Mahdi AL-nasrawi[1,3], Seyed Vahab AL-Din Makki[1], Ali Al-Sabbagh[2,3]

Razi University, Kermanshah, Iran (1), Al Taff University College, Kerbala, Iraq (2), Ministry of communication, ITPC , Iraq (3)
ORCID: 1.0009-0002-2596-4685;3.0000-0003-3270-980x

doi:10.15199/48.2024.07.15

KPI analysis of 4G/5G networks

***Abstract**. The development of mobile networks, especially after the 5G network service entered into implementation and deployment in the world, the increase in demand for broadband, and the increase in the number of subscribers. This created complexity in the networks and difficulty in managing them. Therefore, it has become necessary to study and analyze the key performance indicators (KPI) that provide the potential information needed to successfully deploy the network and study the performance and improved networks. This work therefore describes LTE-4G and NR-5G data measurements and KPI performance analysis of data collected via a drive test (DT) process for two operators in Austria. Data measurements focused on parameters that directly affect network strength and quality, such as Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ), Signal to Interference and Noise Ratio (SINR), Received Signal Strength Index (RSSI), and downlink-uplink data transfer rate (DL/UL throughput). Through the results of analyzing these parameters, it is possible to know the strength and quality of the network and to know the locations of weak points so that a specialist can maintain and address network errors. Finally, analyzing the parameters of key performance indicators provides high flexibility and simplicity in managing and monitoring the performance of mobile networks, reducing complexity, reducing maintenance time and cost, and gaining customer satisfaction.*

Streszczenie.** Rozwój sieci mobilnych, zwłaszcza po wejściu w życie i wdrożeniu usługi sieci 5G na świecie, wzrost zapotrzebowania na łącze szerokopasmowe oraz wzrost liczby abonentów. Spowodowało to złożoność sieci i trudności w zarządzaniu nimi. Dlatego konieczne stało się badanie i analizowanie kluczowych wskaźników wydajności (KPI), które dostarczają potencjalnych informacji potrzebnych do pomyślnego wdrożenia sieci oraz badania wydajności i ulepszonych sieci. Dlatego też w niniejszej pracy opisano pomiary danych LTE-4G i NR-5G oraz analizę wydajności KPI danych zebranych w procesie testu jazdy (DT) dla dwóch operatorów w Austrii. Pomiary danych skupiały się na parametrach, które bezpośrednio wpływają na siłę i jakość sieci, takich jak moc odebrana sygnału odniesienia (RSRP), jakość odebranego sygnału odniesienia (RSRQ), stosunek sygnału do zakłóceń i szumu (SINR), wskaźnik siły odebranego sygnału (RSSI) oraz szybkość przesyłania danych w łączu w dół i w górę (przepustowość DL/UL). Dzięki wynikom analizy tych parametrów można poznać siłę i jakość sieci oraz poznać lokalizacje słabych punktów, aby specjalista mógł konserwować i eliminować błędy sieci. Wreszcie, analiza parametrów kluczowych wskaźników wydajności zapewnia dużą elastyczność i prostotę w zarządzaniu i monitorowaniu wydajności sieci komórkowych, zmniejszając złożoność, skracając czas i koszty konserwacji oraz zdobywając satysfakcję klienta.* (Analiza KPI sieci 4G/5G***)

Keywords: Drive test, KPI, 5G, 4G
Słowa kluczowe: sieć 5G, test KPT

Introduction

The increasing demand for multiple data and high speeds in our world today confirms the important role that modern technology plays in our daily lives. It provides the subscriber with a seamless experience for various applications such as streaming high-quality content and enabling effective remote work, which demonstrates the urgent need to build an advanced and effective communications infrastructure to meet these evolving requirements. Also, the significant surge in broadband data usage and smartphone adoption presents a pivotal factor in advancing mobile network (MN) development in recent years. Users heavily rely on smartphones for a diverse range of services including work, e-commerce, banking, social networking, gaming, and remote healthcare, particularly following the global spread of COVID-19. Thus, this increasing demand for broadband usage emphasizes the necessity of establishing a robust wireless system to ensure a high level of Quality of Service (QoS) [1-3].

