



RESEARCH ARTICLE

A NEW MOBILE APPLICATION FOR PHYSICAL MEASUREMENT IN A CELLULAR NETWORK

Aygün VAROL¹, Bilge KARTAL ÇETİN²

¹Isparta Applied Science University, Faculty of Technology, Electrical Electronic Engineering, Isparta,
aygunvarol@isparta.edu.tr, ORCID: 0000-0002-4029-7676

²Ege University, Faculty of Engineering Electrical Electronic Engineering, İzmir,
bilge.kartal@ege.edu.tr, ORCID: 0000-0002-3338-1538

Received Date:22.04.2020

Accepted Date:12.08.2020

ABSTRACT

Mobile cellular network operators make network parameter measurements called 'driving test' at regular intervals to understand the service quality and plan the network capacity. In order to reduce the man power and the cost required for the driving test, these measurements can be obtained with a mobile application which runs on the user equipment. Moreover, end user measurements of the cellular network parameters can be used to improve network performance in many ways, such as troubleshooting problems in network or determining the number and capacity of base stations.

In this paper, existing smartphone applications for network parameter measurement in the literature has been investigated and a new Andoid based application CoverME (Coverage of My Environment) has been developed. CoverME provides all the measurements performed by existing applications and supports four more additional measurements. The developed application makes the measurement accuracy to be analyzed with the help of the return time (RTT-round trip time) parameter and monitor the battery level. In addition, it limits the energy consumption as it is designed to operate in a semi-autonomous. CoverME keeps a record that contains key performance parameters of LTE communication systems; RSRP, RSRQ, RSSI, CQI values. These values matched with cell ID, download speed, latency and current location for the consistency of the application. As a case study, the measurements were made on a route determined in Isparta province with the developed application. Utilizing obtained measurements, the relationship of these values with each other and the relationship with the download speed were examined.

Keywords: *LTE, Android, Measurement Application, RSRP, RSRQ, RSSI, CQI, Download Speed*

1. INTRODUCTION

Today, it is possible to find smartphone applications developed for all activities of daily life such as health, sports, eating and drinking. As these applications and their diversity are rising, the network requirements of mobile users are increasing and varying day by day. The increase in mobile user's demand for data usage has accelerated the service providers' efforts to provide more capacity and improve the network according to current requirements. LTE (Long Term Evolution) is the most current communication technology offering mobile users high data download speed and high network

capacity [1]. In order to find out the quality of the service provided to the users in LTE, physical measurements are made regularly in the field. With regular monitoring, the user expectation and the quality of service experienced by users can be understood.

The signal values experienced by the end user in communication are necessary to understand the performance of the network and to evaluate the quality of service offered by the operator. Operators use a method called 'drive test' to obtain these values. The drive test involves downloading and uploading data with user equipment or measuring various signal values while a vehicle is travelling on a previously determined route. The measurement results obtained by driving tests are used to determine the coverage area, the capacity of the system, and the quality of service. Through the analysis of the data obtained, operators maintain and improve the quality and performance of the network. However, this test is costly because it requires manpower and cannot fully reflect the real user experience. The desired network parameters can be obtained with a measurement application instead of the driving test [2]. With such a measurement application, operators can reduce the work force and cost required for driving testing. Service providers can obtain data that better reflects the user experience rather than a driving test by offering their customers a number of rewards or discounts in exchange for using this app and sharing the data with the operator.

3GPP (3rd Generation Partnership Project) has defined a standard called Minimization of Drive Tests (MDT) to reduce the workload and expenditure required for driving testing and to achieve the true values experienced by users [3]. MDT uses the operating, management, and maintenance system to collect radio measurements from user hardware along with their location. This system allows recording messaging signals between user equipment and base station [3].

Obtaining information about network parameters on the user side can be useful for users as well as the operators. For example, the mobile user can choose the service provider that is best for their usage habits based on the measurements they perform with the application. For example, high data download and upload speed might be more important selection criteria for a company that shares visual contents with its customers over a mobile network, but for a frequent traveler coverage in rural areas becomes the key selection criteria rather than the data speed.

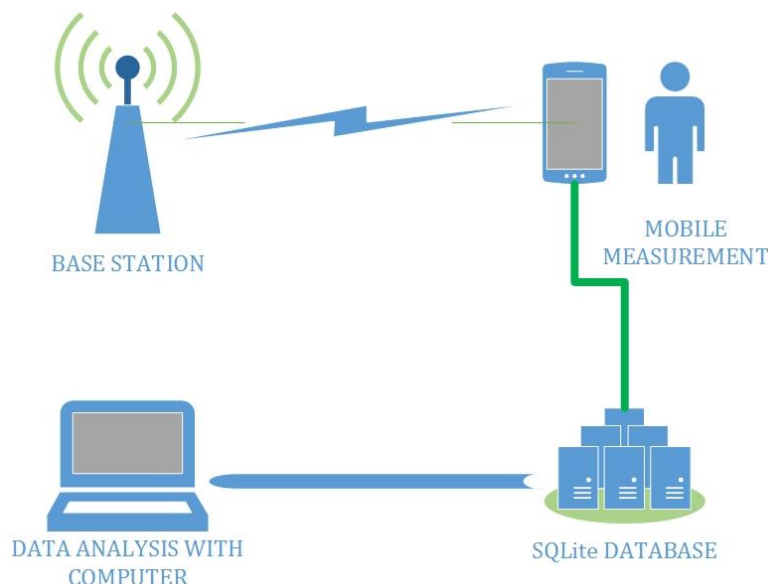


Figure 1. Required components for the measurements.

The most used operating system at smartphones is Android [4]. Android's open-source structure and configurability have made it popular for the application developers. In this study, Android software was used to develop a measurement application due to its widespread use and open source.

When the applications developed for this purpose are examined in the literature, it was seen that the highest number of parameter measurements belong to the Advanced signal status [2] application. In this study, a new application was developed that contains all of the parameters measured by Advanced signal status application, in addition to measuring four different parameters. In the literature, RTT measurement is used to confirm the consistency of the values obtained by the measurement application [5]. It is ensured that the consistency of the measured values in the application is tested with RTT measurement. This application can also measure battery level, network type and data download speed.

As a case study for the developed application, a route was determined in the province of Isparta and the desired data was collected with an Android-based smartphone while travelling at a constant speed in a vehicle. The selected parameters were measured and saved in the SQLite database, and the measurement data was then transferred to the computer and analyzed. Figure 1 shows the main components of the measurements. .

2. EXISTING PHYSICAL MEASUREMENT APPLICATIONS

Mobile networks have become dominant in internet access. Therefore, measuring the end user's network performance has gained interest from developers, users, and network operators. There are many applications in the literature that perform these performance measurements. The parameters and objectives of these applications are briefly explained. The parameters measured by the applications in

the literature are shown in Table 1. A detailed literature review of current practices can be found in [6].

Table 1. Measurement applications and the parameters they measure.

	RSRP	RSRQ	RSSI	RSSNR	CQI	Cell Location	Handover	RTT or PING	Download Speed	Upload Speed	Network Type	Battery Level
Netmap	X							X				
NetworkCoverage	X					X		X			X	
Netradar	X							X		X		
Advanced Signal Status	X	X	X	X	X	X	X					
Mobilyzer								X	X	X		
MobiPerf								X	X	X	X	
OpenSignal	X	X		X					X			
MopEye								X				
Naplytics	X		X						X			
NetMap	X					X			X	X		
CoverME	X	X	X	X	X	X	X	X	X		X	X

Netmap is a community-sourced android application used to measure network key performance indicators such as received power, latency, and data rate. Measurements are made in four different scenarios, including inside, in the city and on the highway. Netmap measures data rate, network connection status, RTT and received power [7].

NetworkCoverage was developed with a focus on multi-source data collection. The measurements are collected on the central server after being performed in different regions on smart devices. The collected data is made available by mobile devices to estimate network performance in certain regions. Thanks to the data, it is possible to improve mobile energy consumption and service quality. They are concerned with the signal strength of the cellular network, RTT and available output parameters in the given region. NetworkCoverage is used to visualize the quality of the cellular network. Signal strength measurements are performed automatically, without user interaction. RTT measurements are usually done manually [8]. However, this application only measures RSRP from LTE signal parameters.

