1. Measurement and Analysis of the LTE Mobile Network

Abstract

This laboratory exercise focuses on measuring key performance indicators (KPIs), including RSRP (Reference Signal Received Power), RSRQ (Reference Signal Received Quality), RSSI (Received Signal Strength Indicator), and RSSNR (Received Signal-to-Noise Ratio) in mobile networks. The aim is to perform measurements using the SIM8200EA-M2 module with the software developed for this exercise and subsequently conduct a quantitative analysis. The goal is to assess signal coverage and reliability, particularly in the context of mobile networks. Through this process, students develop the ability to evaluate network performance and extract essential metrics from 4G networks.

Keywords

Mobile Networks – LTE – RSRP – RSRQ – RSSI – RSSNR – SIM8200EA-M2 – Quantitative Analysis of LTE Coverage

Assignment

1. Familiarize yourself with the SIM8200EA-M2 module and the relevant software for measuring key performance indicators in mobile networks.
2. Understand the significance of the measured parameters, such as RSSI, RSRP, RSRQ, and RSSNR.
3. Perform measurements on three different LTE bands (Band 1, Band 3, Band 20) for 5 minutes at three defined locations.
4. Analyze the impact of frequency band and location on signal quality using the measured data.
5. Evaluate network coverage and reliability based on the obtained data and other relevant information.
6. Present the results of the analysis and coverage in a clear measurement report.

1. Introduction

In today's world, mobile networks have become an integral part of the daily lives of most of the world's population. Within mobile networks, the fundamental concept is the division of extensive areas into smaller cells. Each cell has its own base station (BS), and devices (user equipment - UE) connect to the nearest station in their current location. As users move and transition between cells, the network ensures their uninterrupted connection by connecting them to the most suitable nearby base stations. These approaches and technologies ensure continuous and seamless connectivity for mobile devices.

Among the most widely used networks today are fourth-generation networks (4G). 4G LTE (Long Term Evolution) or E-UTRAN (Evolved Universal Terrestrial Access Network), introduced in 3GPP Rel. 8, is the radio access component of the Evolved Packet System (EPS) - a purely IP-based mobile network standard. As an evolution of 3G UMTS, 4G LTE shares many similarities, such as harmonized frequency bands, but also many significant technological advancements [4]. Using the Orthogonal Frequency Division Multiple Access (OFDMA) multiple access scheme and combining it with higher modulation orders (up to 256QAM), large bandwidths (up to 100 MHz aggregated), and spatial multiplexing techniques (MIMO), very high data transfer rates can be achieved [4]. LTE is developed to support a range of frequency bands - E-UTRA operational bands - which currently range from 450 MHz to 6 GHz. Available bandwidths are also flexible, ranging from 0.2 MHz to 20 MHz. LTE is developed to support both Time Division Duplex (TDD) and Frequency Division Duplex (FDD) duplexing technologies [4].

Every mobile network consists of two basic parts. The first part includes the physical layer (PHY) and the Radio Access Network (RAN). The RAN section coordinates transmissions, assigns channels, and performs other coordination functions. The second part is the Core Network (CN), which connects all access networks. It provides global services such as authentication, roaming, and billing, while also establishing connections with external networks such as the internet [6]. Fig. 1 illustrates the simplified architecture of the LTE network and its basic elements. The network is structured into two main components: the E-UTRAN and the Evolved Packet Core (EPC), as shown in Fig. 1. E-UTRAN is responsible for supervising the radio interface between UE and the network. Conversely, the EPC handles call coordination and data routing between UE and external networks.

