A Standalone Android-based Drive Test Tool with Integrated Heatmap Visualization and RSRP Prediction for LTE Networks

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ABSTRACT
The continuous evolution of mobile communication networks and the growing demand for reliable connectivity have made network performance optimization a central concern for mobile operators, particularly in developing regions such as Cameroon. Conventional drive test (DT) tools such as TEMS Investigation remain costly, vendor-dependent and largely inaccessible to academic institutions and small-scale operators. This work presents the design and implementation of a lightweight, standalone Android Drive Test Tool capable of real-time acquisition, visualization and reporting of cellular Key Performance Indicators (KPIs). The system was developed following the Rapid Application Development (RAD) methodology and adopts a single-tier mobile architecture composed of four logical layers: data acquisition via the Android Telephony API, data management through an embedded SQLite database, local processing and analysis, and visualization using Flutter's cross-platform UI with OpenStreetMap for spatial rendering. Field validation demonstrates that the tool reliably collects LTE KPIs such as RSRP, RSRQ and SINR, while producing georeferenced heatmaps and analytical reports comparable in accuracy to established commercial and open-source tools. A comparative evaluation against GNetTrack Pro confirms that the proposed solution offers equivalent or superior functionality, including user authentication, automated KPI analysis, signal prediction and PDF report export, at effectively zero licensing cost. The resulting application constitutes a portable, operator-independent and cost-effective platform suited to network optimization, academic research and educational training linked to mobile radio engineering.

General Terms
Mobile Communications, Network Optimization, Mobile Computing, Wireless Networks, Android Applications

Keywords
Android Drive Test, Mobile Network Optimization, LTE, RSRP, RSRQ, SINR, Android Telephony API, Heatmap, Flutter

1. INTRODUCTION
Mobile telecommunications have undergone extraordinary growth over the past two decades, transforming how societies communicate, transact and access information. Global mobile subscriber numbers were projected to grow nearly elevenfold between 2010 and 2025 [1], and as this growth continues, operators face mounting pressure to expand and continuously optimize their radio networks in order to preserve both Quality of Service (QoS) and Quality of Experience (QoE). Because the radio access segment forms the most critical and variable link between the end user and the core network, its performance must be continuously monitored, evaluated and tuned.

Radio frequency (RF) planning tools allow operators to simulate coverage and capacity before deployment, but simulation alone cannot guarantee real-world performance [2]. Once a network is live, operational efficiency must be verified in the field, a process known as drive testing (DT). Drive testing involves measuring parameters such as signal strength, interference and throughput while physically moving through a coverage area, thereby capturing the actual experience of subscribers and revealing coverage gaps, interference zones and handover inefficiencies that simulation cannot fully anticipate [3].

Despite its importance, drive testing remains resource-intensive. The dominant tools in the industry, such as TEMS Investigation and Nemo Outdoor, are proprietary, expensive to license, and typically deployed by equipment vendors rather than by the operators themselves. This arrangement often leaves operators with only summarized, post-processed results, limiting their visibility into raw network behavior and constraining their ability to independently diagnose and resolve performance issues. In markets such as Cameroon, where operators like CAMTEL face budget constraints, large rural coverage areas and limited access to specialized RF hardware, this dependency is especially problematic. Looking ahead, the anticipated convergence of network cores around flexible, all-IP, multi-technology architectures [4] is likely to make this dependency even harder to sustain unless more accessible measurement tools become available. The proliferation of capable Android smartphones offers a practical way to close this gap. Unlike vendor-specific measurement systems, Android devices expose cellular parameters (RSRP, RSRQ, SINR, CQI, RSSI, PCI) directly through standard telephony APIs, alongside GPS-based location data. This creates an opportunity to build low-cost, portable and operator-independent drive test tools.

This article presents the design, implementation and evaluation of one such tool: a standalone Android Drive Test application built to collect, analyze, visualize and export mobile network performance data. Unlike many existing Android-based solutions, which are typically restricted to a single network generation or a narrow set of parameters, the presented tool is designed as a complete, self-contained measurement and reporting platform, combining live KPI acquisition, map-based heatmap visualization, statistical analysis and automated PDF reporting within a single mobile application, without reliance on external servers.

The main contributions of this work are as follows:

a) a standalone, single-tier Android architecture that performs acquisition, storage, analysis, visualization and reporting entirely on the device, without external server infrastructure;
b) an integrated analytics layer combining parameter-selectable heatmaps, statistical charts, measured-versus-predicted RSRP analysis and automated PDF reporting;
c) a field validation and a structured feature-based comparison against GNetTrack Pro; and
d) a low-cost, operator-independent platform suited to network optimization, academic research and training in the Cameroonian context.