Netradar consists of a client specifically designed for smartphones and tablets and a number of servers that will serve those clients. Clients perform measurements about the network infrastructure. This system, which collects measurements from users around the world, is called Netradar [9]. Netradar measures download speed, upload speed, RTT and signal strength [10].

Advanced Signal Status shows the possibilities of optimizing measurement operations using widely available Android devices. The application measures RSRP, RSSI, SNR, CQI, RSRQ, SINR, Cell Handover parameters using Android's celllocation, NeighboringCellInfo, CellInfo, PhoneStateListener, ServiceState, SignalStrength, TelephonyManager libraries [2].

Mobilyzer is a platform created for conducting mobile network measurement experiments. Mobilyzer is designed around three main parameters: the isolation of network measurement, the realization of measurements, and the platform can be deployed as a library and easily adaptable by other applications [11]. Mobilyzer is a library used by measurement applications rather than a measurement application. It can be integrated into measurement applications using Mobilyzer's API. It can be used for TCP data rate, RTT and ping measurements.

MobiPerf is an open source application for measuring network performance on mobile platforms. MobiPerf measures at regular intervals in the background. MobiPerf is one of the applications that uses the Mobilyzer library. The application works on Android and iOS devices for 2-3 minutes to obtain basic network information, network performance information. As a mobile network measurement system MobiPerf, contains two major components: one is the user application running on mobile devices and the other is the Linux server under their control. Measurement parameters: network characteristics, carrier name, network type, Cell ID, signal strength, Local IP address, GPS, downlink and uplink tests [12].

OpenSignal is a measurement platform that performs an accurate and current measurement of the user experience using the crowdsourcing measurement technique. The app collects and reads crowdsourcing signal information. LTE signal parameters measured by the application are RSRP, RSRQ and RSSNR [13].

Mopeye is a passive-active permanent monitoring application, as opposed to active measuring applications. This method does not generate separate network traffic to the devices. MopEye stops all network traffic and makes the measurement then transfers the collected information. Thus, MopEye can accurately measure RTT (round trip time) without the need for additional network traffic. MopEye monitors network traffic initiated by other apps available on the phone using a VPN service. App measures RTT between the application where the network traffic is created and the server [14].

Nappytics is designed as an Android library, with the goal of being a measurement network tool that can be easily incorporated into any Android application. This library selects the most appropriate application protocol, depending on the network conditions experienced by the user. For example, for LTE technology, the network parameters used are selected as RSRP, RSSI and download speed [15].

NetMap is designed to capture specific parameters that affect network performance and user experience at the application layer. The app collects information for 2G, 3G and 4G, while recording user position with GPS. Netmap measures data rate, network connection status, RTT, and received power [16].

3. MEASUREMENT PARAMETERS FOR LTE CELLULAR NETWORK

In the design of the measurement application, it is necessary to determine the parameters that best represent the performance of LTE communication systems. The four basic radio resource management (RRM) metrics in LTE are CQI, RSRP, RSRQ, and RSSI. The channel quality measurement represented by the SINR measurement is used in link adaptation and packet planning. RSRP and RSRQ are used in handover (switching between networks using different radio technology) decision making [17].

In smartphones, the factors affecting the performance perceived by users are listed as: TCP data rate, RTT, retransmission rate, TCP handshake time, Ping [18]. Signal quality and strength, network operator factors are required to determine channel capacity. None of the LTE-specific signal parameters sufficient enough to determine the download speed without other parameters. Only when all parameters used together, by gathering, they can explain some of the variability in the model. Understanding the factors that determine download speed is valuable for both users and operators. With these factors, users wish for the best performance services and devices that are practically possible. And the network operators can understand how to increase and improve their infrastructure.

It is not easy to achieve signal strength criteria in LTE connections. In 2G and 3G technologies, there was the metric called the Received Signal Strength Indicator (RSSI), which specifies the received signal strength, which is always precise and easy. The RSSI metric was useful in the case that frequencies were not reused in multiple cells. In a single cell, the signal strength could be described directly with a single frequency. Due to the increasing number of users, it was necessary to use the same frequencies again at regular intervals. With the advancement of digital modulation technologies, network operators were able to develop increasingly complex and overlapping cell topologies. Since reuse of the same frequencies led to interference between neighboring cells, it became difficult to obtain information about network performance by using the RSSI metric alone. Instead of the RSSI value used in 2G and 3G, three LTE-specific signal criteria that can be measured on Android-based devices are RSRP, RSRQ and RSSNR parameters [13]. Key performance parameters for a cellular network introduced below.

3.1. Key Performance Parameters

The most important metric on the user side for evaluating the service quality of a network is the data rate and latency. In addition, key performance parameters that must be monitored by operators in order to use network resources efficiently and ensure service quality can be listed as RSRP, RSRQ, RSSNR, RSSI, CQI, SINR, and RTT.

- **RSRP**
Reference Signal Received Power (RSRP), is a cell-specific signal strength-dependent metric used as an input for cell selection and handover decisions. RSRP for a given cell is defined as the average power (Watt) of the source elements carrying cell-specific reference signals within the bandwidth [17]. The RSRP value range is from -140 to -44 dBm.
- **RSRQ**
Reference Signal Received Quality (RSRQ) measurement is a cell-specific signal quality metric. Similar to RSRP measurement, this metric is used to sort between different cells based on their signal quality. This metric can be used as input in scenarios where RSRP measurements are not sufficient to make reliable cell selection / handover decisions [17].
- **RSSNR**
Reference Signal Signal to Noise Ratio (RSSNR), is a measure of the signal-to-noise ratio of the reference signal and therefore provides an indication of the quality of the link. This metric can be used to assess the interference effect, and therefore in urban areas RSRP may be high [13].

- **RSSI**
Reference Signal Strength Indicator (RSSI), is the total power received by the source element in dBm. Although not critical for LTE, its measurement is important to understand its relationship with other parameters. RSSI is a combination of signals from all sources, including power from the serving cell, the non-serving cell, the common channel, and the adjacent channel interference [19].
- **CQI**
Channel Quality Indicator, carries information about how good or bad the communication channel quality is. There are 15 different CQI values in LTE and it maps between CQI and modulation scheme. For example, the CQI's 10 value corresponds to the 64QAM modulation scheme [20].
- **RTT**
Round-Trip Time (RTT), is the time it takes for a signal packet to reach and return to a specified target from the source. The measurement of this parameter is done to ensure the consistency of the application.

The importance of these parameters varies according to the requirements of the application. For example, broadcasting video requires high data rate and low packet loss hence RTT has less impact on quality. In contrast, audio connections require low RTT, but low data rate and high packet loss are acceptable [21].

3.2. Other Measured Parameters

- **Network Type**
This parameter is used to determine if the base station is exchanged horizontally or vertically between two networks using different radio technology or within the same network. When the cell location changes while in the same network type, it is concluded that this handover is horizontal, if the network type and the cell location change, this handover is vertical.
- **Location**
Required for the location where the signal values will be recorded. In this way, the coverage map can be created.
- **Cell Location and Cell ID**
Returns the identity of the cell the user is in. Required to capture the handover event.
- **Battery Level**
Battery level monitoring is necessary to determine the effect of the battery on the measurements. It is also used to determine the energy consumption of the application .

The received signal level (RSL) from each cell in the network is one of the basic RF measurements. In LTE networks, this measurement is provided from the reference sequence and is called RSRP. The reference signal is transmitted at constant power. Signal strength measurements determine the received cell strength and cell coverage. For this reason, RSRP is used to identify holes in the coverage area. In addition, RSRP measurement is essential in troubleshooting and establishing correlation with other key performance indicators (data rate and latency). This measurement determines the allocated modulation scheme and encoding rate. To measure received power,

professional tools including receivers and channel carriers are used. Alternatively, RSRP can be measured using the app on an ordinary smartphone [22].