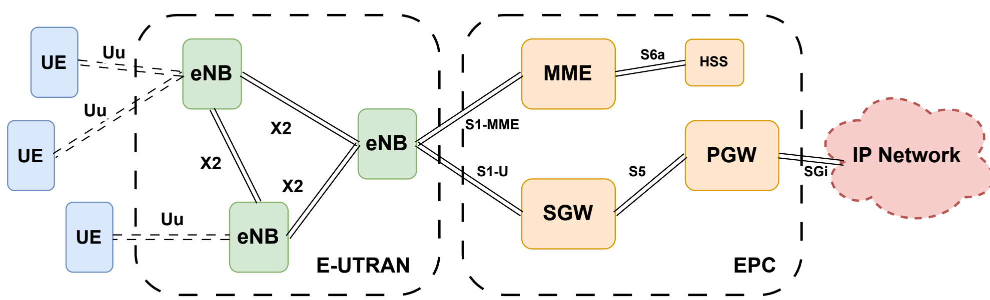


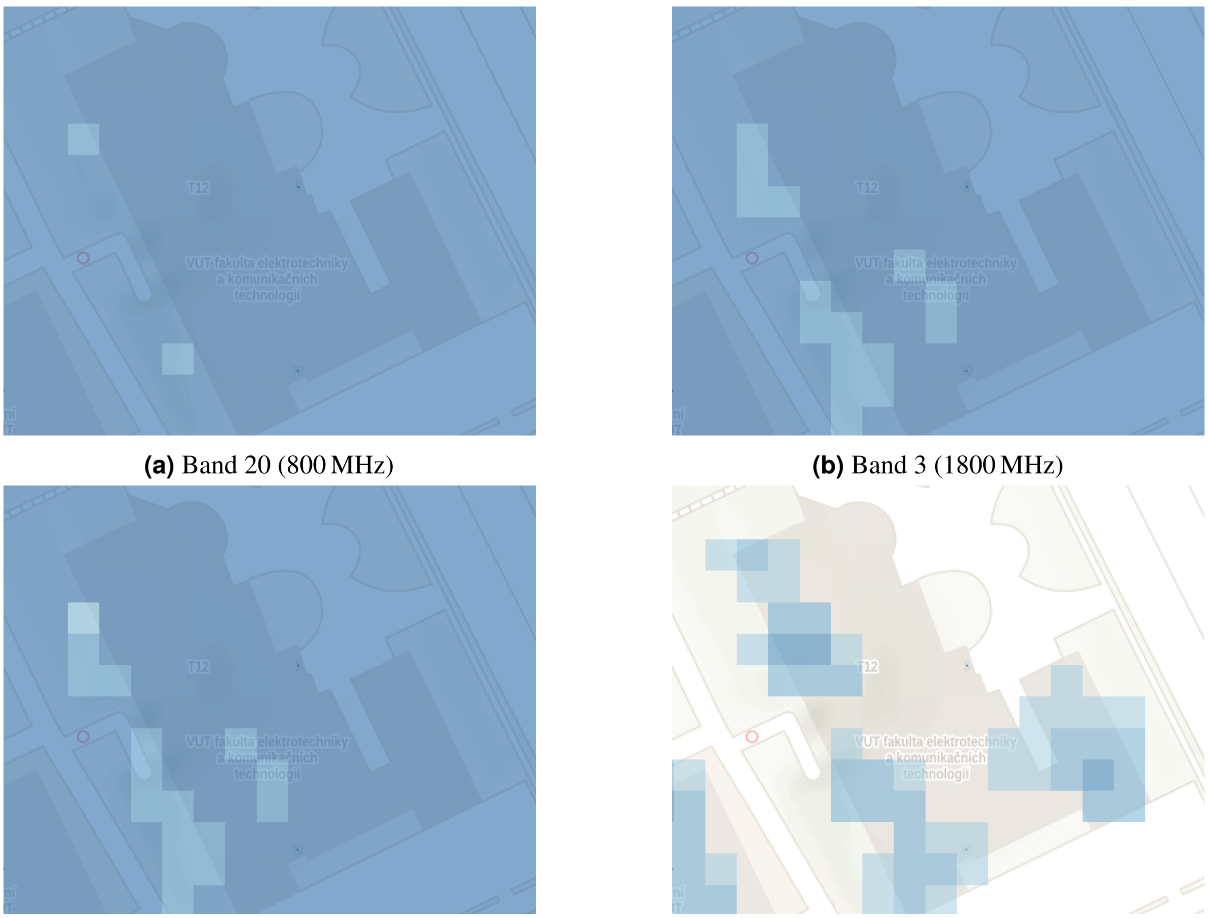
Figure 1. LTE network architecture

Unlike traditional 3GPP networks, the LTE network adopts a unified architectural structure by combining Radio Network Controller (RNC) and NodeB into E-UTRAN NodeB (eNodeB). These eNodeBs handle circuit switching at base stations, optimize the network, reduce system latency, and minimize costs associated with creation and maintenance [5]. LTE primarily relies on an IP-based core network. The use of all-IP network architecture significantly simplifies the design and operation of LTE air interface, radio network, and CN [8].

Fig. 1 illustrates the connections (via interfaces) between various network elements. These connections include the *Uu* interface, which connects UEs to eNBs, the *X2* interface, which interconnects eNBs, the *S1-MME* interface, which connects eNBs to the Mobility Management Entity (MME) entity, the *S6a* interface, which connects MME to the Home Subscriber Server (HSS), the *S1-U* interface, which provides connectivity between eNBs and the Serving Gateway (SGW) responsible for routing data traffic between UEs via the *S5* connection to the Packet Data Network Gateway (PGW), and the *SGi* connection linking to other IP networks such as the internet. In 4G networks, UEs include various types of devices, including mobile phones, smart terminals, multimedia devices, and streaming devices [5].

1.1 4G network coverage in the measurement location (Technická 12)