The remainder of this article is organized as follows. Section 2 reviews related work in drive testing methodologies and existing Android-based solutions. Section 3 describes the proposed system architecture and development methodology. Section 4 details the implementation, including the technology stack, the core functional modules and the main LTE parameters captured. Section 5 presents and discusses the results, including the test scenarios, the system validation and a comparative evaluation against GNetTrack Pro. Section 6 concludes the article and outlines directions for future work.

2. LITERATURE REVIEW

2.1 Classical Drive Testing

Traditional drive testing relies on a measurement chain composed of a test mobile station, a GPS receiver for geolocation, and a laptop running specialized acquisition software. This configuration allows engineers to simulate real usage scenarios (call setup, session continuity, mobility handling) while logging radio parameters against location. The authors of [5] demonstrated this classical approach for GSM networks using dedicated equipment, scanners and logging tools, producing a robust, field-validated methodology; however, this approach was restricted to GSM technology and did not explore smartphone-based acquisition, illustrating a persistent gap between traditional and modern measurement approaches. More broadly, this classical approach is constrained by two persistent problems: the high cost of licensed software and hardware, and the logistical burden of transporting and coordinating multiple pieces of equipment, which restricts where and how often testing can be performed.

2.2 Android-Based Drive Testing

Because modern smartphone chipsets expose engineering-level radio measurements, Android devices have increasingly been explored as low-cost substitutes for dedicated DT hardware. Commercial platforms such as TEMS Investigation remain the benchmark for multi-technology, multi-vendor drive testing, offering extensive real-time capability; however, their licensing cost and hardware dependencies place them out of reach for most academic or small-scale projects.

Several Android-native efforts have made partial progress toward closing this gap. The authors of [6] developed CoverME, an Android application measuring network KPIs alongside round-trip time and battery consumption directly from a smartphone, demonstrating that operational costs and staffing needs could be significantly reduced; however, that implementation lacked cloud-based data aggregation and any form of map or heatmap visualization, limiting its usefulness for spatial optimization work. Similarly, [7] combined a mobile measurement client with a RESTful API and a cloud database to centralize collected data across devices and technology generations, but the analytical and reporting layer (map-based analytics, per-sector visualization and structured report generation) remained comparatively limited in that implementation.

A broader survey of Android measurement platforms reveals a recurring pattern of narrow scope. NetworkCoverage [8] is a crowdsourced measurement application restricted largely to RSRP-based signal strength assessment. Mobilyzer [9] is a reusable measurement library rather than a standalone application, designed to isolate and standardize network measurement routines for integration into other tools. MobiPerf [10] is an open-source performance measurement system combining a mobile client with a Linux-based server, targeting network characteristics such as carrier information, signal strength and uplink/downlink throughput rather than full drive-test analytics. MopEye [11] is a passive monitoring approach that measures per-application round-trip time without generating additional network traffic, prioritizing measurement efficiency over spatial or handover analysis. Netradar [12] is a client-server measurement system focused on throughput and signal strength collected from users worldwide.

Taken together, these tools illustrate that most existing Android-based platforms are designed either as passive crowdsourced measurement collectors or as reusable measurement libraries rather than as complete, standalone drive test applications. They typically capture a narrow subset of KPIs and provide little to no structured reporting suitable for operational or academic use. The authors of [13] verified the accuracy of 3G and 4G received-power measurements collected through a crowdsourcing Android application, confirming that smartphone-based measurement can achieve accuracy suitable for network assessment. This reinforces the viability of the Android-based approach adopted in this work, even as the surveyed tools collectively fall short of integrated visualization and reporting. Commercial GIS-based reporting tools such as MapInfo Pro can visualize DT data on a map, but remain costly, static in their analytics (they cannot dynamically relate one parameter to another, e.g., SINR against an RSRP range) and offer limited graphing capability.

2.3 Identified Gap

Across the reviewed literature, three recurring limitations stand out:

e) Proprietary tools remain too costly and complex for academic or small-operator use.
f) Existing Android-based alternatives, while demonstrating technical feasibility [6, 13], generally lack integrated visualization, heatmap analytics and export-ready reporting.
g) Many solutions are implemented as libraries requiring further integration effort [9] rather than as ready-to-use, standalone applications.