However, with the persistent growth in user numbers, achieving this optimization becomes challenging, underscoring the importance of evaluating network performance. And on a global scale, the projected total count of mobile devices is expected to hit 18.22 billion by the year 2025, marking an increase of 4.2 billion devices compared to 2020 levels. Additionally, the number of internet users is growing at a yearly rate of 7.6%, roughly translating to an average of 900,000 new users each day. Consequently, 4G/5G networks monitoring and scanning play a vital role in assessing mobile networks statistics, crucial for optimizing 4G/5G networks within a specific region [4-6].

Fundamentally, performance parameters, often referred to as Key Performance Indicators (KPIs), vary based on the services provided. These KPIs encompass data influencing network coverage and capacity, including signal strength and quality, as well as download and uplink throughput. Moreover, KPIs serve as indicators to determine if a device or equipment meets the requisite criteria for successful deployment. The mobile operator's primary focus revolves around ensuring optimal performance of cellular networks and evaluating Quality of Service (QoS). These aspects directly impact both profitability and customer satisfaction. QoS is a critical determinant in the competition for subscribers, necessitating efficient optimization of the cellular network to meet users' essential service needs [7-10]. KPI, or Key Performance Indicator, is a measurable metric used to evaluate the performance and effectiveness of a mobile network. KPIs help in assessing the network's success in meeting its objectives and goals. They are essential for monitoring and managing the network's performance to ensure optimal functionality and user satisfaction [11].

These KPIs help mobile network operators monitor and improve various aspects of their networks to ensure a reliable, high-quality experience for users and meet business objectives effectively. Different KPIs may be prioritized based on the specific goals and focus of the mobile network operator.

KPI data is collected through the DT process using a set of tools such as a GPS, a scanner, a laptop with the Teams program installed, and a mobile phone with an Internet connection. After the data collection process, we obtain a raw data file that is processed and filtered according to the required parameters [12-14].

A detailed statistical analysis of the cellular networks in Austria City is conducted, utilizing Key Performance Indicators (KPIs) obtained from DT carried out by two prominent cellular network operators.

These measurements are for five categories: bus, train, car, walking, and static. The measurements of each category were isolated separately, and the measurements of each network were also isolated, and analyzed, and their results were taken. The focus was on 4G and 5G networks, as they are a modern technology that uses high bandwidth, high transmission rate, low delay, and low error rate. The data was analyzed and charts were drawn using Excel, and the locations of incorrect and duplicate measurements were identified and deleted so that the results could be read accurately. This analysis delves into the 4G-LTE network, providing an initial understanding of LTE network coverage for the specified operators in the region, relying on data measurements such as RSRP, RSRQ, RSSI, SINR, and DL Throughput.

Throughput, both downlink (DL) and uplink (UL) is an important key performance indicator (KPI) in mobile networks. It represents the speed or rate at which data is transferred between the user's device and the network (DL) or from the user's device to the network (UL). Throughput is an important factor in determining the Quality of Service (QoS) provided to users. Meeting or exceeding expected productivity levels is critical to maintaining high service quality and maintaining subscriber satisfaction [10,11].

These data measurements play a crucial role in network planning, feasibility studies, modelling, and overall development. As a result, wireless network operators can leverage these measurements to effectively assess and determine appropriate KPIs for enhancing network performance [1,12].

2 Research method:

4G networks have been instrumental in enabling mobile broadband and many modern applications, while 5G networks represent a jump forward in terms of speed, low latency, and connectivity. 5G is poised to support a new era of technological innovation, including the Internet of Things (IoT), autonomous vehicles, and a wide range of applications that demand high-speed, low-latency connectivity [15-18]. This increases the complexity of monitoring and managing the network and maintaining stable, high-quality services provided to subscribers. To facilitate the process of managing and monitoring networks and maintaining the quality of services, KPI technology must be used by collecting data through the DT process [19-22].

DT is the process of systematically collecting data from routes to characterize the cellular network. Hence, it has tremendous importance for optimization and network planning. Under certain conditions, DT provides results that are reasonable for deploying or assessing the performance of networks in practical RF environments [23-27]. Practically, the experiment area can be divided into major and detailed roads. In the detailed road test, data are collected from all the public roads which contain all the streets and avenues. On the other hand, only long and wide avenues that have a traffic density are used in the major road test. These collected data can include voice or data services, signal levels, signal quality, interference, dropped calls, blocked calls, service level statistics, quality of Service, Handover information, a neighbouring cell, and GPS location coordinates [28-32]. The data measurements have been focused on the parameters that affect the network directly, such as Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ), Signal to Interference and noise Ratio (SINR), Received Signal Strength Indicator (RSSI), and Downlink, Uplink Throughput (DL, UL Throughput). To obtain the working status of the network and the locations of its weak points, the readings obtained through the DT process are compared with the standards of the parameter reading ranges approved by international communications organizations to reach knowledge of the network’s status. We mention the ranges for some important parameters, according to the range of signal strength and quality level for each parameter, as shown in Table 1.

