Performance Evaluation of Palestinian Mobile Networks Based on Crowdsourcing Measurements

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***Abstract*—The evaluation of mobile network performance involves assessing various key performance indicators (KPIs) that gauge the efficiency and effectiveness of these networks. The key performance indicators of the Palestinian mobile networks are usually monitored by the mobile network operators (MNOs) through their operation support subsystems and the carried-out drive tests. This include the received signal level, received signal quality, drop rate, handover success rate, packet loss, latency, throughput, etc. The Palestinian ministry of telecommunications and information technology (MTIT) together with the Palestinian Telecom Regulatory Authority (PTRA) also conduct performance measurements for the mobile networks through drive tests to monitor the quality of service (QoS) measurements delivered by each mobile operator and compare them with the standard KPIs benchmark limits. They aim to enhance user experience and network efficiency. However, these performance measurements either from the MNOs or the regulation agency are limited and do not reflect the exact end user experience. Therefore, in this paper, we address the performance evaluation of the Palestinian MNOs based on a large community of connected people smartphone crowdsourcing technique. Here, using smartphone crowdsourcing can collect continuous real-time data on network performance from a large number of smartphone users with various locations. Thus, the quality of experience (QoE) can be evaluated from the end user perspective with a bigger data set. In this paper, we have developed and implemented a smartphone application called "Signal Sense" for crowdsourced mobile network measurements. The performed measurements include location information, signal level, signal quality and throughput for 3G mobile networks in Palestine. The evaluation of these measurements reflects the relative performance of the Palestinian MNOs.**

***Keywords*—smartphone crowdsourcing, mobile network operators, key performance indicators, quality of experience**

I. Introduction

In the past literature, a great deal of interest has been paid to the planning, evaluation and optimisation of mobile networks [1] and [2]. In [3], the authors has provided a comprehensive study on the evaluation and optimization of JAWWAL GSM mobile network in Jenin, a city in Palestine [3]. The key performance indicators (KPIs) from the operation support subsystem and the drive test results were evaluated and compared before and after optimizing the networks. This include the received signal level, received signal quality, traffic channel drop rate, and handover success rate. The authors in [4] compared the performance of four competitor GSM mobile network operators (MNOs) in Nigeria in terms of the received signal quality. The result provided helps mobile network operators to improve signal quality and ensure improved network coverage. In [5], the authors evaluate the reliability and quality of signal of 3G Universal Mobile Telecommunications Sytem (UMTS) technology of three competitor MNOs over two cities in Nigeria. An intensive drive test measurement was conducted, taking into consideration, signal-to-interference ratio as the key performance indicator.

Crowdsourcing is a relatively novel paradigm that was introduced by Jeff Howe [6]. It is the technique of processing a task by a large community of connected people instead of a designated agent. Best practices and recommendations for crowdsourced quality of experience (QoE) assessment are discussed in [7]addressing the issues of reliability, incentives, in a large set of conducted QoE crowdtesting studies.

Mobile network crowdsourcing has several advantages. Firstly, making it much easier to cover a wide range of locations, situations and users. Secondly, allowing groups other than the network operator to assess the performance of a mobile network. Thirdly, allowing collection of continuous real-time datasets from end-user perspective. Fourthly, it facilitate big data analytics as crowdsourced data becomes big data with time.

Smartphone crowdsourcing has recently attracted the research community [8][9][10][11] and [12]. Indeed, in [8], the major opportunities and challenges of the smartphone-based crowdsourcing approach are identified, and some relevant network monitoring applications are pointed-out. The authors in [9] reviewed the opportunities and challenges of using crowdsourced measurements of about 2 million data entry in Austria for benchmarking mobile networks. These crowdsourced measurements are available as an open data collected by the Netztest mobile application tool. The study highlights the importance of open source applications and open data sets in achieving neutrality and repeatability. In [10], the authors investigate end-to-end reliability and packet loss performance comparisons of MNOs in Turkey by using crowdsourced dataset from end user applications for about one year duration. The research in [11] developed a framework to define and determine the behavior of MNOs from crowdsourced datasets. They investigate whether one can differentiate MNOs by using crowdsourced end-to-end network measurements by identifying patterns between various mobile systems and disclose their differences from the end-user perspective.

