Mapping and analyzing of signal coverage of 4G/5G mobile networks

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Abstract—This paper addresses the enhanced measurement of signal coverage, capacity, and reliability in mobile networks, particularly with the growing prevalence of 4G and 5G technologies. Given the escalating importance of these networks in everyday activities, there arises a demand for open-source solutions to evaluate and enhance their performance effectively. The objective of this research is to analyze gathered data to pinpoint areas necessitating network enhancements and to develop open-source software and hardware solutions for extracting essential performance metrics (KPIs) from 4G/5G networks. The proposed system offers an interface for assessing network performance and signal coverage, enabling cost-efficient measurements across diverse environments.

Index Terms—coverage mapping, 4G, 5G, key performance indicators, mobile networks, optimization, machine learning, interpolation, data analysis

I. INTRODUCTION

The increasing dependence on ‘4G’ and ‘5G’ networks highlights the crucial need to comprehend signal coverage, capacity, and reliability for uninterrupted connectivity. This paper introduces open-source software and hardware solutions designed to extract key performance indicators (KPIs) from these networks. We conducted static measurements for seven days at the BUT campus in block A04 and dynamic measurements throughout March 2024 in Brno City, concentrating specifically on LTE Band 3 (1800 MHz). Our findings unveil fluctuating KPIs even in static scenarios, with discernible time-of-day influences. The outcomes of dynamic measurements are leveraged to construct coverage maps.

II. METHODOLOGY

This paper primarily focuses on driving conducted by a bicycle or a car to measure long distances or walking tests to collect substantial data. The measurement methodology, as depicted in Fig. 1, involves collecting data from the mobile site using a measuring device, storing it in log files (preferably on the cloud but now on the device’s internal memory), and retrieving it for visualization. This aligns with practices used by most Mobile Network Operators (MNOs) or companies specializing in benchmarking mobile networks. They employ drive tests categorized by environment and dynamic measurements, utilizing sophisticated equipment and vehicles for real-world scenario capture. These measurements provide crucial input for optimization and planning to enhance overall network performance.

III. MEASUREMENT DEVICE

Currently, various applications and devices, such as “G-NetTrack” and “TEMS Pocket,” support mobile network measurements, as seen in papers [1] and [2]. This paper introduces an effort to design a novel measurement device and explores the selection between 4G and 5G modules integrated with GNSS technology.

Current module availability narrowed the choice to Simcom SIM8200EA-M2 and Quectel 5G RM502Q, both supporting high data speeds in both directions. Both manufacturers offer development boards, easing module integration. Both modules share a similar price range and have USB 3.1 for potential high-speed tests.

Despite the advantages of Quectel in [3], where both modules were tested for DL/UL speeds and latency using tools OpenSpeedTest, LibreSpeed, iPerf3, RTT, and ping. The Waveshare 5G module was selected for the measurement due to difficulties encountered in making the Quectel module operational.

Further detailed information about the Waveshare 5G module is provided in Table 1. However, it is noteworthy that this module only supports the n78 band (3600 MHz) in 5G NSA, which is currently deployed in the Czech Republic.

A. Processing Unit

After evaluation, Raspberry Pi (RPI) 4 Model B was chosen for its cost-effectiveness and high performance. Its Quad-core Cortex-A72 64-bit SoC @ 1.8 GHz and two USB 3.0 ports with 5 Gbps transfer capacity ensure efficient throughput. The
IV. DATA VISUALIZATION

Inspired by the ‘TEMS Discovery’ by InfoVista, our visualization tool offers a map interface for exploring measured areas with color-coded signal quality samples. Utilizing Python tools, specifically Dash and Plotly, the application provides interactive data visualization, meeting project requirements effectively.

The Dash application comprises a dropdown data selector, map display using OpenStreetMap API, waveform graphs, and filtering capabilities. Structured into two parts, it runs analytics on a high-processing device and measurement settings directly on the Raspberry Pi using Gunicorn. Users can access settings via a browser on a connected device to the Pi hotspot, facilitating seamless parameter customization.

V. KEY PERFORMANCE INDICATORS

In terms of KPIs, critical parameters are analyzed to understand mobile network properties such as coverage, capacity, quality, reliability, etc. These KPIs play a vital role in improving Quality of Experience (QoE) and Quality of Service (QoS).

- **RSSI (Received Signal Strength Indicator)** - Received Signal Strength Indicator (RSSI) is defined as the linear average of the aggregate received power, measured in watts. It is observed within the configured OFDM symbol and across the measurement bandwidth, encompassing N number of RBs [4].

- **RSRP (Reference Signal Received Power)** - RSRP is characterized as the linear average of the power contributions (measured in watts) from the RE responsible for carrying the CRS conducted in designated measurement frequency bandwidth, as specified in [4].

- **RSRQ (Reference Signal Received Quality)** - RSRQ is expressed as the ratio of N times the RSRP to the E-UTRA carrier RSSI, where N represents the number of RBs within the E-UTRA carrier RSSI measurement bandwidth. Both the numerator (N times RSRP) and the denominator (E-UTRA carrier RSSI) measurements are conducted over the identical set of RBs [4].

VI. MEASURED DATA

A. Static Signal Measurement

A static indoor measurement was conducted at Pod Palackeho Vrchem dormitory on the BUT campus from 9:40 a.m. on Friday, March 22nd to 9:40 a.m. on Friday, March 29th. The measurement device was positioned under a table in a second-floor room in block A04, aligning with the base station located at Brno - Královo Pole, Kolejni 2905/2, block A04 of the BUT dormitory, with CellID 790278. Despite being on the opposite side of the building from the cell, there was no Line Of Sight with the cell.