In the Czech Republic, three main mobile network operators (MNOs) - O2, T-Mobile, and Vodafone - provide comprehensive mobile signal coverage across the country. 4G network coverage varies depending on the specific radio frequency band. 4G technology in the Czech Republic primarily relies on four radio bands (Bands): Band 20 (800 MHz), Band 3 (1800 MHz), Band 1 (2100 MHz), and Band 7 (2600 MHz). Bands 1, 3, and 7 are strategically utilized as capacity layers in areas with high population density, such as large cities, ensuring robust coverage and high data transmission speeds. Band 20 serves as a backbone band, excelling in providing broader coverage in less populated and rural areas. Fig. 2 illustrates the coverage of all bands by the T-Mobile operator at the Technická 12 location (other operators are practically the same) based on measurements conducted by the Czech Telecommunication Office (CTO) [3].



(a) Band 20 (800 MHz) **(b)** Band 3 (1800 MHz)

(c) Band 1 (2100 MHz) **(d)** Band 7 (2600 MHz)

Figure 2. 4G LTE coverage (all bands) of the T-Mobile operator in the Technická 12 locality (*valid on : 06.05.2024*)[3]

As seen from Fig. 2, coverage at Technická 12 address is available for Bands 1, 3, and 20, therefore, only these bands are measured in this task using Subscriber Identity Module (SIM) card from T-Mobile operator.

1.2 Key Performance Indicators (KPIs)

To determine important characteristics of mobile networks such as coverage, capacity, quality, reliability, etc., it is essential to obtain Key Performance Indicators (KPIs).

Before defining individual KPI metrics, it is appropriate to look at the physical layer of LTE (FDD). The Radio Resource Grid, depicted in Fig. 3, is divided into time and frequency units called Resource Blocks (RBs), with a duration of 0.7 ms and a width of 180 kHz. Each RB consists of 12 subcarriers, which are 15 kHz wide in the

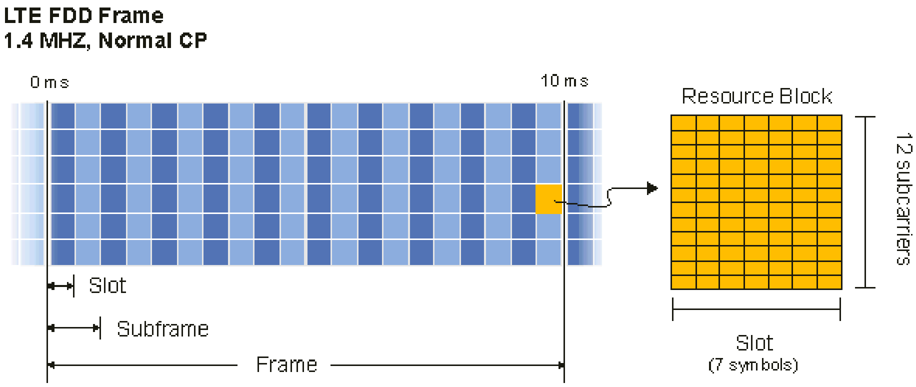


Figure 3. Illustration of LTE FDD frame [7]

