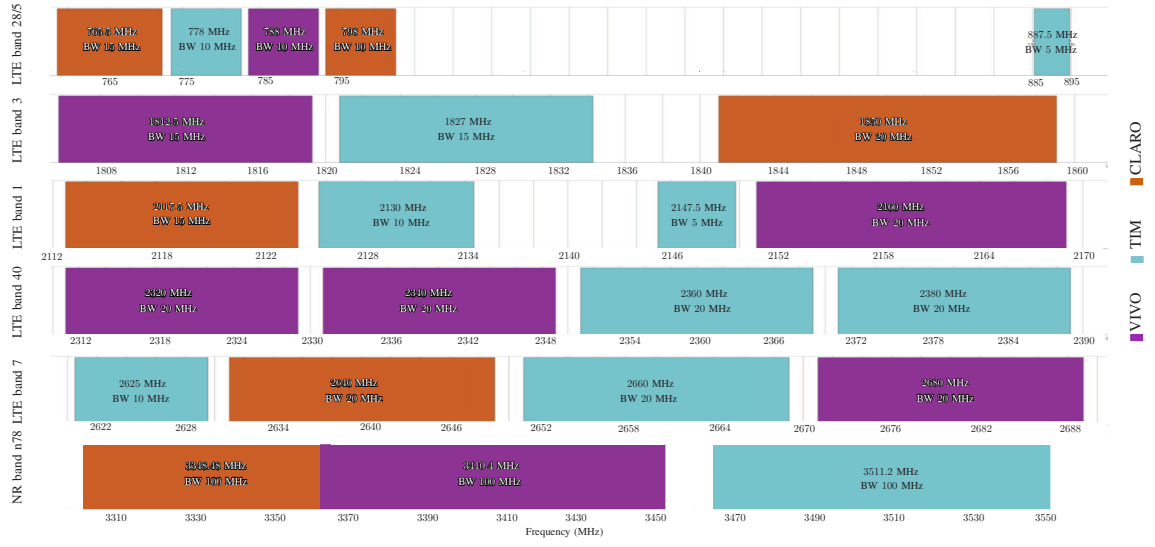


Fig. 3: The channel inventory of LTE and NR bands and mobile network operators.

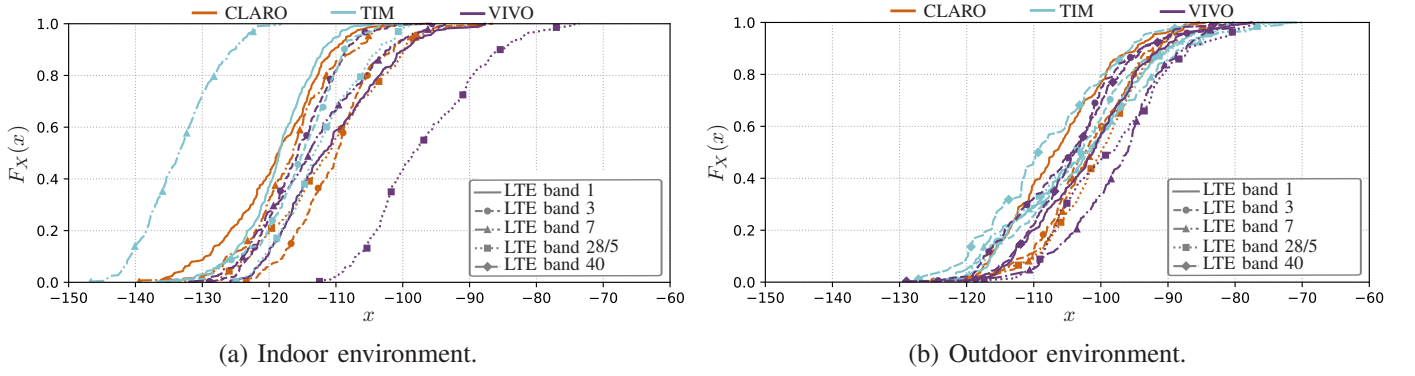


Fig. 4: ECDFs of RSRP (dBm) for 4G LTE of all mobile network operators.

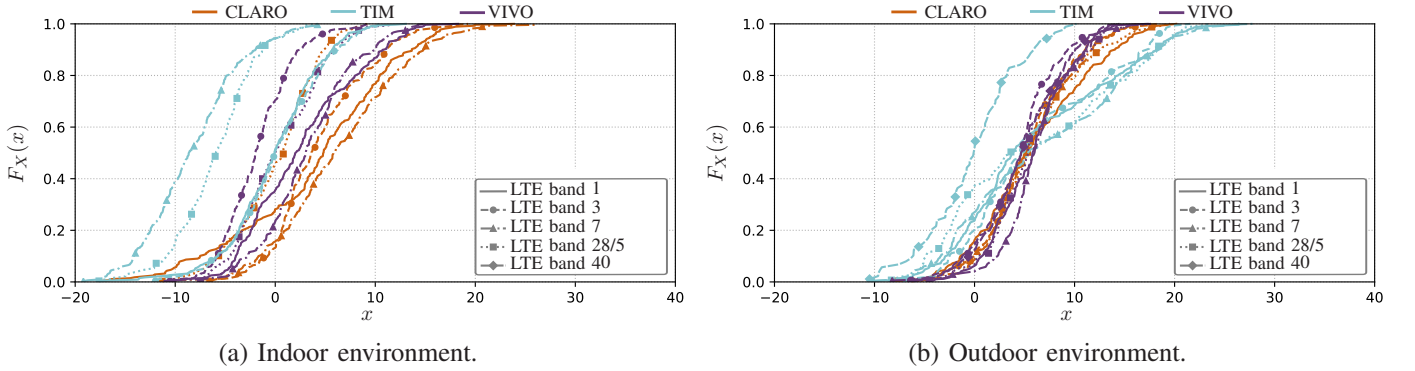


Fig. 5: ECDFs of SINR (dB) for 4G LTE of all mobile network operators.