In addition to these parameters, the application measures the parameters EVDO (Evolution Data Optimized) RSSI, EC/IO (the Ratio of the Received Energy to the Interference Energy), SNR (Signal-to-Noise Ratio), CDMA (Code Division Multiple Access) RSSI, EC/IO which are 3G technology, and GSM RSSI, BER which are 2G technology. The purpose of these measurements is to capture signal parameters when a collapse occurs in the network .

4. MEASUREMENT CONSISTENCY

As smartphone used for the measurement, the results have been exposed to many factors, therefore, these measurements may not be the values that users expected. In order to be able to rely on the measurement results of the application, first of all the factors affecting these measurements should be known and their effects should be minimized. For this purpose, the factors affecting the measurement results were examined in this section.

One of the factors affecting the measurement results is the delay. To see the effect of the delay , the RTT measurement is performed and the consistency of the measurement is tested by using the obtained RTT results. RTT measurement are defined based on RFC 2681 [23] and contains a time stamp immediately before sending the packet and immediately after receiving the packet [24].

Although there are many measurement applications available, the consistency of measurements is not efficient. Using RTT as a metric, the performance of smartphone-based network metrics can be evaluated [5]. Other factors affecting measurement results might be listed as application models, Android architecture and network protocols. Detailed information about these effects can be found in [24].

5. ENERGY CONSUMPTION OF MEASUREMENTS IN SMARTPHONES

This section describes some situations that cause energy consumption in mobile networks. Thus, the energy required by the developed application per measurement can be determined.

- **Location Measurement**

Location-based apps have become increasingly popular on smartphones in recent years. Using these applications actively may drain the battery due to intensive location-sensing operations.

GPS energy consumption is between 400mW – 600mW. Using GPS continuously on a smartphone with a battery of 1000mAh will end battery life in 6 hours. GPS location detection and reporting times are 4 to 5 and 10 to 12 seconds, respectively [25].

- **Connection Speed**

The increase in data rates of cellular 3G/4G networks, coupled with the growth of mobile application use, is significantly affecting the quality of service the user perceives. QoE can be affected in two ways: first, data rates on networks decrease when multiple users take turns requesting content; second, data transfer on slow connections consumes considerable energy over fast connections. Both can be avoided by better management of available resources [21].

- **Handover**

It is the name given to the transition between two networks using different radio technologies or between base stations on the same network. In a heterogeneous network environment, vertical and horizontal handover is a very desirable feature. An effective handover solution provides fixed connectivity to mobile users and allows seamless transition between different networks. Thus, by improving the user experience, it enables the best quality of service. But changing the network requires more device energy.

Handover can be between base stations with the same technology (horizontal Handover) or it can trigger change in radio technology, such as 2G to 3G or 3G to LTE (vertical Handover). Horizontal Handover usually occurs from the movement of the user. To study the effect of move, measurements at different speeds are required [26], [10].

After investigating the parameters to be measured, the factors affecting these parameters and the energy consumption of the measurements, the CoverME application was designed by considering all these parameters.

6. PROPOSED NEW MOBILE APPLICATION: COVERME

In this section, the libraries and tools used in the design of the measurement application and the parameters measured by the application and overall operating principle of the application are explained.

Android Studio is an IntelliJ IDEA-based, formal Integrated Development Environment (IDE) environment for developing Android applications. The application can be developed for all Android devices thanks to the editor and developer tools of Android Studio. Utilizing its emulator, the designed application can be tested. With Android-enabled libraries and external libraries, applications can be created for various purposes.

The developed measurement app CoverME detects the performance of the cellular network the smartphone is in its coverage. To this end, it measures RSRP, RSRQ, RSSI, RSSNR, Download Speed, Cell ID and location. These values are stored in the internal memory of the phone with SQLite for analysis. Utilizing the obtained measurement a coverage map is created for the cellular network. Measurement parameters can be accessed through the libraries provided by Android. Three Android classes (TelephonyManager, LocationManager and BatteryManager), one library (SQLite) and one external class (facebook network connection class) that are used to make these measurements are listed below.

- 1)android.telephony TelephonyManager
- 2)android.os BatteryManager
- 3)android.location LocationManager
- 4)android.database.sqlite SQLiteOpenHelper
- 5)facebook network-connection-class

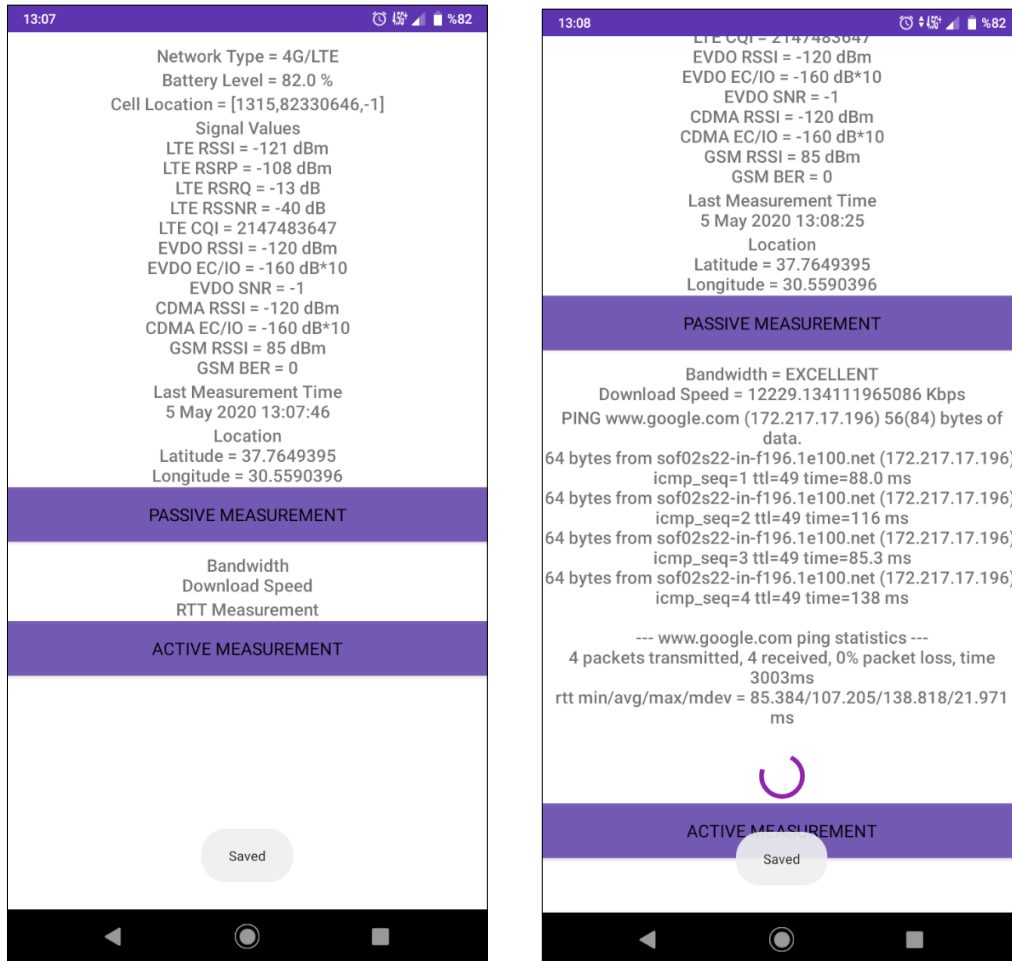
The measurement application can be used on API 27 Android 8.1 Oreo devices or latter version devices. CoverME performs two different measurements, active and passive measurements. Active measurements are download speed and RTT measurements that require internet and generate additional network traffic. Passive measurement performs LTE signal parameters, cellular network

type, cell location, battery, GPS measurements that do not require internet and do not generate additional network traffic. Figure 2 shows the screenshots during the passive and active measurements.