This work addresses these gaps directly by combining real-time multi-generation KPI acquisition with integrated OpenStreetMap-based heatmap visualization, statistical analysis and automated PDF report generation, all within a single, self-contained Android application requiring no external server infrastructure.

2.4 KPI, QoS and QoE Relationship

Quality of Service (QoS) reflects a network's technical ability to meet defined performance requirements (accessibility, availability, continuity and integrity), as measured objectively through counters and drive tests [2]. Quality of Experience

(QoE), by contrast, reflects the subscriber's subjective perception of that same performance. Key Performance Indicators (KPIs) serve as the standardized, measurable bridge between the two: they are collected from the network (via counters or drive testing) and used both to assess QoS directly and to infer probable QoE outcomes [14]. A drive test tool's value therefore depends not just on which KPIs it captures, but on how effectively it turns raw KPI data into actionable insight, the central design motivation of this work.

3. SYSTEM ARCHITECTURE AND DESIGN METHODOLOGY

3.1 Solution Overview

The proposed solution, hereafter referred to as T-Track, is a standalone mobile drive test tool that operates entirely on Android devices, without requiring an external server for its core functionality. Rather than treating measurement and analysis as separate stages, as several prior tools do [8, 9], the application integrates cellular data acquisition, local processing, spatial visualization and reporting within a single mobile platform. This eliminates dependency on network connectivity during field data collection and reduces deployment complexity, while retaining measurement accuracy and analytical depth comparable to commercial alternatives.

3.2 Architectural Layers

The system follows a single-tier mobile computing model, in which the user interface, business logic and data storage all run on the same device. This architecture was selected for its simplicity, ease of deployment and suitability for field conditions where connectivity cannot be guaranteed. Figure 1 shows the overall architecture, which is organized into four logical layers:

h) **Data Acquisition Layer:** This layer interfaces directly with the device's telephony and location hardware. It extracts signal strength indicators, cell identity parameters and handover-related events via the Android Telephony API, while the Geolocator API supplies GPS coordinates, associating every measurement with a precise geospatial position.

i) **Data Management Layer:** Collected measurements are persisted locally using SQLite, an embedded, lightweight database engine. Each stored record includes a timestamp, GPS coordinates, the relevant cellular KPIs and cell identity information. This layer is optimized for offline operation, ensuring data integrity even without continuous internet access.

j) **Processing and Analysis Layer:** Raw measurements are processed locally to derive secondary KPIs and detect network events of interest, including coverage gaps, handovers between cells and predicted RSRP values. This layer also performs the statistical aggregation used to drive charts and performance summaries.

k) **Visualization and Reporting Layer:** This layer renders the user-facing interface, presenting processed results through maps, charts and structured reports, and providing export functionality for use outside the application.

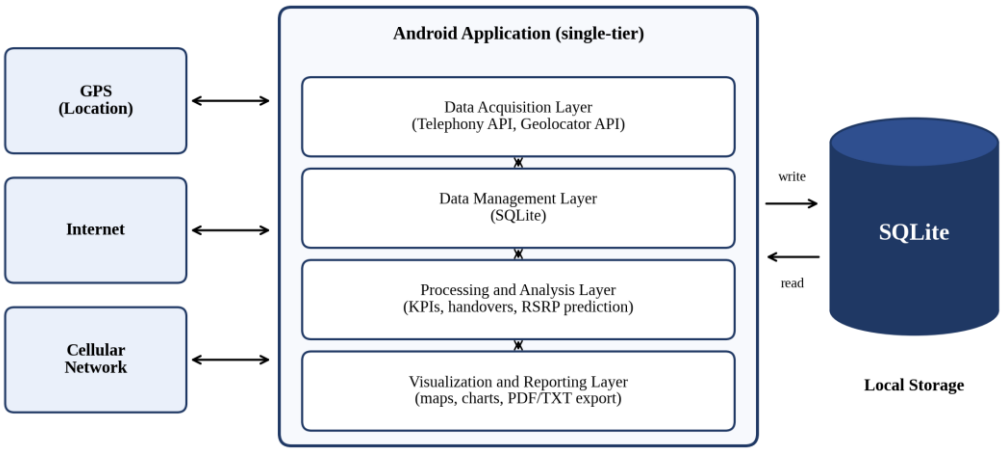


Figure 1: Architecture of the proposed solution

3.3 Development Methodology

Development followed the Rapid Application Development (RAD) model, chosen for its emphasis on iterative prototyping, continuous stakeholder feedback and incremental delivery of functional components, which is well suited to a project with requirements that evolved as feedback was gathered from network engineers, academic supervisors and prospective student users. The RAD process proceeded through four phases: requirements determination, user design (executed as a cycle of prototyping, testing and refinement across low-, medium- and high-fidelity stages), construction and implementation.