Table 1. 5G ranges signal strength and quality.

Parameters	*Excellent Range (dB)*	*Good Range (dB)*	*Fair Range (dB)*	*Poor Range (dB)*
RSRP	>=-90 dBm	-90 dBm to -105 dBm	-106 dBm to -120 dBm	<-120 dBm
RSRQ	>=-10 dB	-10 dB to - 15 dB	-15 dB to - 20 dB	<-20 dB
RSSI	>=-50 dBm	-50 dBm to -75 dBm	-75 dBm to -90 dBm	-90 dBm to - 100 dBm
SINR	>= 20 dB	20 dB to 10 dB	10 dB to 0 dB	< 0 dB (negative values)

2-1 Mathematical background:

To find the values of the KPI parameters in mathematical form, previous studies and research conducted studies to find special laws and equations to find the values of these parameters, and after in-depth studies and derivations, the following equations were achieved:

(1) RSSI (dBm)=Pt-PL(d)…………………

Where:

Pt indicated the signal transmission power.

PL(d) indicated the path loss when the distance is d.

(2) RSRP (dBm) = RSSI (dBm) − 10log(12N) …..…....[1]

(3) RSRQ = N ∗ (RSRP/RSSI) ……………………….[1]

Where:

N is the number of RB (Resource Block) and its changeable number based on scheduling for each UE.

(4) SINR (in dB) = 10 * log10(S / (I + N)) …………………

Where:

S represents the power of the desired signal (Signal Power).

I represents the power of interference (Interference Power).

N represents the power of background noise (Noise Power).

(5) CQI = (SINR - a) / b ……………………..…………

Where:

CQI is the Channel Quality Indicator.

SINR (Signal-to-Interference-plus-Noise Ratio) is a key parameter representing the quality of the received signal.

"a" and "b" are constants determined by the specific implementation and the wireless standard. These constants are used to map the SINR value to the CQI value within the allowable CQI range.

Different wireless standards and specific equipment may use different mappings between SINR and CQI, and the constants (a and b) may vary. Therefore, the exact formula and mapping may differ between different 4G LTE or 5G systems. It's important to consult the relevant documentation or specifications provided by the wireless network equipment manufacturer or standard organizations for precise details on CQI calculation for a specific system.

2-2 Data processing:

First, the raw data is provided by Technical University of Wien by record in an operational network with 2x2 MIMO, 20MHz BW. Mobile network data in Austria was obtained via DT, but we obtained it through several raw Excel files, and it contained many errors and deviations in the readings for unknown reasons. The reason for these errors may be due to: an error in the operation of the devices, an error in the network itself, or a change in the weather condition. Or other than that. Data were collected from five categories: car, train, bus, walking, and static.

We collected the data and consolidated it into one Excel file. The data contained many networks such as 2G, 3G, 4G, and 5G. We separated the data for each network

separately, and more focus was placed on the 4G and 5G networks, as they are currently the newest and the demand for connection to them has increased. The data also contained the readings of some important KPI parameters that affect the quality of mobile networks, such as RSRP, RSRQ, SENR, CQI, downlink and uplink throughput, etc.
We plotted this data with Excel charts in the first stage for the purpose of analysis. We noticed through the charts that they contain some errors and deviations in the readings. They were processed and filtered, and then again, we drew new charts. It was also noted that they contain long periods in which the readings are similar and repeated for several periods. This is not realistic in communications technology, and they were also filtered. We also found the correlation matrix and statistics for each parameter for the three categories. The analysis, processing, and filtering processes were carried out in three stages until the best result, almost error-free, was reached, as shown in Fig.3.