The mobile Internet experience from end user perspective in Germany is evaluated by [12]. The authors statistically analysed a dataset with throughput measurements provided by Tutela Ltd., which covers about 2.5 million end user mobile throughput tests across Germany in the first six months of the year 2019. In [13], an android-based smartphone application that uses a crowdsourcing technique to collect some KPIs of all MNOs in Nigeria was designed and implemented. This smartphone application contains a web service entity that collects regularly signal level and location information of end users and stores them on a local mobile database as well as on a centralized database at the webserver. The mobile application maps the crowdsourced information on the google map of Nigeria.

For the last years, several crowdsourced mobile network measurement start-ups have emerged which use the smartphone of the end users as a measurement device. Among them are Opensignal [14], Cellmapper [15], Tutela [16], speedtest by Ookla [17]. These enterprises publish annual reports on the performance of mobile network all over the world. They compare the performance of MNOs in terms of coverage, capacity and quality. Nevertheless, for the special case of Palestine, we need to develop a specific smartphone crowdsourced data measurement tool to compare the performance of the MNOs on a national level. Therefore, in this paper, we have in and implemented a smartphone application for crowdsourced mobile network measurements. In addition, we have evaluated the relative performance of the Palestinian mobile networks in terms of signal level, signal quality and throughput. The developed mobile application not only provides information about the 3G network speed (capacity) at specific locations, but also measures 3G network coverage and quality in terms of received signal code power (RSCP) and signal to interference plus noise ratio (Ec/No).

The rest of the paper is organized as follows. In section II, the structure of the suggested smartphone crowdsourcing measurement system for evaluating the performance of MNOs is presented. In section III, the developed smartphone crowdsourcing application "Signal Sense" is introduced. In section IV, the performance results of the MNOs are presented and evaluated. Conclusions remarks are drawn in section V..

II. Smartphone Crowdsourcing Measurement System

In a recent research paper [18], the authors propose a conceptual model for crowdsourcing innovation from a cybernetic and knowledge management perspective. This model integrates the theory of open innovation and cybernetics, providing a new view of crowdsourcing innovation process design. It identifies five systemic characteristics that ensure ongoing efficiency for the innovation process:

1. Knowledge Flow Controls: These mechanisms regulate the flow of ideas, information, and intellectual assets within the crowdsourcing process.
2. Feedback Loops: Just like in cybernetics, feedback loops play a crucial role in adjusting and improving the innovation process.
3. Adaptability: The system must be adaptable to changes, new inputs, and evolving requirements.
4. Goal Orientation: Clearly defined goals guide the crowdsourcing efforts.
5. Self-Organization: Crowdsourcing processes exhibit self-organizing behavior, akin to cybernetic systems.

This framework provides valuable insights for managers designing successful crowdsourcing initiatives. By understanding the cybernetic principles at play, organizations can harness the collective intelligence of crowds more effectively and drive innovation forward. Therefore, in our suggested crowdsourcing system we adopted the systemic characteristics to ensure the efficiency.

The structure of the suggested smartphone crowdsourcing measurement system for evaluating the performance of MNOs is shown in Fig. 1. The basic operation of this system uses a smartphone application that users have to install. The developed application measures, stores and tracks mobile network performance on their devices. The application collects measurements of various network parameters such as received signal strength, received signal quality, latency, packet loss, and throughput. The measurements are anonymously shared with a central database and web servers that aggregates and analyzes the data from hundreds or thousands of users. The analysis of the measurements provides insights into the performance of the network, which can be used to determine areas of performance improvement for MNOs. The results are show on an interactive map to help users identify areas of good coverage. On the other hand, the measured data can be used for benchmarking against competitors and identifying areas where MNOs need to improve their network infrastructure.

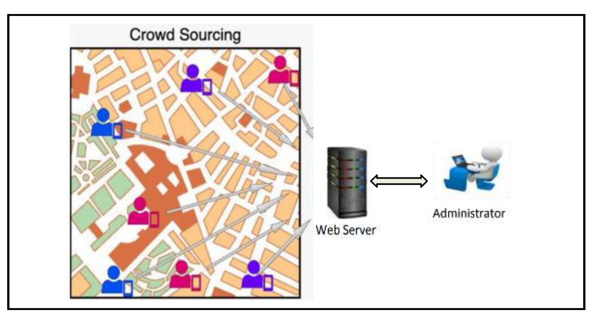

Fig. 1. Structure of the suggested smartphone crowdsourcing measurement system.