Requirements were gathered from four stakeholder groups. Network engineers identified the critical KPIs, threshold values and reporting formats needed for operational relevance. Academic supervisors emphasized reproducibility, data export capability and educational value. Telecommunications students provided feedback on usability and learning curve. End users prioritized portability, ease of use and robustness under real field conditions.

3.4 Use Case Diagram

Figure 2 presents the use case diagram of the designed tool. The network engineer is the primary actor and interacts with the authentication, permission, drive test, analysis and reporting functions, which in turn rely on the SQLite database, the Android Telephony API and the GPS service.

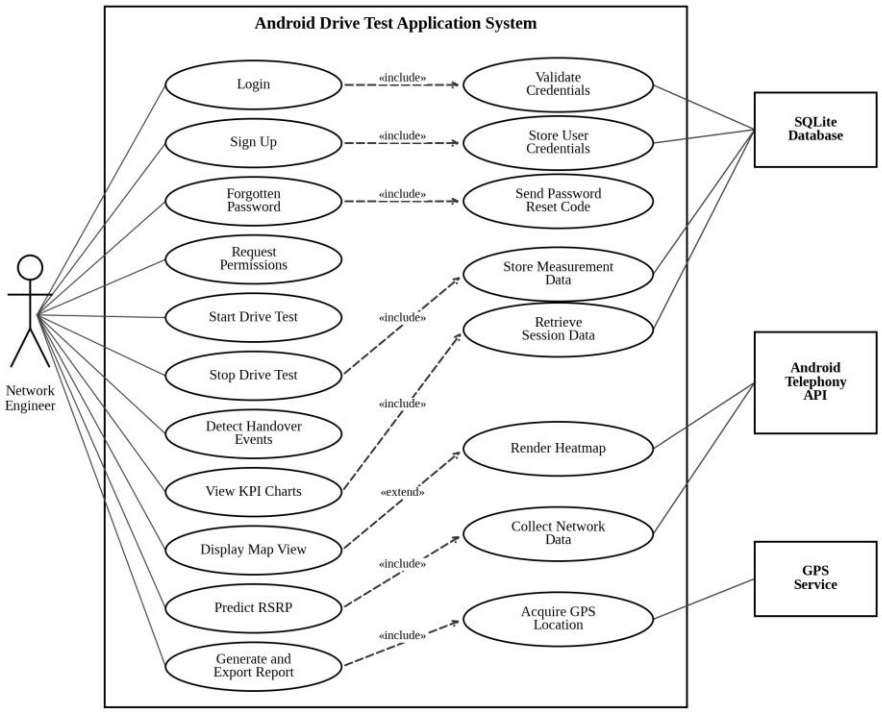


Figure 2: Use case diagram of the Android Drive Test Tool

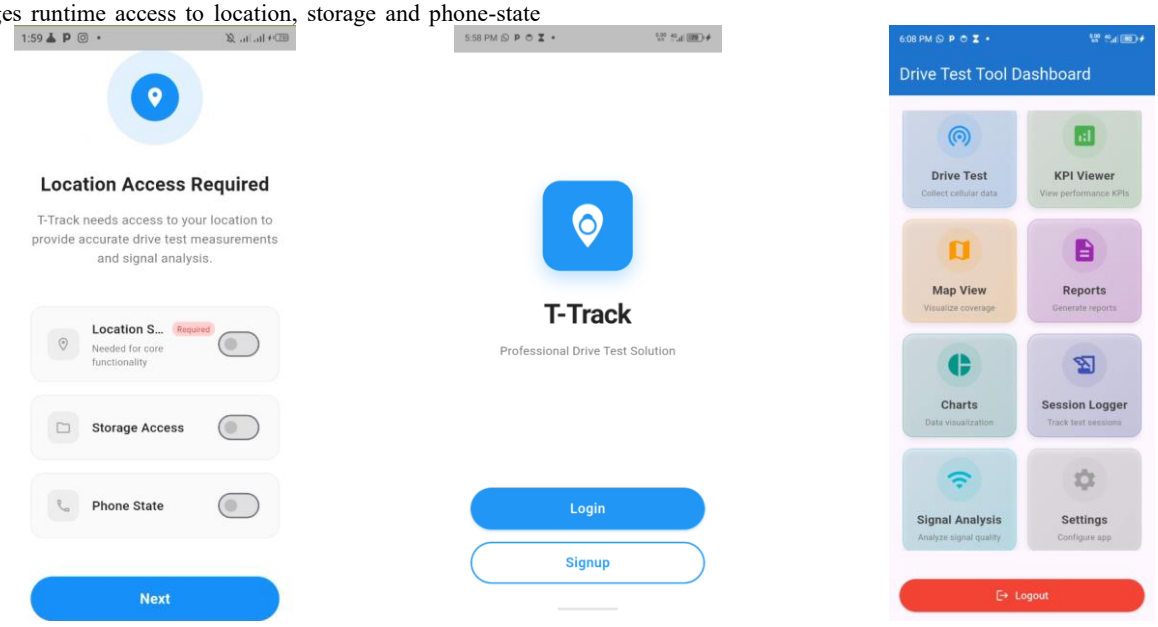
4. IMPLEMENTATION

4.1 Technology Stack