3 Results and discussion:

This section analyzes important KPIs for LTE-4G and NR-5G cellular networks and presents the results of these analyses. DL/UL throughput, RSSI, SINR, RSRP, and RSRQ are some of the KPIs tested. 4G/5G KPIs were measured by two telecom operators in Austria. The data was merged from several Excel files and standardized, each according to its category. The data collected via DT, as we mentioned previously, contains five categories: car, train, bus, walking, and static. Below is a description of the KPIs analyzed. Fig.3 shows the average RSRP and RSRQ measurements for three categories of car, walking, and static respectively for the 4G network. Fig.4 shows the average RSRP and RSRQ measurements for three categories of car, walk, and static respectively for the 5G network. A comparison of the statistical analysis of the KPIs of the data is shown in Table 2. In more detail, the first part of Table 2 compares the statistical measurements of RSRP (dBm) for three categories: car, walking, and static. The results showed an average RSRP of -102, -100, and -116 dBm, which is the signal strength for the three categories. The second part of Table 2 was the average RSRQ, -14, -15, -13 dB, which represents the signal quality. Moreover, the third and fourth parts of Table 2 represent the statistical data comparison of RSSI (dBm) and SINR (dB) measurements, and the average RSSI is within the range of the acceptable condition. In contrast, the average SINR falls within the range of fair condition for the car category and static, and poor condition for the walking category.

Fig. 5 also shows the average RSRP and RSRQ measurements for the car category for two operators A&B, and LTE and NR technologies. Finally, Fig. 6 shows the average RSRP and RSRQ measurements for the walking category for two operators A&B, and two technologies LTE and NR. The results shows that the measurements of operator B were somewhat better than operator A.

4 Conclusion

In this paper, we examined the KPIs that have an important role in the process of improving the performance of 4G-5G networks because they provide useful information to facilitate the monitoring and management of networks. Data measurements were collected via the DT process for five categories: car, train, bus, walking, and static for two operators in Austria. Analysis and comparisons were made between the following parameters RSRP, RSRQ, RSSI, and SINR for 4G-5G networks. The results of analysis and comparison showed that the networks of both operators were operating within a good and fair range. However, the B operator measurements were somewhat better than the A operator. In future work, we aspire to find alternatives to the DT process, as it is a difficult, expensive process, requires additional staff, and takes a long time to obtain results, going through several stages. Alternatives, for example, are advanced application that runs on mobile phones, the results of which are sufficient to determine the strength and quality of the network, saving us from the lengthy details of the DT process.

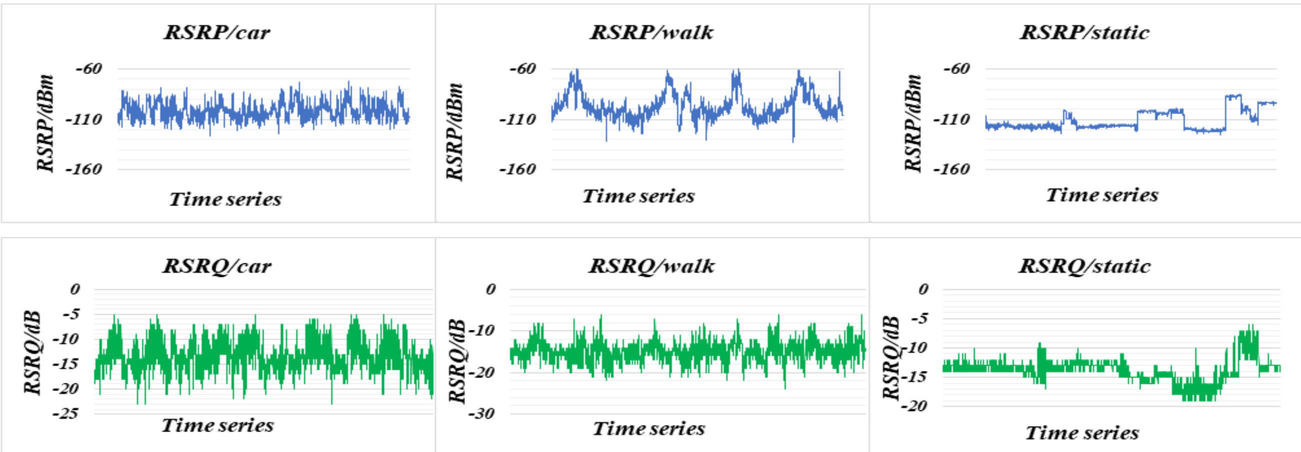
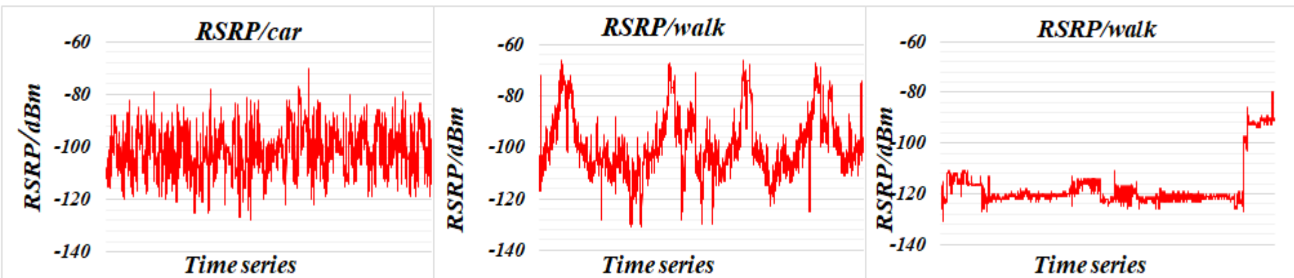