Fig. 6. In this measurement campaign, NR was detected only in band n78 (3.3–3.8 GHz), whereas LTE was observed in multiple bands. Therefore, the NR analysis provides a single-band view per operator. Since n78 is a mid-band allocation, its performance reflects a coverage–capacity trade-off and requires careful planning for both outdoor macrocell coverage and indoor service availability.

1) *Coverage Performance*: The ECDFs of the measured SS-RSRP values are shown in Fig. 6a. In the indoor sce-

nario, CLARO provides the best NR coverage, with $P_{50} \approx -110$ dBm. TIM and VIVO exhibit lower indoor received power levels, with medians of $P_{50} \approx -113$ dBm and $P_{50} \approx -118$ dBm, respectively. The lower tail remains severely degraded for all operators, with P_5 typically between -130 and -120 dBm. These results indicate frequent edge-of-coverage or penetration-limited indoor conditions, with no relevant occurrence of “Good” or “Excellent” coverage.

In the outdoor scenario, the ECDFs shift toward

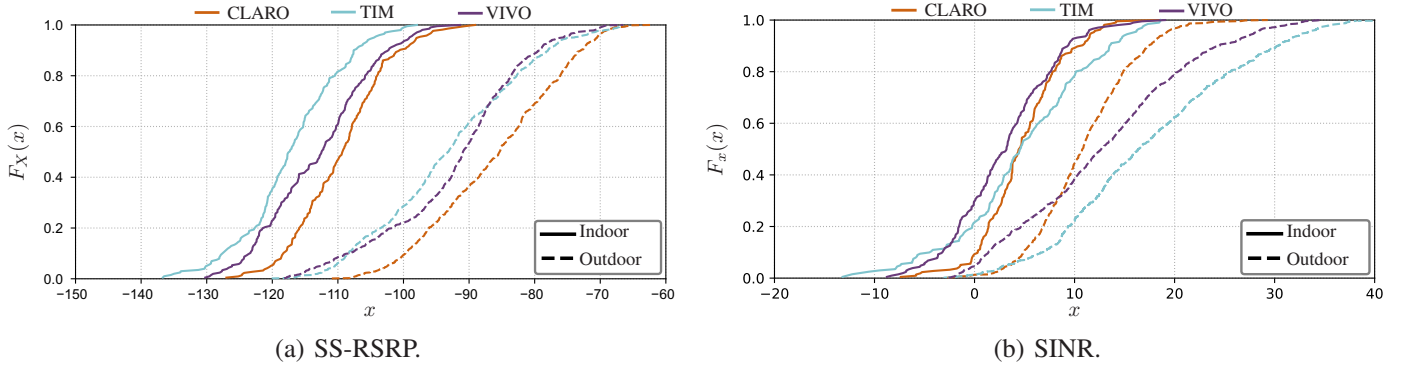


Fig. 6: ECDFs of SS-RSRP (dBm) and SINR (dB) for 5G NR of all mobile network operators.

higher SS-RSRP values for all operators. VIVO and TIM reach medians around $P_{50} \approx -90$ dBm and $P_{50} \approx -95$ dBm, respectively, placing their median coverage near the “Good”/“Moderate” boundary and in the “Moderate” class, respectively. CLARO achieves the strongest outdoor coverage, with $P_{50} \approx -85$ dBm, concentrating a larger fraction of samples in the “Good” and “Excellent” classes. Overall, indoor NR coverage remains dominated by “Poor” SS-RSRP, while outdoor coverage improves substantially.

2) *Link Quality Performance*: The ECDFs of the measured SINR values are shown in Fig. 6b. For the indoor scenario, the mobile network operators exhibit comparable median SINR values but differ in the lower tails of their ECDFs. TIM and CLARO achieve similar medians, with $P_{50} \approx 4$ dB, placing most samples in the “Moderate” class. However, their low-percentile behavior differs: CLARO remains closer to the “Poor”/“Moderate” boundary, whereas TIM shows a more pronounced low-SINR tail. VIVO presents the worst indoor link quality, with $P_{50} \approx 2.5$ dB and $P_5 \approx -5$ dB.

For the outdoor scenario, the SINR ECDFs shift toward higher values for all operators, increasing the fraction of samples in the “Good” and “Excellent” classes. TIM offers the best outdoor link quality, with $P_{50} \approx 16$ dB and $P_5 > 5$ dB. VIVO follows with $P_{50} \approx 13$ dB, although its lower tail reaches approximately $P_5 \approx 0$ dB. CLARO has a P_5 comparable to TIM but the lowest outdoor median, around $P_{50} \approx 11$ dB, despite providing the highest outdoor SS-RSRP. The attained results indicate that improved received power does not necessarily yield gains in link quality, suggesting interference-limited behavior outdoor.

V. CONCLUSION

Based on a measurement campaign, this study evaluated 4G and 5G mobile coverage and link quality at the UFJF campus. The ECDF-based analysis of measured RSRP/SS-RSRP and SINR values shows that indoor environments remain challenging for both LTE and NR, with lower received power and degraded link quality compared with outdoor areas. Although outdoor coverage improves, link-quality gains are not always proportional, suggesting interference-limited performance. Overall, the existing mobile network operators do not provide adequate coverage and link quality for the evaluated campus, indicating the need for network densification,

improved cell planning, and optimized radio infrastructure deployment in both indoor and outdoor environments.

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