The application was built using the Flutter framework within Android Studio, chosen for its single-codebase cross-platform capability, modern UI toolkit and efficient native API integration. Persistent local storage is handled by SQLite via the sqflite plugin, while spatial visualization is implemented with flutter_map and flutter_map_heatmap, both built on OpenStreetMap, paired with the latlong2 package for distance and coordinate computations. The permission_handler package manages runtime access to location, storage and phone-state permissions, path_provider resolves file system locations for exported reports, and fl_chart renders the line, bar, pie and scatter visualizations used throughout the analytics interface.

4.2 Core Functional Modules

The implemented system comprises eight main modules: Permission Handling, Authentication (Signup/Login), Home Dashboard, Drive Test Execution, Map View, KPI Viewer, Chart Visualization and Report Generation. Figure 3 presents (a) location access, (b) authentication and (c) drive tests dashboard views.

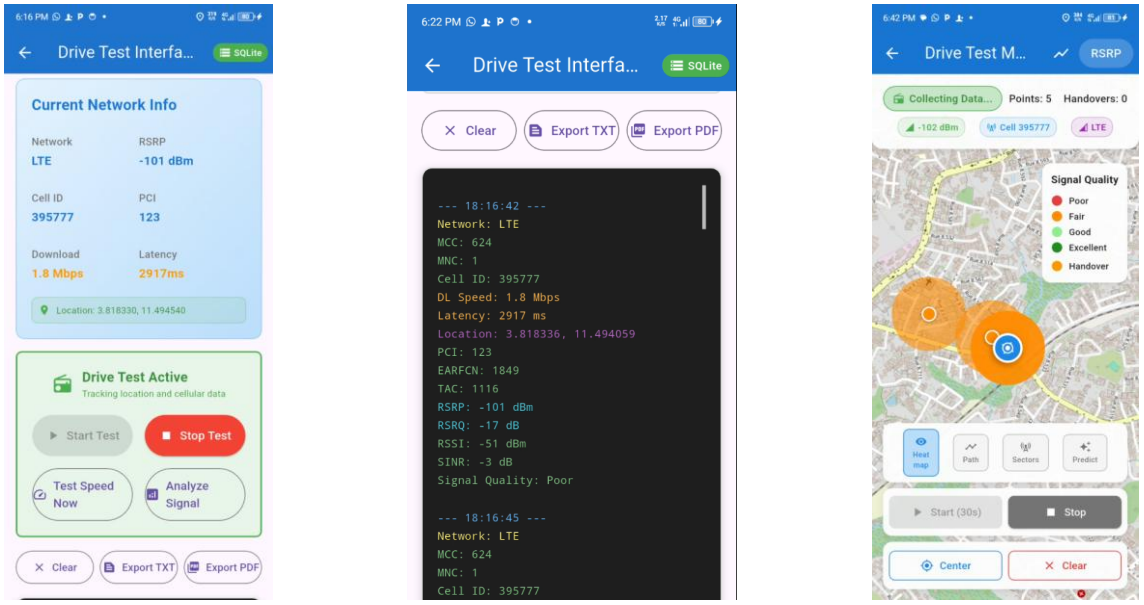


(a) (b) (c)