Fig.3 RSRP and RSRQ for three categories in 4G network.



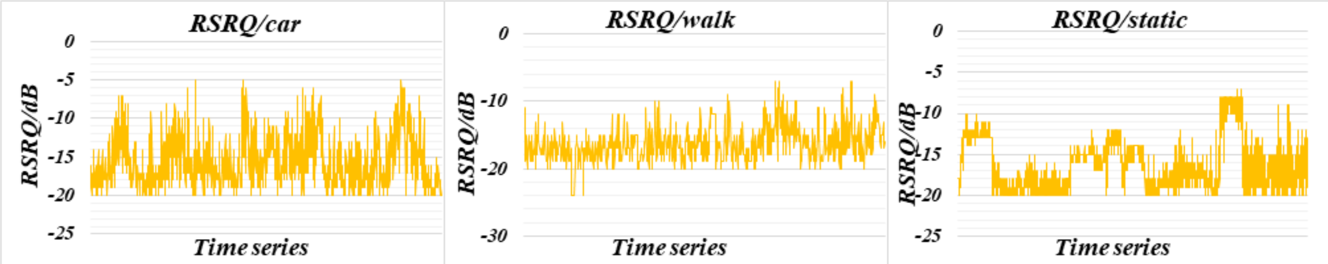


Fig.4 RSRP and RSRQ for three categories in 5G network.

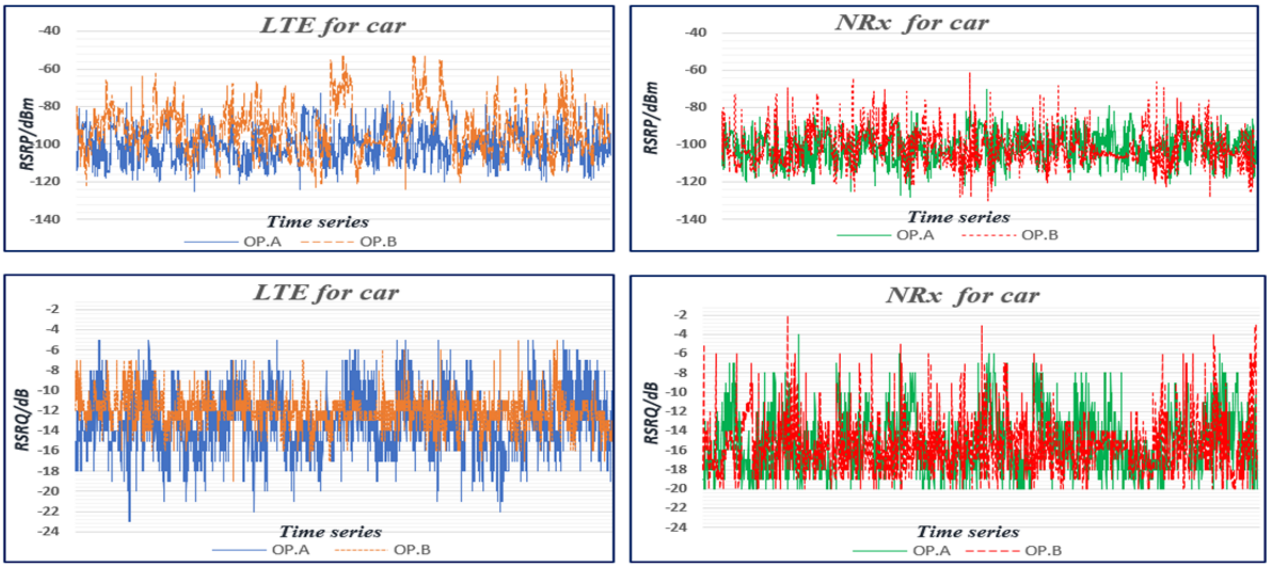


Fig. 5 RSRP and RSRQ for category car two operators A&B and two technologies LTE and NR.