III. DEVELOPED SMARTPHONE CROUDSOURCING APPLICATION

The researchers developed and implemented a smartphone crowdsourced application that they named “Signal Sense”. The logo of the developed application is shown in Fig. 2. It will be available on Google Play store soon. The application has the following key features:

A. *User-friendly interface*

The mobile application provides an intuitive and user-friendly interface for users to report their network connectivity experiences. Users should be able to rate the connectivity quality (e.g., good, normal, poor) and provide additional notes or comments. The reporting interface is accessible and compatible with various mobile devices. The developed application user interface is shown in Fig. 3. It allows the user to rate the network performance. After submitting the rating, the user will have information about network performance including download speed and delay.

B. *Crowdsourced reports*

The application provides visual representations of network coverage, such as interactive maps and coverage maps, to aid network administrators in identifying areas of poor connectivity. Upon logging into the application, users will be greeted with a personalized dashboard that provides an overview of their network type, name and statistics. The dashboard will present a clear and concise summary of the user's network connectivity experiences, including connectivity ratings, average speeds, and any recent alerts or notifications. The application will offer a dedicated reporting form that allows users to submit their network connectivity experiences easily. The reporting form will include fields for users to rate their connectivity (good, normal, poor) and provide additional notes or comments about their experience. It also includes options to specify the type of connection (mobile or Wi-Fi) and capture relevant metrics such as signal strength, download speeds, latency, and any other parameters deemed important for analysis. Fig. 4 shows an example of network report page for administration mode.

C. *Digital maps*

The application will incorporate interactive maps that enable users to visualize and pinpoint areas of their institution where network connectivity issues are experienced. Users will be able to navigate the map, zoom in/out. The interactive maps will provide a visual representation of signal strength or connectivity ratings, allowing users to identify areas with consistent issues. Fig. 5 shows an example of connectivity status on digital map around Al-Quds University.

D. *Infrastructure integration*

The application seamlessly integrates with the existing network infrastructure. It is compatible with various network devices, including routers, access points, and switches, to gather relevant network statistics. It also adheres to strict data privacy regulations and ensure the anonymity of users when reporting their connectivity experiences.

E. *Application Modes*

The developed smartphone crowdsourcing application operates in two modes: User Mode for public users and admin mode for administrators. In the User Mode, public users rate the connectivity status (Good, Normal, Poor), and provide additional notes up to 250 characters. After submitting, the download speed and ping will appear. The interactive map then shows the system measured three colored dots. Red dot represents bad network. Yellow dot represents normal network. Green dot represents good network as shown in Fig. 5.

In the Admin Mode, administrators can report network connectivity status according to the reports from users. Each report is labeled by date, time, network type, mac address, user rating and detailed system parameter values. According to the mobile network technology (2G, 3G, 4G, 5G), MNC, MCC, latency, Operator, Download Speed, Downlink, Uplink, WCDMA-Level, WCDMA-ECNO, GSM-RSSI, GSM-BER, GSM-Level and signal strength are collected as shown in Fig.4.

Fig. 2. Logo of the developed smartphone crowdsourcing application

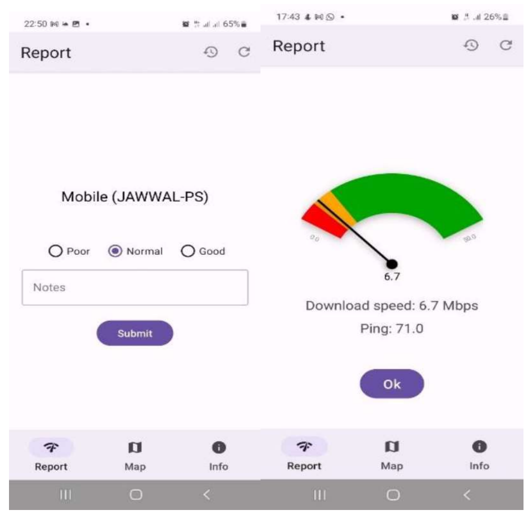

Fig. 3. Smartphone application user Interface.