Figure 3: Display for permission, authentication and home screens

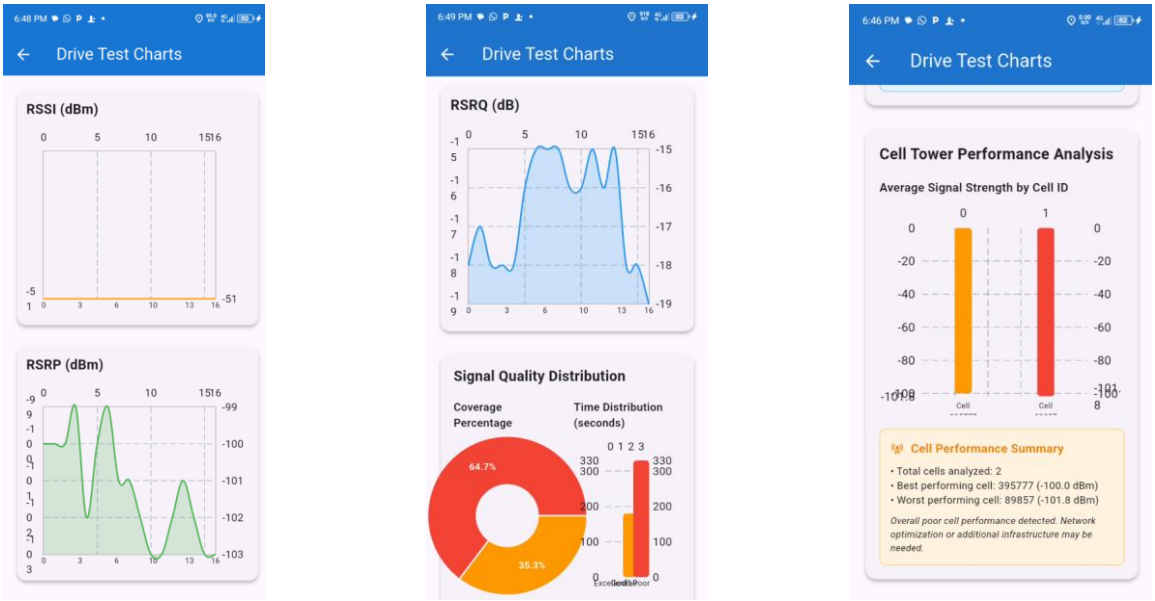
From the dashboard, the **Drive Test module** initiates real-time parameter capture via the Android Telephony Manager, logging data continuously to the local SQLite database as the user moves through the test area. It displays live network type, RSRP, Cell ID, download/upload speed and latency, and allows the session to be exported in .txt or .pdf format once stopped.

The **Map View module** renders the resulting route and a color-coded heatmap reflecting signal strength (RSRP, RSRQ or RSSI) at each logged point, with handover locations flagged to help engineers pinpoint zones of weak coverage or excessive interference. This approach echoes the map-based visualization used by earlier Android measurement platforms [8, 12], but extends it with dynamic, parameter-selectable heatmap layers rather than a single fixed metric. The KPI Viewer summarizes recorded metrics (average signal strength, handover counts, data rates), while the Chart Visualization module renders relationships such as RSRP versus distance or handover distribution over time. Figure 4 presents the display for the map view interfaces (a), (b) and (c), and Figure 5 presents the chart visualization module (a), (b) and (c).



(a) (b) (c)

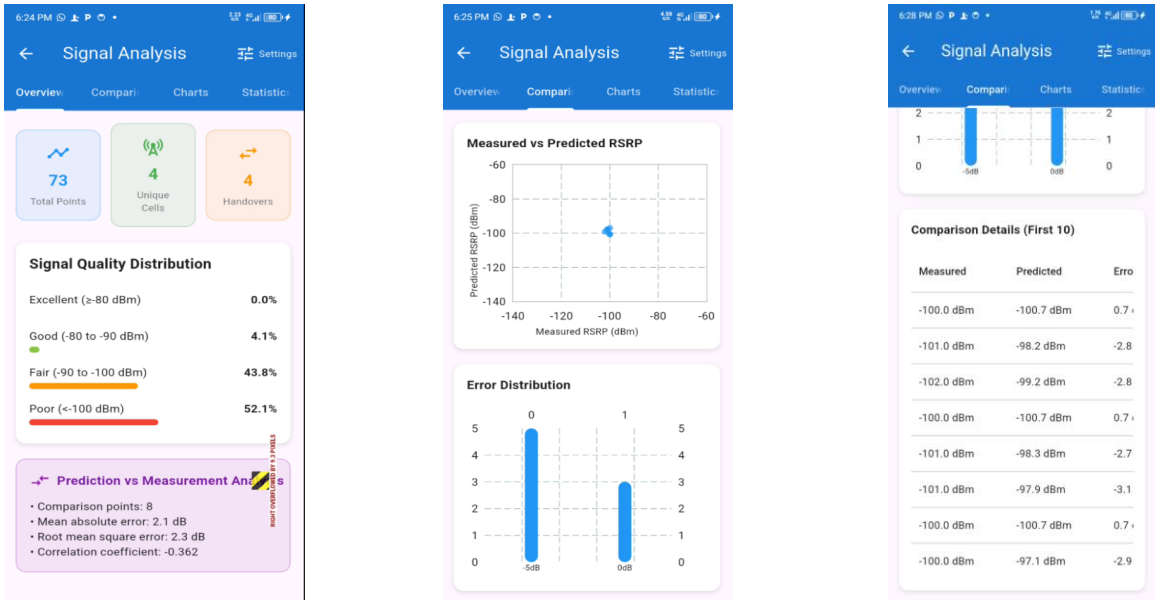
Figure 4: Display for map view interface screens