Fig. 2 illustrates all measured samples and 15-minute averages of all measured signal KPIs.

The measurement was conducted during normal college operation, resulting in significant user presence on weekdays, while fewer users were present during the weekend.

The measurement utilized the proposed solution discussed in this work within the operational LTE network of the Czech MNO T-Mobile. Signal KPIs (RSRP, RSRQ, RSSI, RSSNR) were recorded at a frequency of one sample per second using the provided hardware and software.

The measuring module was configured to the specified cell 790278 in LTE band 3 (1800 MHz, FDD (Frequency Division Duplex)).

As depicted in Fig. 2, variability is evident even in the static measurement of cellular network signal metrics. Notably, an intriguing pattern emerges, revealing periodic behavior in the RSRP and RSSNR metrics corresponding to the time of day. During peak working hours, RSRP and RSSNR values tend to decrease due to high cell load. Conversely, in the early

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<table>
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<th>Key aspect</th>
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<td>5G Frequency Bands (NSA)</td>
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TABLE I
SIM8200EA-M2 SPECIFICATIONS.

RPi’s popularity and affordability make it practical, supporting Python programming and essential packages. The final setup includes a 40000 mAh battery power bank, Waveshare 5G module, RPi, and GNSS antenna.

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![Fig. 2. Static Measurement Conducted at Pod Palackeho Vrchem dormitory on the BUT campus from March 22nd to March 29th.](image)
morning hours, typically between 1:00 a.m. to 6:00 a.m., these values increase, peaking around three to four o’clock in the morning daily.

The relationship between RSRP and RSSI demonstrates a significant negative correlation, with a correlation coefficient of -0.8.

Concurrently, notable deviations are observed during peak cell load, typically occurring between 8:00 p.m. to midnight. During these periods, the RSRP data exhibits significant downward spikes, corroborating the bimodal distribution evident in the histogram of RSRP values in Fig. 3. This distribution highlights two prominent values, predominantly around -80 dBm and, during peak load hours, approximately -110 dBm.

The RSRP demonstrates a substantial standard deviation of 15.145 dBm, indicating significant variability in signal strength even during static measurements. In contrast, RSRQ, RSSI, and RSSNR exhibit low standard deviations, suggesting a consistently clean and strong signal when measured in a static environment. Fig. 4 presents more detailed distributions of individual metrics through boxplots.

B. Dynamic Signal Measurement

In the dynamic measurement phase, multiple walk and public transport tests were conducted to assess signal coverage across the city of Brno. The measuring device, locked to LTE band 3, was securely placed in a backpack. These measurements were conducted throughout March. The measured route in the form of RSRP points is depicted in Fig. 5.

Fig. 6 illustrates individual distributions depicted through boxplots of respective measurements. The median values of RSRP and RSSI exhibit greater variability across different data sets compared to RSRQ and RSSNR.

The empirical cumulative distribution function (CDF) of the RSRP sample from individually measured sets in Fig. 7 reveals noteworthy insights. On Friday, March 29, approximately 50% of the sample fell below the -141 dBm limit. Similarly, on Thursday, March 14, with about 50% probability, the sample is below the -135 dBm limit. In contrast, the last dataset displays more favorable results, with only 16% of the sample below the -140 dBm threshold on March 6 and 30% on March 30. The better performance observed on March 6 is likely attributed to it being conducted as a walk test, while the others were conducted in public transport vehicles, resulting in significant attenuation.

C. Interpolation of Measured Data

For approximating coverage maps python package `scipy.interpolate`, is used. Three interpolation methods were applied to determine the most suitable coverage for a given area, as can be seen in Fig. 8 using a designed visualization tool.

- Bilinear Interpolation calculates a weighted average of the four nearest points.
- The Nearest Neighbor preserves input values without alteration, producing blocky results.
Cubic Convolution analyzes the 16 closest points to interpolate with a smooth curve, excelling in smoothing continuous data.

The bilinear method was identified as the optimal approach, displaying an acceptable distribution of interpolated samples. Conversely, the nearest neighbor method appeared visually complex, while enhancing the accuracy of the cubic method mandates additional track measurements within a specified area to achieve improved interpolation.

VII. CONCLUSION

In this study, we introduced a methodology for gathering KPIs from both 4G and 5G networks. By employing the SIM8200EA-M2 module and RPi 4 Model B alongside Python packages such as Plotly and Dash, we devised a comprehensive approach for data collection, visualization, and analysis. Through static measurements conducted over 7 days within LTE band 3, we amassed and scrutinized over 600,000 KPI samples, unveiling notable fluctuations in cellular network signal metrics. Daily patterns emerged in metrics like RSRP and RSSNR, with peak load hours exhibiting diminished values and a robust negative correlation observed between RSRP and RSSI. Furthermore, dynamic measurements conducted across the city of Brno throughout March underscored the variability across datasets, with RSRQ and RSSNR maintaining stability. The empirical CDF depicted divergent performance levels, with walk tests yielding superior results compared to measurements conducted within public transport vehicles. Additionally, we employed three interpolation methods to construct an LTE band 3 coverage map, determining the bilinear method to be the most optimal. Plans include extending measurements to encompass 5G and other bands within LTE technology.

REFERENCES


1Data visualization tool: https://github.com/michalizn/coverage-analysis