The application automatically performs passive measurements every time one of the values changes, without the need for the user to press the button, and saves it to the SQLite database with a timestamp. When the data is successfully saved, the user is informed via a (Toast) notification message. For the active measurement, the active measurement button must be clicked by the user. In the active measurement, the application downloads a 100 MB file and divides it by the processing time to achieve the download speed. To obtain RTT, measurements performed in the active mode and the application pings the website 'google.com'. In this ping process, the application sends 4 packets to 'google.com'. The time that these packets reach and return to the target is determined. The minimum / average / maximum / standard deviation RTT values of the 4 packets that sent, packet loss and total processing time are displayed in the terminal. RTT is used to confirm accuracy in active measurement, but is not stored in the database. Flowchart for the measurement process is given in Figure.3. TelephonyManager class is used to obtain Network Types, Cell Location and Signal Parameters. D To obtain battery level and location BatteryManager and LocationManager classes are used, respectively.

General Mobile GM 8 smartphone was used for measurements. As seen in Figure 2, the value of LTE CQI data is '2147483647' which is the maximum value of the 32-bit String variable. CoverME measurement application has the ability to measure CQI, but this false CQI value seen because the smartphone used in the measurements does not support CQI measurement. The measurements supported by smartphones differ by models and brands. The ability of the phone to measure the desired measurement needs to be considered before using any app for physical measurements.

CoverME measurement application can be developed for IOS devices. However, this is not possible with Android Studio. Although IOS and Android devices look similar on the outside, operating systems on the inside are very different. The codes used in the IOS application design are in different languages and different structures. IOS developers use Mac-supported Xcode as a program. The programming language used by these developers is Swift. The IOS library with the signal parameters is Core Telephony. Since the market share of mobile operating systems is 74.14% for Android and 25.26% for IOS, the platform on which the application will run is selected Android [4].



a) Passive Measurements

b) Active Measurements

Figure 2. CoverME Passive/Active Measurement Interface.

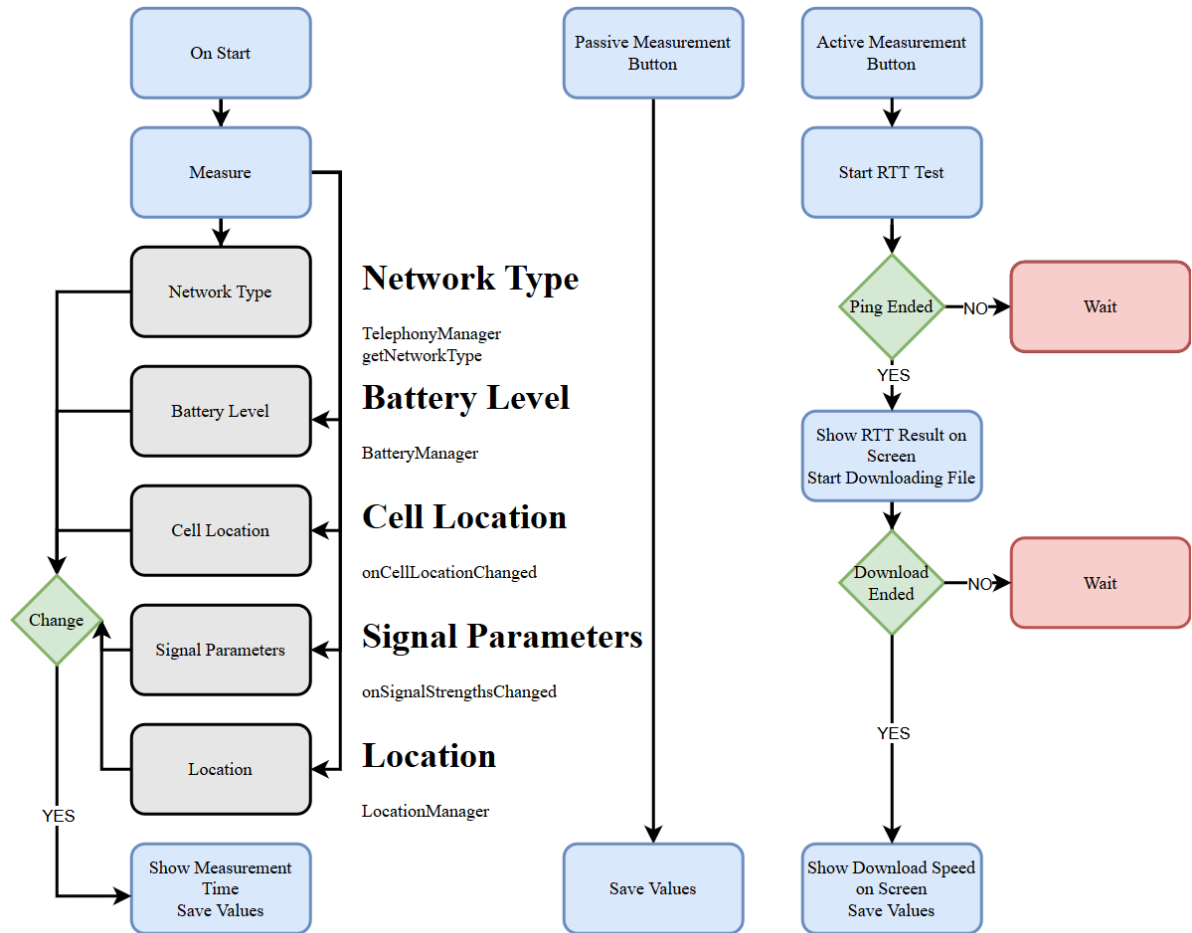


Figure 3. Flowchart of the Measurement Process

7. MEASUREMENTS AND DISCUSSIONS

Using the developed measurement application CoverME, 1186 measurements were carried out in different neighborhoods of Isparta. 85% of the measurements were made on foot, and 15% were carried out on the vehicle with an average of 40 km/h. 838 of the measurements are available since they have both location and download speed values. With these measurements, a coverage area has been created in Google My Maps. Each marker on the map represents a measurement. By clicking on the marker, the performance of the cellular network of its location can be accessed.

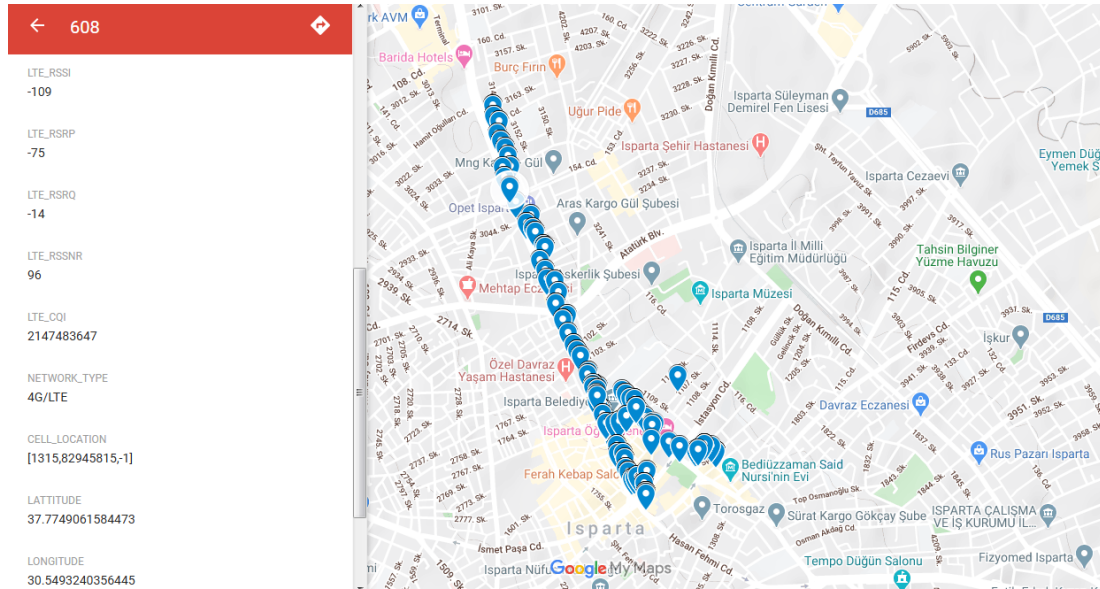


Figure 3. Isparta MyMaps Image.