(a) (b) (c)

Figure 5: Display for chart visualization module

In addition, the **Signal Analysis module** compares measured against predicted RSRP values, exposing the error distribution and descriptive statistics (mean, standard deviation) to characterize measurement quality, as shown in Figure 6.



(a) (b) (c)

Figure 6: Display for signal analysis module

4.3 Main LTE Parameters Captured

Because the deployment context of the application is mainly 4G, the implementation focuses on LTE-specific radio parameters, even though there exists a multitude of parameters. Nevertheless, the application is capable of measuring parameters from other network generations. The main 4G parameters are list below:

a) **RSRP (Reference Signal Received Power):** indicates coverage strength; values above −75 dBm indicate excellent quality, while values below −95 dBm are generally unacceptable and associated with call drops [14].

b) **RSRQ (Reference Signal Received Quality):** derived from RSRP and RSSI, it indicates signal quality and interference level; values above −9 dB indicate an excellent experience [14], while values of −13 dB indicate significant throughput degradation.

c) **SINR (Signal to Interference plus Noise Ratio):** a vendor-defined quality metric which complements RSRQ.

d) **Throughput, CQI and PCI:** capturing the achievable data rate, the supportable modulation order and the unique cell identity, respectively. They are critical in handover analysis and interference conflict detection.

5. RESULTS AND DISCUSSION

5.1 Test Setup and Scenarios

To assess the tool under varied conditions, the application was field tested across multiple sessions and scenarios. Table 1 summarizes the configuration of the test campaign, and Table 2 reports the KPI statistics obtained for each scenario.

Table 1. Configuration of the Field Test Campaign

Parameter	Value
Test device(s) and Android version	Samsung A50s(Android 11)
Operator / network	MTN/LTE
Test area(s) and route length(s)	Yaoundé about 1.5km
Number of sessions and scenarios	3 sessions (A, B, C)
Sampling interval	30s
Total duration / number of samples	30min/ 60 samples per session

5.2 KPI Acquisition and System Validation

The implemented application was field tested across multiple sessions, confirming reliable real-time acquisition of RSRP, RSRQ and SINR at configurable sampling intervals, accurate GPS-based georeferencing of measurements and stable background logging. These results are consistent with prior findings that crowdsourced, smartphone-based power measurements can achieve accuracy suitable for network assessment purposes [13]. The color-coded heatmaps produced for each session made coverage gaps and zones of poor signal quality immediately identifiable, and handover locations were flagged automatically along the route. Table 2 summarizes the KPI values recorded per scenario; the values can be interpreted with the thresholds given in Section 4.3.

Table 2. Summary of Recorded LTE KPIs per Scenario

Scenario	Samples	Mean RSRP (dBm)	Mean RSRQ (dB)	Mean SINR (dB)
A	60	-83.0	-9.6	3.2
B	60	-94.1	-12.6	1.5
C	60	-99.6	-10.1	2

5.3 Measured versus Predicted RSRP

The Signal Analysis module compares measured RSRP with the values predicted by the path-loss model implemented in the Processing and Analysis Layer. The error between the two series is characterized by its distribution and by descriptive statistics (mean and standard deviation), as reported in Table 3. These indicators provide a quantitative measure of the quality of the prediction and of the measurements.

Table 3. Measured versus Predicted RSRP Error Statistics

Metric	Value
Mean error (dB)	1.8
Standard deviation of error (dB)	0.4
Number of compared samples	9

5.4 Report Generation and Export

Automated PDF report generation was validated across multiple sessions, consistently producing structured output containing session metadata, statistical summaries, KPI trend analysis, handover logs and coverage assessments. Sessions can additionally be exported in plain-text (.txt) format, which facilitates post-processing in external tools.