frequency domain, and 7 OFDMA or SC-FDMA symbols (depending on the communication direction) in the time domain [1]. The small yellow squares represent Resource Elements (REs), which are the smallest units of the resource grid composed of one subcarrier in the frequency domain and one symbol in the time domain.

Let's analyze some of the most important measured network parameters, from which data is collected for analysis and conclusions on how to improve service quality and reliability.

- **RSSI (Received Signal Strength Indicator)** - RSSI is defined as the linear average of the aggregated received signal power, measured in watts. It is observed within the configured OFDM symbol and over the measuring bandwidth, including N number of RBs. This comprehensive measurement takes into account signals received by UE from various sources, including serving and non-serving cells in the same channel, interference from adjacent channels, thermal noise, and other contributing factors [2]. Typically, higher RSSI values (e.g., >-65 dBm) indicate stronger signal strength, and lower RSSI values (e.g., <-85 dBm) indicate weaker signal strength.

- **RSRP (Reference Signal Received Power)** - RSRP is characterized as the linear average of power contributions (measured in watts) from REs responsible for transmitting cell-specific reference signals (CRS). This measurement is performed within the designated frequency measurement bandwidth as specified in [2]. Usually, higher RSRP values (e.g., >-80 dBm) indicate stronger signals. Conversely, lower RSRP values (e.g., <-100 dBm) indicate weaker signals.

- **RSRQ (Reference Signal Received Quality)** - RSRQ is expressed as the ratio of N times RSRP to the RSSI of the E-UTRA carrier, where N represents the number of RBs within the E-UTRA carrier RSSI measurement bandwidth. Both the numerator (N times RSRP) and the denominator (RSSI of the E-UTRA carrier) are measured over the same set of RBs [2]. Again, higher RSRQ values (e.g., >-10 dB) indicate higher signal quality, and lower RSRQ values (e.g., <-20 dB) indicate poorer signal quality.

- **RSSNR (Reference Signal Signal to Noise Ratio)** - RSSNR is not defined by the 3GPP specification as the above metrics (and therefore is not reported to the serving cell), but is typically defined by the UE manufacturer (in this case, SIMCom). RSSNR is the ratio of the power of usable signals measured from CRS to the average noise within the measurement bandwidth. A higher RSSNR value (e.g., >15 dB) indicates good signal-to-noise separation, hence signal quality.

1.3 SIM8200EA-M2 Module

This module is manufactured by SIMCom Wireless Solutions. The baseboard of this module is equipped with a standard M2 connector, which allows connection to various 4G or 5G communication modules with M2. It also features a built-in USB3.1 port, audio connector and decoder, SIM card slot, etc. Combined with a configuration script and, for example, the AT command "`AT+CPSI?`", basic system UE information can be obtained. This mainly includes signal measurements such as RSRP, RSSI, RSRQ, and RSSNR. Additionally, this AT command provides

Table 1. SIM8200EA-M2 Specification

Key Aspects	SIM8200EA-M2
5G Category	5G NSA/SA
5G Frequency Bands (NSA)	n78
4G Category	Cat-20
4G Frequency Bands	All supported
Max. Download Speed	4 Gbps
Max. Upload Speed	500 Mbps
Max. RF Output Power	23 dBm
Satellite Systems	Supported
USB	USB 3.1
Price	300 €

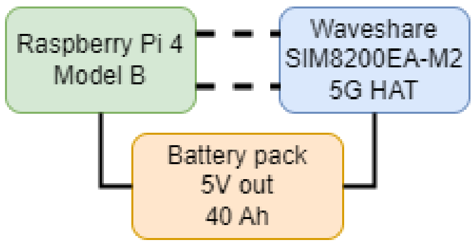


Figure 4. Connection of individual components of the measurement device

other useful information such as DL frequency and active set RF band, Physical Cell Identity (PCI) identification, and identification of the cell serving the next location used by the base station, as well as bandwidth configuration for both downlink and uplink channels.