Measurements are made by the end user via smartphone and stored in the database in its internal memory. The data collected were analyzed on the computer, and the correlation between LTE signal values and download speed was plotted. To determine whether the battery level has an effect on the measurements, the download speed is also plotted by the battery percentage.

The graphics were created with the Curve Fitting tool. Exponential model for two-dimensional graphics and Polynomial model with a grade 2 for three-dimensional graphics were used.

7.1. Correlation of LTE RSRP value with download speed

Figure 5 shows the relationship of RSRP value with download speed. High download speeds (60 Mbps>) occurred when the LTE RSRP value was -70 dBm and above. When the graphic in Figure 5 is examined, different download speeds can be seen at the same RSRP values. This indicates that the download speed is not only dependent on RSRP. There are different RSRP values for the same download speed values. However, it can be concluded that a certain RSRP value must be exceeded in order to increase the download speed. The highest download speed value was measured between -60 and -50 dBm of LTE RSRP. The lowest value of LTE RSRP was measured between -110 and -100 dBm. Measurements below 10 Mbps continued up to -60 dBm. In general, according the measurement results it was concluded that the increase in RSRP value has a positive effect on the download speed.

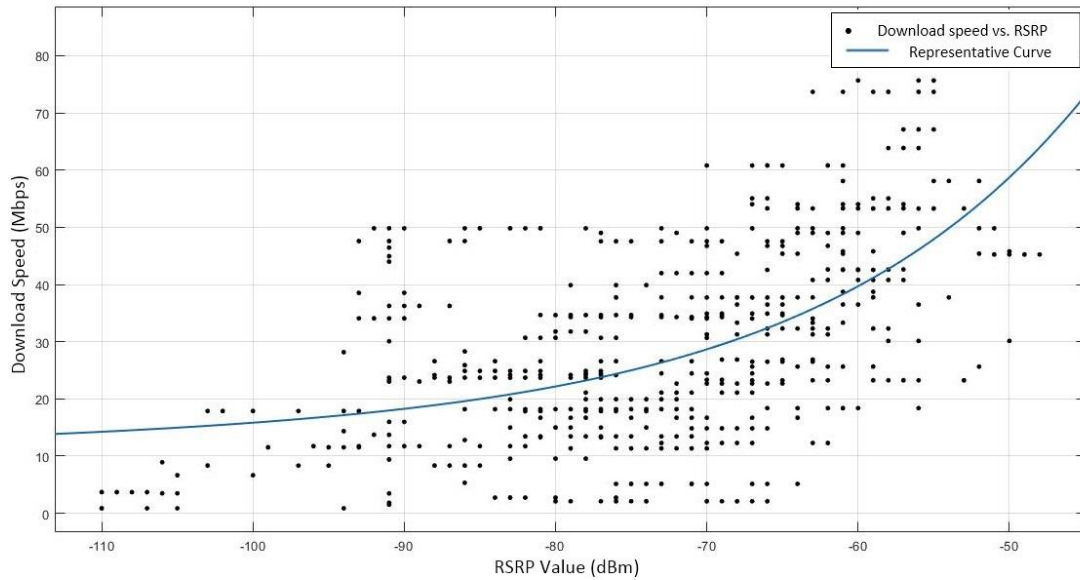


Figure 4. RSRP graph.

7.1.1. Correlation of LTE RSRQ value with download speed

Figure 6 shows the download speed according to the RSRQ change. Based on the curve we obtained with Curve fitting, the increase of LTE RSRQ also increased the download speed. The highest download speed measurement was realized at -12 dB of RSRQ. Measurements were made at different speeds at the same value of RSRQ. This is due to the effect of other parameters on download speed. Low download speed measurements were taken even at high values of RSRQ. For measurements made at values less than -14 dB for LTE RSRQ, the download speed could not exceed 50 Mbps. High download speeds were achieved only after this level of RSRQ. Also, for measurements with RSRQ values greater than -9 dB, the download speed has always been above 15 Mbps. Although the increase in RSRQ value increases the average data rate, it is not enough to evaluate network performance alone.

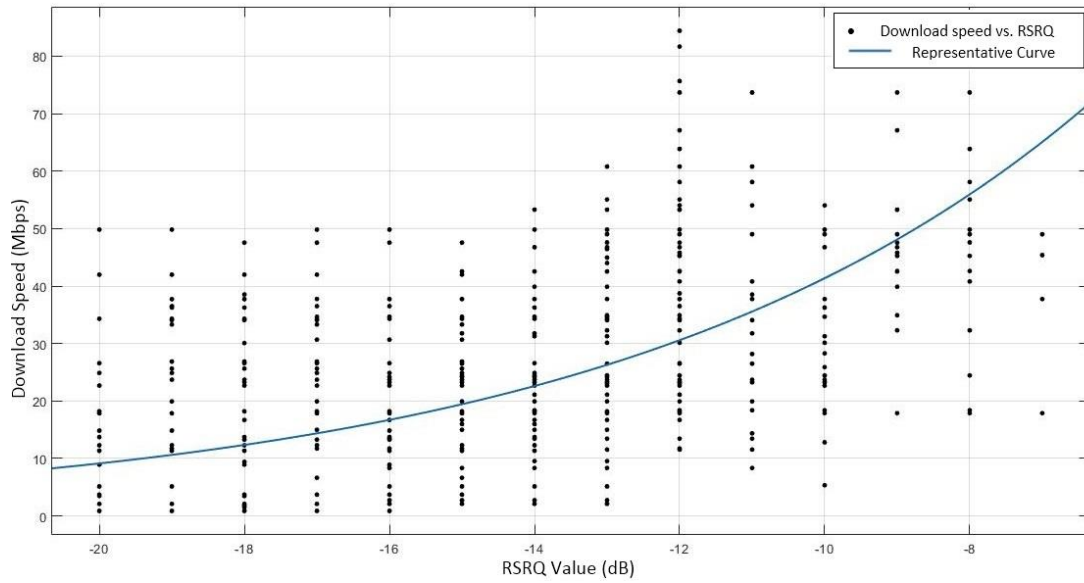


Figure 5. RSRQ graph.

7.1.2. Correlation of LTE RSSI value with download speed

Figure 7 shows the effect of RSSI on download speed. The graph in Figure 7 shows that high download speeds are achieved at high RSSI values. Download speed measurements of 50 Mbps and faster performed LTE RSSI values greater than -110 dBm. In general, LTE RSSI value has been found to affect download speed in a linear way, but this effect is limited.

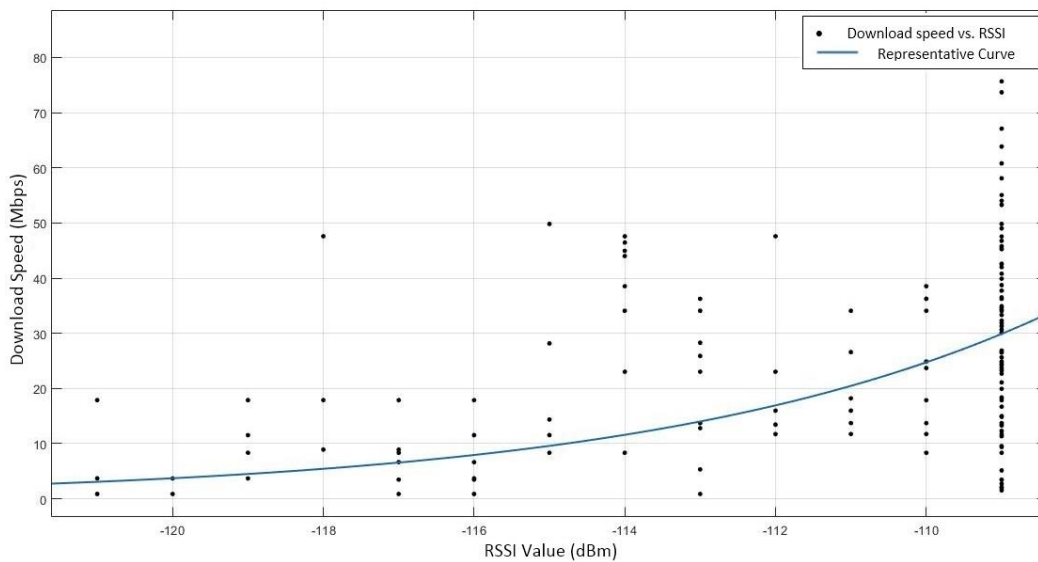


Figure 6. RSSI graph.