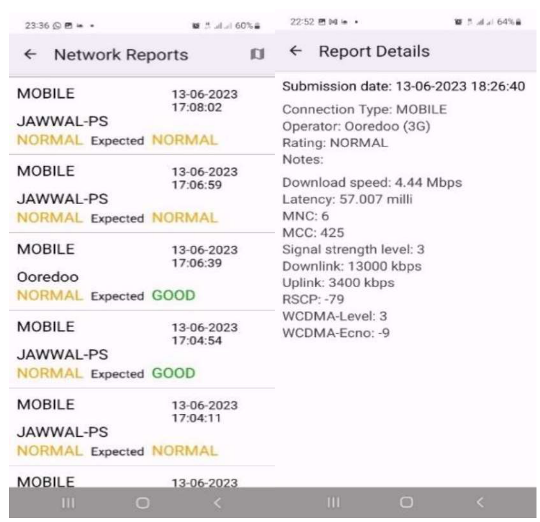

Fig. 4. Example of network report page for Admin mode.

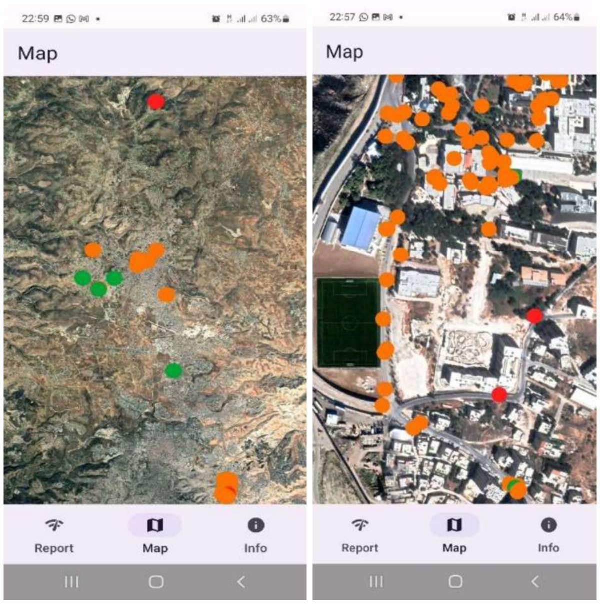

Fig. 5. Connectivity status on digital map.

The application provides a user-friendly interface that is intuitive, visually appealing, and easy to navigate. Users are able to report their network connectivity experiences by providing details such as signal strength, connection stability, download/upload speeds, latency, and any additional notes or comments. The application allows users to view network coverage maps that visualize areas of strong and weak connectivity.

IV. MEASUREMNET RESULTS AND PERFORMANCE EVALUATION

In this section, we are focusing our attention on two main performance parameters of 3G WCDMA mobile networks. Particularly, Received Signal Code Power (RSCP) and Signal-to-Interference-plus-Noise ratio S/(Io+No) technically noted by Ec/Io or Ec/No. It should be noted that the RSCP is the network coverage parameter that is an indication of the signal strength while Ec/No reflects the quality of the connection.

A. *Received Signal Code Power (RSCP)*

The RSCP stand for the received power on one code over the Control Pilot Channel (CPICH). It is an indicator that determines the strength of network coverage and measured in dBm. It is also used in downlink power control, handover decision, cell selection, and to calculate the link budget. A heat map allows to visually identify the areas with robust network coverage as well as areas where the coverage may be weaker. The values of RSCP ranges from around -50 dBm (very strong) to around -120 dBm (very weak) [19]. The RSCP is related to the Received Signal Strength Indicator (RSSI) that corresponds to the total received radio power including the interference and noise as shown in (1):

$$RSSI[dBm]=RSCP[dBm]-Ec/No[dB] \quad (1)$$

B. *Signal-to-Interference-plus-Noise Ratio Ec/No*

The Ec/No stands for the received energy per chip over the total received noise power spectral density through the CPICH channel. It is a measure of the quality of the received signal as it takes into account the interference power from other users and cells. Typical values for Ec/No are from -25 dB (poor) to -3 dB (Excellent). The Ec/No in units of dB is related to RSCP in units of Watt and RSSI in units of Watt as shown in (2):

$$Ec/No[dB]= 10\ Log_{10}\ (RSCP/RSSI) \quad (2)$$

According to a survey conducted at Al-Quds University, researchers gathered information from students about the current status of the 3G network and identified areas where improvements could be made. The coverage percentage of two 3G Palestinian mobile network operators (Jawwal and Ooredoo) versus RSCP based on crowdsourced measurements around Al-Quds University is shown in Fig. 6. It is clear that the coverage distribution of Jawwal mobile network is better than that of Ooredoo, Indeed, Jawwal network has high coverage percentage in the case of high values of RSCP which correspond to excellent and exceptional values.