Important parameters and specifications of the used module are in Table 1.

In Fig. 4, a block diagram of the entire measurement device is displayed. The setup includes a Raspberry Pi 4 Model B, a 5G HAT from Waveshare, and a battery pack with a 5V output and a capacity of 40Ah.

In Fig. 5, a simple application for network performance measurement is shown. The application allows users to name the measurement, specify its duration in seconds, and select the preferred measurement band. There are two buttons: "Start" (green), which initiates the measurement process, and "Stop" (red), which terminates the measurement process. Real-time information is displayed below the button to obtain an overview of the measurement start, and a status bar visually indicates the progress of the measurement. The application runs locally directly on the measurement device and can be accessed via a web browser at the 'loopback' address with port 8050 (i.e., "http://127.0.0.1:8050/").

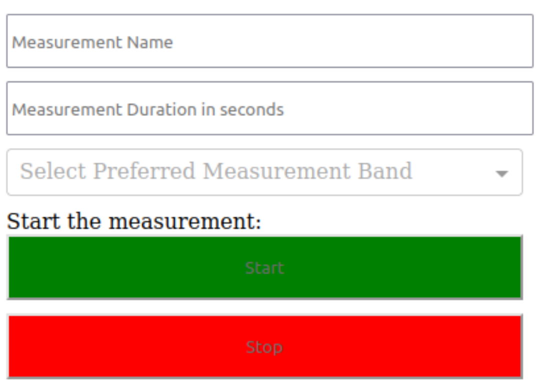


Figure 5. Application for measurement settings

2. Measurement procedure

3. Take the prepared cable (with USB Type C - USB Type C connectors) at your workstation and connect the battery pack to the Raspberry Pi. Using the second cable (with USB Type A - USB Micro connectors), connect the SIM8200EA-M2 module to the Raspberry Pi, or to the output from the battery pack (according to the block diagram on Figure 4). If everything is connected correctly, the **LED indicators** on both devices should light up. Next, use an HDMI cable (with HDMI Standard - HDMI Micro connectors) to connect the Raspberry Pi to the monitor at your workstation. Ensure that the monitor is turned on. The monitor should automatically detect the signal from the HDMI cable. **Wait for the operating system to start**.

In the top left corner of the screen, you will find the icon for the Firefox web browser. Click on it to start the browser. Be patient with loading the applications (due to the Raspberry Pi's performance, these tasks are not the fastest, so they may take some time). Once the web browser loads, enter the following address into the search bar: `127.0.0.1:8050` and press Enter on your keyboard. This will connect you to the application running on the Raspberry Pi, which is used to configure the measurements. If the application does not start, restart the Raspberry Pi by disconnecting and reconnecting the USB-C cable, and repeat the process.

If the application loads successfully and you see all the elements as shown in Figure 5, you can proceed further. Before setting up and starting the measurements, it is necessary to **restart the SIM8200EA-M2 module** using the reset button on the side of this module. The white reset button is located on the side, along with the USB Micro connector, the ON/OFF switch, and the headphone jack connector. After pressing the button, the module's green LED, indicating connection to the network, should stop flashing. Wait a few seconds until the module starts flashing the green LED again, indicating that it is connected to the network and ready for measurements.

Now it's time for the measurement part. The measurements will take place at **three locations**:

- The first one is located **directly at the workstation**, so you don't need to move anywhere.
- Perform the second measurement in a room **closest to one of the windows**.
- The third one **in the corridor near the emergency exit** facing the Pod Palackého Vrchem dormitory.