7.1.3. Correlation of LTE RSSNR value with download speed

Figure 8 shows the relationship between download speed and RSSNR value. The highest download speed measured between 200 dB and 250 dB of RSSNR value. It is seen that it is possible to reach high download speeds after 50 dB of RSSNR. For measurements greater than 120 dB of RSSNR, the download speed is not less than 10 Mbps. In some cases where RSSNR is less than -100 dB, there are exceptions that can reach the download speed of 50 Mbps. The reason for this is that other parameters that affect the download speed are partially good (when the measurements are examined, it has observed that the RSSI value is high in these values). Based on the measurements, RSSNR has a positive correlation with the download speed most of the time. This can also be seen from the representative curve obtained with curve fitting. However, as can be seen from the graph same download speed might be obtained for a large range of RSSNR values.

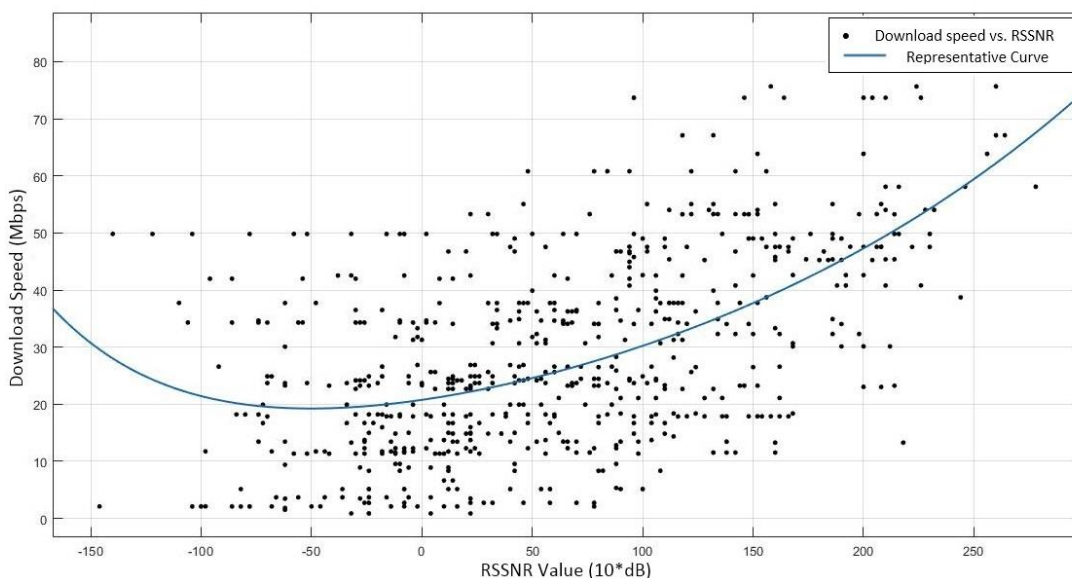


Figure 7. RSSNR graph.

7.1.4. Correlation of battery level with download speed

Figure 9 shows the effect of the percentage of the battery on the download speed. High download speeds are achieved when the battery is almost fully charged. In cases where the battery is less than 80%, the download speed could not exceed 60 Mbps. The lower the battery level, the lower the download speeds in the measurements. This can be understood from the peak values of the download speed in the measurement groups that occur in battery percentages.

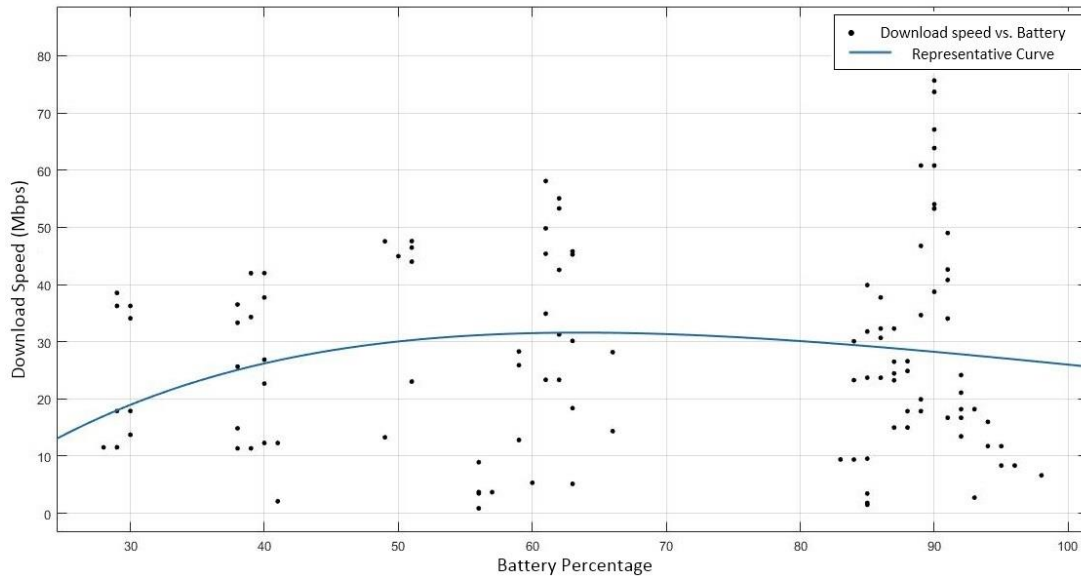


Figure 8. Battery graph.

Since the download speed does not change depending on a single parameter, different speed values are observed at the same points in two-dimensional graphics. In order to better explain this situation, the variation of the download speed depending on two parameters has also been drawn in three dimensions. These drawings were created using the Matlab Curve Fitting tool using Polynomial, x and y with grades 2.

7.2. Correlation of LTE RSRP and LTE RSRQ values with download speed

Figure 10 shows the relationship of download speed to both RSRQ and RSRP. Low download speed measurements are observed even at high values of RSRQ. Hence, it was concluded that the effect of RSRQ value on download speed is limited. However, it is seen that both RSRQ and RSRP should be high in order to reach high download speeds. At the very large values of the RSRQ value, even though the RSRP value is very small, the data download speed has been found to be around 15 Mbps. However, when the RSRQ and RSRP values are compared, it can be said that the RSRP value plays a more decisive role in the download speed compared to the RSRQ value.

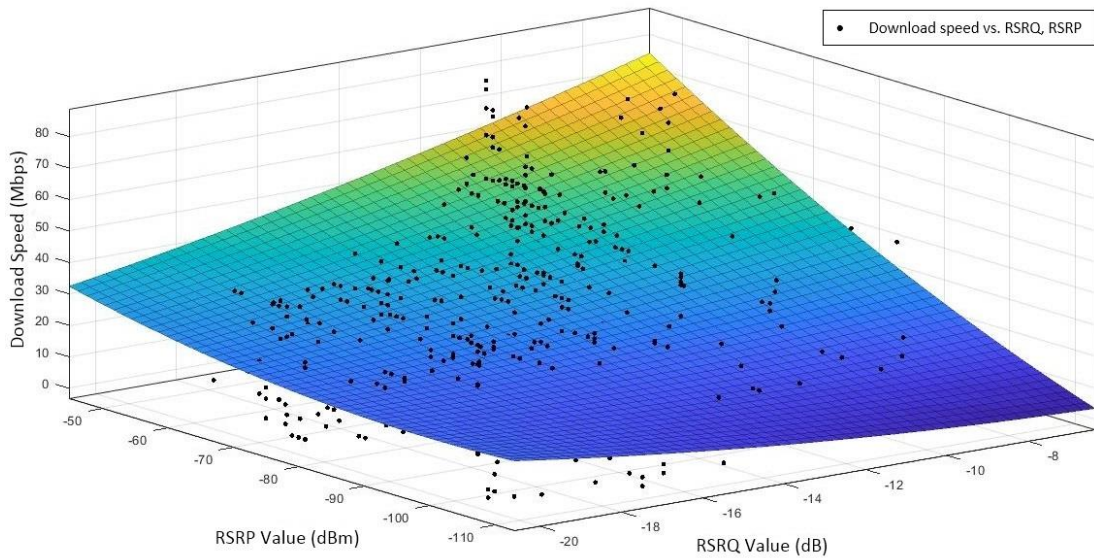


Figure 9. RSRP and RSRQ graph.