Fig. 7 shows the quality percentage of the two 3G Palestinian mobile network operators versus Ec/No based on crowdsourced measurements around Al-Quds University. According to Fig. 7, the quality distribution of Jawwal mobile network is much better that that of Ooredoo. High quality percentage is noticed in the case of Jawwal network that corresponds to “very good” and “excellent” values of Ec/No.

According to Fig.6 and Fig. 7, the optimization engineers at Jawwal mobile operator managed to have exceptional signal coverage while maintaining excellent signal quality.

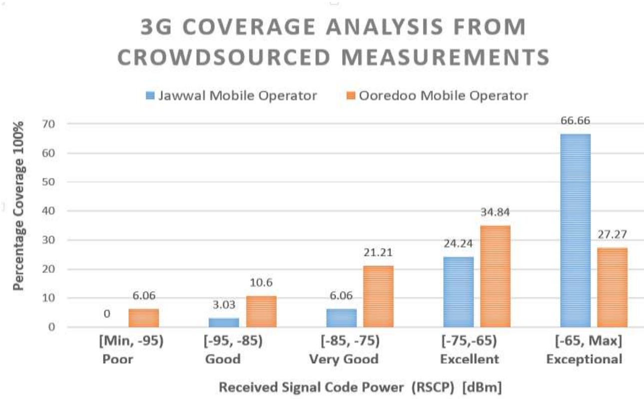

Fig. 6. Coverage distribution of 3G mobile networks based on crowdsource measurements.

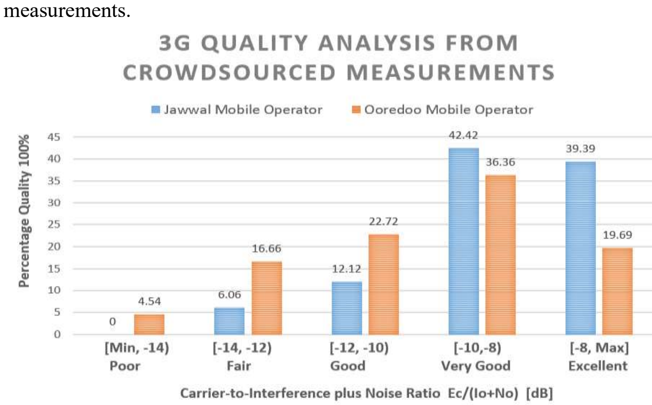

Fig. 7. Quality distribution of 3G mobile networks based on crowdsource measurements.

V. Conclusion

This research explored the potential of crowdsourcing in optimizing network experiences. Mobile users at Al-Quds University were able to see mobile coverage information available and made accessible through the Signal Sense mobile application and the digital maps. Rich data on network connectivity, coverage and quality was gathered. Signal strength, download speeds, coverage, and user feedback revealed critical insights. Weak signal zones and connectivity gaps were illuminated, guiding targeted infrastructure upgrades and data-driven decision making. As a result, network operators can provide seamless connectivity and enhance user experience for students, faculty, staff as well as the community around Al-Quds University.

Signal Sense proves the impact of harnessing collective data in transforming network experiences. The potential of user-driven insights, facilitating ongoing enhancements and tailoring network operations to accommodate diverse user needs. The integration of advanced analytics, streamlined automation, and the potential extension to larger networks signifies promising avenues for refining the crowdsourcing paradigm. It lays a foundation for a future where data-informed decision-making, propelled by active user engagement, becomes crucial in optimizing network management methodologies. Overall, Signal Sense has demonstrated the value of crowdsourced data in enhancing network experiences and holds potential for broader applications. The provided network information related to speed/capacity at specific locations, network coverage and quality was essential to improve user experience.

However, future research must delve deeper into the user engagement and data collection consistency, exploring innovative approaches like gamification and targeted incentives to encourage consistent data collection. By encouraging a vibrant ecosystem of user participation, network optimization, using crowdsourced data will help in delivering exceptional experiences for all.

The success of the Signal Sense within Al-Quds University opens the possibility for expanding its implementation to other educational institutions and geographical areas facing similar network connectivity challenges.

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