The procedure for all measurements will be similar:

First, set up the measurement using the application in the browser, i.e., choose a suitable measurement name in the Measurement Name section, for example, location1_band1 (for subsequent measurements, you can proceed similarly, i.e., location1_band3, location1_band20, location2_band1...). In the second section Measurement Duration in seconds, select the measurement duration in seconds. For the first measurement at the workstation, enter a value of 300. For subsequent measurements, where you will be moving, choose a slightly larger value, taking into account the movement to the respective location, so for example 320. In the next section Select Preferred Measurement Band, select the band to be measured. At each location, perform measurements for all three LTE bands (EUTRAN-BAND1, EUTRAN-BAND3, and EUTRAN-BAND20), totaling approximately 15 minutes of measurement at each location. After selecting the band, click on the green Start button, and a status bar and information indicating the start of the measurement should appear.

If the measurement is at a location other than directly at the workstation, disconnect the HDMI cable and move with the measuring device to the respective location. Wait for the measurement to complete (about 5 minutes). If you are measuring somewhere other than the workstation, return to the workstation, reconnect the HDMI cable to the Raspberry Pi, and check that the measurement has been completed. Then follow the same procedure for the other two bands. Be careful to change the name of measurement, so you don't overwrite the measured data with the new measurement.

4. After measuring all LTE bands at all three locations, prepare a USB flash drive and connect it to one of the USB ports on the Raspberry Pi. Using the icon named Files, navigate to the file explorer. In the left sidebar, navigate to the following path: Home > Desktop > MeasuredData. Select all the measured CSV files you