7.2.1. Correlation of LTE RSRP and LTE RSSNR values with download speed

Figure 11 shows how the download speed changes according to RSRP and RSSNR values. When RSRP is very small (<-100 dB) RSSNR values greater than 0 dB, a small increase in download speed has occurred. The high download speed is achieved only if these two values are high.

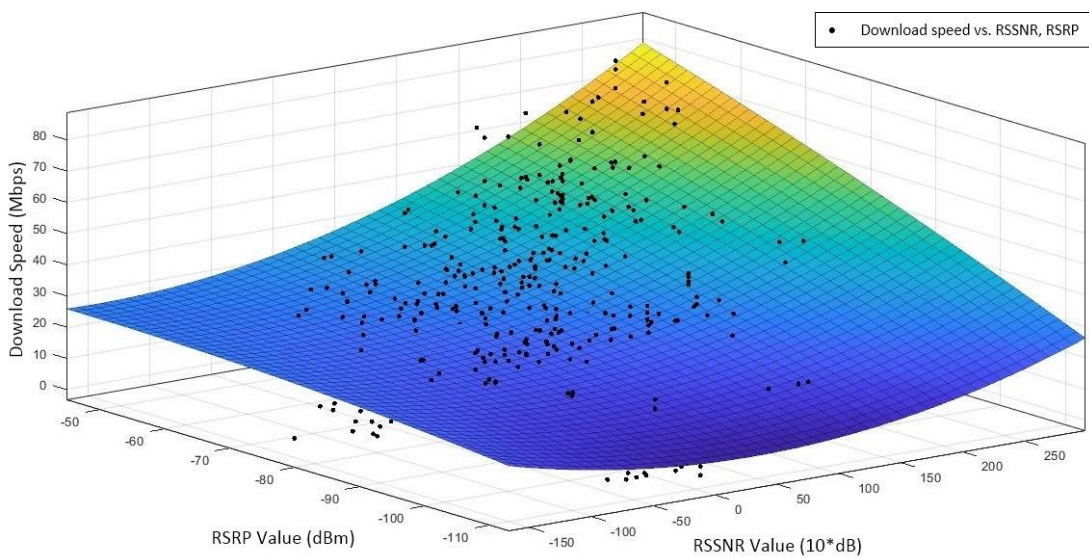


Figure 10. RSRP and RSSNR graph.

7.2.2. Correlation of LTE RSSI and LTE RSRQ values with download speed

When the graph in Figure 12 is examined, it is observed that the RSSI value has no effect on the data download speed. As can be seen from the graph, even RSSI is at very low value, the data download speed takes a wide range of values. For example, for the same RSSI value, the data rate can be 10 Mbps or 70 Mbps. According to obtained results, it is observed that there is no positive or negative correlation between RSRQ and RSSI.

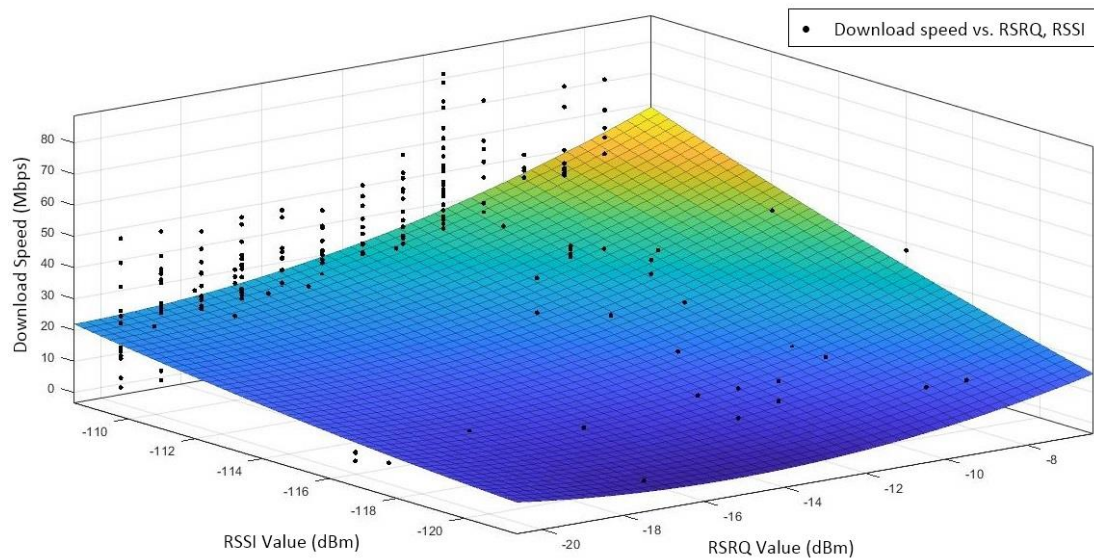


Figure 11. RSSI and RSRQ graph.

7.2.3. Correlation of LTE RSSI and LTE RSSNR values with download speed

Figure 13 shows how both RSSI and RSSNR affect the download speed. As can be seen from the figure, it is observed that RSSNR has a positive effect on the download speed regardless of RSSI value. It can be concluded that the RSSNR value must necessarily be high to achieve high data rates. For example, if the point where the RSSNR value is 50 dB is examined in the figure, it can be seen that even at the lowest value of the RSSI, the data rate of 20 Mbps can be exceeded.

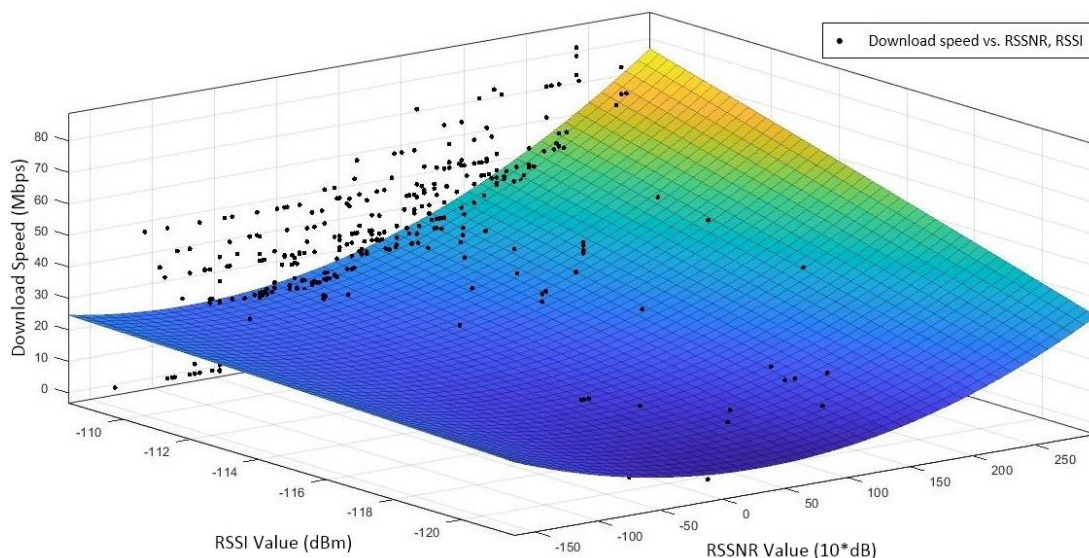


Figure 12. RSSI and RSSNR graph.