5.5 Comparative Evaluation Against GNetTrack Pro

To assess the relative maturity and completeness of the developed Android tool, a structured feature-based comparison was conducted against GNetTrack Pro, a widely used Android-based commercial drive test application. The results are summarized in Table 4.

Table 4. Feature Comparison of T-Track versus GNetTrack Pro

Feature	T-Track	GNetTrack Pro
User authentication	Yes	No authentication
Network support	2G/3G/4G/5G	2G/3G/4G/5G
KPI analysis	Automated	Manual + automated
Signal prediction	Yes (path-loss model)	No predictions
Platform	Android	Android
Export formats	PDF, TXT	TXT
GPS tracking	Customizable to different intervals	Automatic
Handover detection	Automatic	Automatic
Background logging	Logging of different sessions	Not present
Data storage	SQLite	Local

The two applications are equivalent in platform, network-generation support and automatic handover detection. T-Track goes further on five points: it provides user authentication, fully automated KPI analysis, RSRP prediction based on a path-loss model, PDF report export in addition to TXT, and background logging of distinct sessions, a capability that is not present in GNetTrack Pro. It also lets the user customize the GPS sampling interval, whereas GNetTrack Pro tracks automatically. These differences make T-Track better suited to structured analysis and reporting, which is precisely the gap identified in Section 2.3, while its zero licensing cost keeps it accessible to academic and small-scale operational users.

5.6 Achievement of Research Objectives

The results confirm that a fully integrated Android drive test solution, combining acquisition, storage, spatial visualization, statistical analysis and reporting, can be implemented without specialized hardware or server infrastructure, directly addressing the cost and accessibility barriers identified in the literature review [3, 5]. The heatmap and multi-chart visualization capabilities distinguish the tool from prior Android-based efforts, most of which separate measurement from analysis or omit spatial visualization entirely [9, 10, 11]. Real-time KPI acquisition via the native Telephony APIs was confirmed reliable across extended sessions, and the persistent local SQLite storage layer maintained integrity even under session lengths well beyond those of typical single-route drive tests.

5.7 Limitations

The current implementation is scoped primarily to 4G/LTE parameters, reflecting the deployment context of telecommunications in Cameroon. RSRP remains statistically rather than physically modeled. Finally, the evaluation to date has relied on a feature comparison and field validation rather than on large-scale statistical accuracy benchmarking against a certified reference instrument, which would be a valuable next step.

6. CONCLUSION AND FUTURE WORK

This work has presented the design, implementation and validation of a standalone Android Drive Test Tool that addresses persistent cost, accessibility and transparency limitations in conventional drive testing practice. By integrating real-time KPI acquisition, GPS-based georeferencing, OpenStreetMap-driven heatmap visualization, statistical analysis and automated PDF reporting into a single self-contained mobile application, the tool provides network engineers, researchers and students with a low-cost, operator-independent alternative to proprietary drive test platforms. Field validation and comparative evaluation against GNetTrack Pro confirm that the tool achieves functional parity and, in several respects, offers an advantage over established Android-based alternatives, while remaining accessible to resource-constrained academic and operational contexts such as those found in Cameroon.

The study also has limits. The tool currently targets 4G/LTE, its RSRP prediction relies on a statistical rather than a physical propagation model, and its accuracy has not yet been benchmarked at scale against a certified reference instrument. These limits define the future scope of this work, which includes the following points:

a) **Large-scale benchmarking:** repeated campaigns with several devices, operators and environments (urban, suburban, rural, indoor), compared against a certified reference drive test instrument to quantify measurement accuracy statistically.
b) **Improved prediction:** replacing the statistical path-loss model with physically based propagation models, or with machine-learning models trained on the collected measurements, to improve RSRP prediction accuracy.
c) **5G NR support:** extending the acquisition, analysis and visualization layers to 5G NR KPIs and to non-standalone deployments.
d) **Extended test capabilities:** adding active tests such as call setup success and drop rates, and throughput and latency test sessions, to complement the passive radio measurements.
e) **Interoperability:** adding export formats compatible with GIS and post-processing tools, and optional cloud synchronization and multi-device aggregation, while preserving the offline-first design.
f) **Operational and educational deployment:** trials with operators such as CAMTEL and in telecommunications courses, in order to collect user feedback and assess the

tool's practical and pedagogical impact.

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