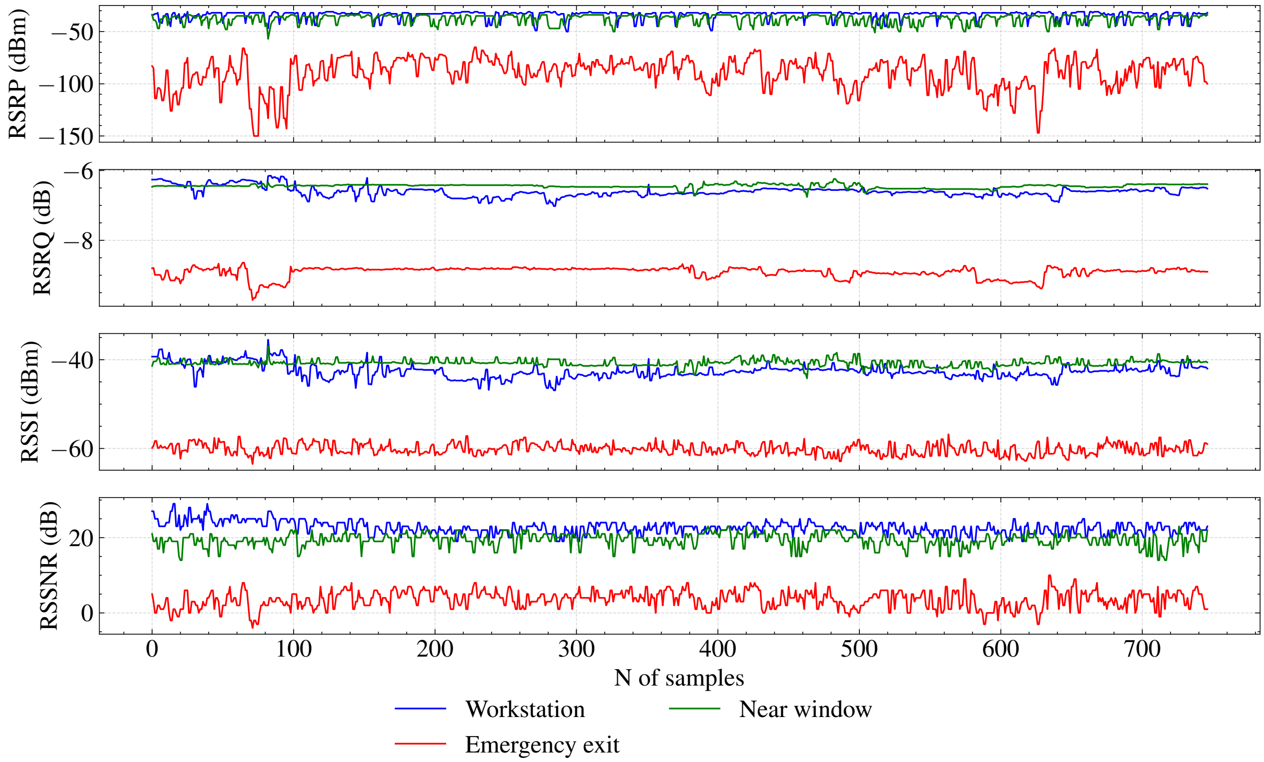


Figure 6. Measured values depicted graphically over time at individual stations for LTE Band 1

have recorded, then right-click on the selected files. Choose the option Copy to... . Another window with the file explorer will open, where you should see your USB flash drive in the left sidebar. Click on it (or create a new folder for the measured data if necessary) and click on the green Select button in the top right corner of the window. Remove all the measured data using the option Move to Trash and eject your USB flash drive from the Raspberry Pi. Disconnect all connections and return everything to its original state.

Create three graphs illustrating all the measured metrics (RSRP, RSRQ, RSSI, and RSSNR) over time for each measured band. To create these graphs, you can proceed as follows. Use suitable data visualization software such as Python with libraries like `Matplotlib` or `Seaborn`, or MATLAB. Create three graphs, each containing four subplots, with each subplot displaying one of the measured metrics over time. These graphs can be arranged in columns, where each column represents one metric. The graphs should be labeled with axis labels, legends, and other relevant information for proper understanding of the data. An example of such a graph for Band 1 is shown in Figure 6.

Next, create boxplots for each measured band, which are useful for visualizing the distribution and variability of data sets. They help quickly identify the median, quartiles, and potential outliers. When analyzing signal strength, boxplots can provide an overview of how values differ between different locations or bands. Boxplots allow easy comparison of multiple data sets on one graph, facilitating the identification of differences and trends. An example of boxplots for Band 1 is shown in Fig. 7.

5. From the created graphs, such as those in Fig. 6 and Fig. 7 for individual bands, perform a simple analysis and evaluate network coverage and reliability. Consider and observe fluctuations in **RSRP, RSRQ, RSSI, and RSSNR** over time at each location. Then compare the signal strength metrics at the workstation, emergency exit, and window to identify clear differences in average signal strength or variability. What might be the reason for weak signal in a given location or, conversely, the reason for strong signal? Recall the conditions during the measurements, and try to spot an eNodeB from the window if there is one. Analyze how different metrics correlate with each other (you can use the *corr()* function in MATLAB or in Python with the `pandas` and `numpy` libraries) and determine