8. CONCLUSION

In this study, a smartphone application was developed in order to measure specific parameters in the LTE communication network. The relationship between RSSI, RSSNR, RSRQ and RSRP values measured in the field and correlation of these values with the download speed was analyzed. Based on the analyses, it is seen that measured parameters RSSI and RSRQ increase the average data download speed, but they do not provide accurate information about network performance or instantaneous data rate. In other words, a good data rate value can be obtained at a measured point where the RSRQ value is too small, whereas the opposite can occur in a case where the data rate value at a very high RSSI or RSRQ value can be quite low. In addition, RSSNR and RSRP values enable accurate inferences about data rate performance below and above certain values. For example, a specific threshold value for RSRP and RSRQ can be mentioned in order to exceed a specific data rate value.

Measurement application CoverME is an application that covers all the parameters measured by measurement applications in literature. Cell location, network type, signal parameters, download speed and delay are measured with this application. In the next phase of the study, measurements will be made in different field classifications (Stadium, campus, concert area, intercity roads etc.) and will be classified for different movement speeds of the mobile user. In addition, by transforming the application into a crowd-sourcing application, gaining the ability to collect large amounts of data in a short time and determining the uploading speed is the next step in the work.

REFERENCES

- [1] Cisco Annual Internet Report (2018–2023)
- [2] Albero, F. M., Štern, A., & Kos, A. (2013). Mobile network measurements using Android. In ERK-2013 International Electrotechnical and Computer Science Conference (pp. 97-100).

- [3] Johan J, Wuri A. H., Sean K., Gyula B. (2012). Minimization of Drive Tests in 3GPP Release 11, IEEE Communications Magazine.
- [4] <https://gs.statcounter.com/os-market-share/mobile/worldwide>, Feb 2019 - Feb 2020, Son Erişim 21.04.20.
- [5] Li, W., Mok, R. K., Wu, D., & Chang, R. K. (2015, April). On the accuracy of smartphone-based mobile network measurement. In 2015 IEEE Conference on Computer Communications (INFOCOM) (pp. 370-378). IEEE.
- [6] Goel, U., Wittie, M. P., Claffy, K. C., & Le, A. (2015). Survey of end-to-end mobile network measurement testbeds, tools, and services. IEEE Communications Surveys & Tutorials, 18(1), 105-123.
- [7] Lauridsen, M., Rodriguez, I., Mikkelsen, L. M., Gimenez, L. C., & Mogensen, P. (2016, April). Verification of 3G and 4G received power measurements in a crowdsourcing Android app. In 2016 IEEE Wireless Communications and Networking Conference (pp. 1-6). IEEE.
- [8] Kaup, F., Jomrich, F., & Hausheer, D. (2015, March). Demonstration of NetworkCoverage–A Mobile Network Performance Measurement App. In International Conference on Networked Systems (NetSys) (Vol. 77, No. 7, pp. 228-230).
- [9] Sonntag, S., Schulte, L., & Manner, J. (2013, April). Mobile network measurements–It's not all about signal strength. In 2013 IEEE Wireless Communications and Networking Conference (WCNC) (pp. 4624-4629). IEEE.
- [10] Sonntag, S., Manner, J., & Schulte, L. (2013, May). Netradar-measuring the wireless world. In 2013 11th International Symposium and Workshops on Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks (WiOpt) (pp. 29-34). IEEE.
- [11] Nikraves, A., Yao, H., Xu, S., Choffnes, D., & Mao, Z. M. (2015, May). Mobilyzer: An open platform for controllable mobile network measurements. In Proceedings of the 13th Annual International Conference on Mobile Systems, Applications, and Services (pp. 389-404).
- [12] Huang, J., Chen, C., Pei, Y., Wang, Z., Qian, Z., Qian, F., ... & Bahl, P. (2011). Mobiperf: Mobile network measurement system. Technical Report. University of Michigan and Microsoft Research.
- [13] Caine, J., Gill, B., Johnston, S., Robinson, J., & Westwood, S. (2014, September). Modelling download throughput of LTE networks. In 39th Annual IEEE Conference on Local Computer Networks Workshops (pp. 623-628). IEEE.
- [14] Wu, D., Li, W., Chang, R. K., & Gao, D. (2016). MopEye: Monitoring per-app network performance with zero measurement traffic. arXiv preprint arXiv:1610.01282.
- [15] Alepuz, I., Cabrejas, J., Monserrat, J. F., Perez, A. G., Pajares, G., & Gimenez, R. (2017, June). Use of mobile network analytics for application performance design. In 2017 Network Traffic Measurement and Analysis Conference (TMA) (pp. 1-6). IEEE.

- [16] Lauridsen, M., Rodriguez, I., Mikkelsen, L. M., Gimenez, L. C., & Mogensen, P. (2016, April). Verification of 3G and 4G received power measurements in a crowdsourcing Android app. In 2016 IEEE Wireless Communications and Networking Conference (pp. 1-6). IEEE.
- [17] Afroz, F., Subramanian, R., Heidary, R., Sandrasegaran, K., & Ahmed, S. (2015). SINR, RSRP, RSSI and RSRQ measurements in long term evolution networks. *International Journal of Wireless & Mobile Networks*.
- [18] Huang, Junxian & Xu, Qiang & Tiwana, Birjodh & Mao, Zhuoqing & Zhang, Ming & Bahl, Paramvir. (2010). Anatomizing Application Performance Differences on. 165-178. 10.1145/1814433.1814452.
- [19] Almohamedh, H., Al Qurashi, F., & Kostanic, I. (2014). Mobile videos quality measurements for long term evolution (LTE) network. vol. I, 505-509.
- [20] https://www.sharetechnote.com/html/Handbook_LTE_CQI.html, Son Erişim 21.04.20.
- [21] Kaup, F., & Hausheer, D. (2013, October). Optimizing energy consumption and qoe on mobile devices. In 2013 21st IEEE International Conference on Network Protocols (ICNP) (pp. 1-3). IEEE.
- [22] Hazza A.S., Humaid A.S., Ivica K., Josko Z. (2018). Verifying Measurements of Reference Signal Received Power (RSRP) on LTE Network using an App on Android Smartphones, 2018 IEEE 9th Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON), Canada.
- [23] <https://tools.ietf.org/html/rfc2681>, Son Erişim 21.04.20.
- [24] Xue, L., Ma, X., Luo, X., Yu, L., Wang, S., & Chen, T. (2017, May). Is what you measure what you expect? factors affecting smartphone-based mobile network measurement. In IEEE INFOCOM 2017-IEEE Conference on Computer Communications (pp. 1-9). IEEE.
- [25] Zhuang, Z., Kim, K. H., & Singh, J. P. (2010, June). Improving energy efficiency of location sensing on smartphones. In Proceedings of the 8th international conference on Mobile systems, applications, and services (pp. 315-330).
- [26] Apoorva Prakash M V, Dr. MC Padma (2014). Battery-Bandwidth Based Handover Framework for 3G/WLAN Using Android Handheld Devices, *Journal of Engineering Research and Applications*

ABBREVIATIONS

2G	Second Generation
3G	Third Generation
3GPP	The 3rd Generation Partnership Project
4G	Fourth Generation

BER	Bit Error Rate
CDMA	Code Division Multiple Access
CQI	Channel Quality Indicator
EC/IO	The Ratio of the Received/Good Energy to the Interference/Bad Energy
EVDO	Evolution Data Optimized
GPS	Global Positioning System
GSM	Global System for Mobile Communication
LTE	Long Term Evolution
MDT	Minimization of Drive Tests
QoE	Quality of Experience
RF	Radio Frequency
RFC	Request For Comments
RRM	Radio Resource Management
RSL	Received Signal Level
RSRP	Reference Signal Receive Power
RSRQ	Reference Signal Received Quality
RSSI	Received Signal Strength Indicator
RSSNR	Reference Signal Signal to Noise Ratio
RTT	Round-Trip Time
SINR	The Signal-to-Interference-Plus-Noise Ratio
SNR	Signal-to-Noise Ratio
TCP	Transmission Control Protocol
VPN	Virtual Private Network

INFORMATION

This study is partially supported by a research project with number of 16-muh-033 at the Ege University.