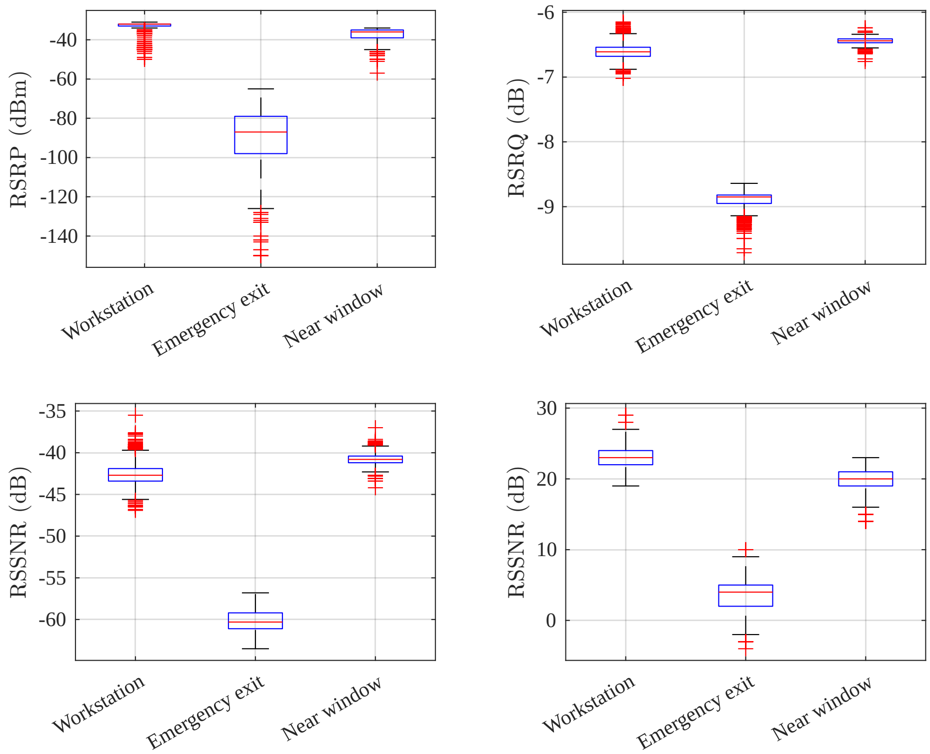


Figure 7. Measured values depicted graphically in boxplots at individual stations for LTE Band 1

whether they usually increase and decrease together or if there are situations where one metric is strong and the other is weak. Use visual inspection to observe trends and patterns on the graphs, supplemented by statistical analysis to calculate average signal strength, standard deviation for variability, and correlation coefficients between metrics. When comparing bands, take into account the frequency used by the band and the signal propagation characteristics at that frequency.

3. Reference, recommended literature

[1] 3GPP. *LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation (3GPP TS 36.211 version 14.2.0 Release 14)*. Online. `https://www.etsi.org/deliver/etsi_ts/136200_136299/136211/14.02.00_60/ts_136211v140200p.pdf`, [cited 2024-05-06]. Apr. 2017.

[2] 3GPP. *LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer; Measurements (3GPP TS 36.214 version 14.2.0 Release 14)*. Online. `https://www.etsi.org/deliver/etsi_ts/136200_136299/136214/14.02.00_60/ts_136214v140200p.pdf`, [cited 2024-05-06]. Apr. 2017.

[3] Český telekomunikační úřad. *Veřejné širokopásmové pokrytí mobilní sítě 4G a 5G v pásmech 700MHz, 800MHz, 1800MHz, 2100MHz, 2600MHz a 3600MHz*. Online. `https://vportal.ctu.gov.cz/mobile/mapa`, [cited 2024-05-06]. 2024.

[4] Halberd Bastion RF. *4G LTE*. Online. `https://halberdbastion.com/technology/cellular/4g-lte`, [cited 2024-05-06]. 2024.

[5] Huawei. *AR100, AR120, AR150, AR160, AR200, AR1200, AR2200, AR3200, and AR3600 V200R010 CLI-based Configuration Guide - Interface Management*. Online. `https://support.huawei.com/enterprise/en/doc/EDOC1100034069/f110c2e7/lte-network-architecture`, [cited 2024-05-06]. Aug. 2023.

[6] Janeba, Matej and Lehoczký, Peter and Galinski, Marek and Milesich, Tomáš and Danko, Ján and Kotuliak, Ivan. "*Evaluation of LTE and 5G qualitative parameters for V2X use cases*". In: *2022 IEEE Zooming Innovation in Consumer Technologies Conference (ZINC)*. 2022, pp. 165–169. DOI: `10.1109/ZINC55034.2022.9840619`.

[7] Keysight. *LTE Physical Layer Overview*. Online. https://helpfiles.keysight.com/csg/89600B/Webhelp/Subsystems/lte/content/lte_overview.htm, [cited 2024-05-06]. 2024.

[8] Sauter, Martin. *From GSM to LTE-Advanced Pro and 5G An Introduction to Mobile Networks and Mobile Broadband*. 4th ed. John Wiley & Sons, Ltd., 2021, p. 617. ISBN: 9781119714705.

4. Used devices and tools

- Waveshare 5G HAT with SIM8200EA-M2 module
- Raspberry Pi 4 Model B
- Battery pack 40 Ah
- Monitor
- USB, HDMI cables