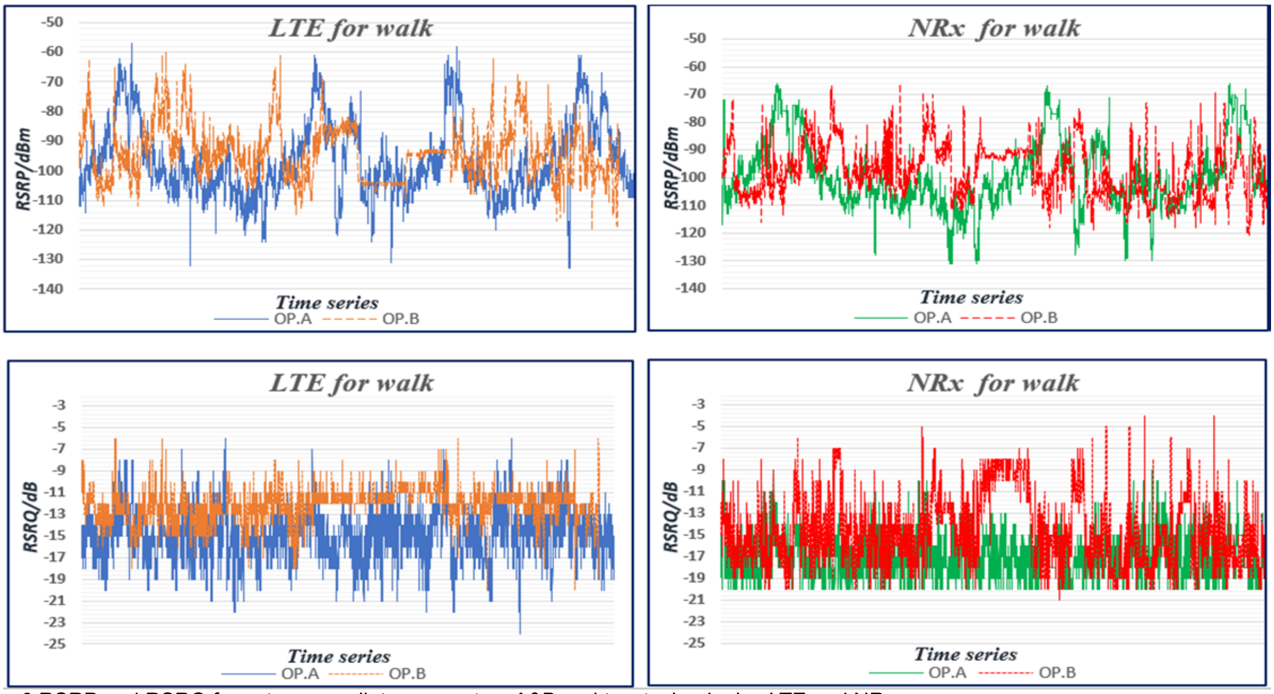


Fig. 6 RSRP and RSRQ for category walk two operators A&B and two technologies LTE and NR.

Table 2. RSRP, RSRQ, RSSI, and SINR for three categories car, walk and static

Metrucs	RSRP (dBm)			RSRQ (dB)			RSSI (dBm)			SINR (dB)		
	car	walk	static	car	walk	static	car	walk	static	car	walk	static
Count	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000
Median	-102	-100	0116	-14	-15	-13	-84	-82	-94	2	-2	5
Max	-72	-53	-85	-5	-6	-6	-54	-40	-54	24	22	27
Min	-126	-133	-125	-23	-24	-19	-94	-94	-94	-17	-16	-5
Std	*8.267*	*12.54*	*9.87*	*2.67*	*2.13*	*1.99*	*7.89*	*12*	*6.89*	*6.016*	*4.59*	*45.77*
>90%	*-81*	*-65*	*-86*	*-7*	*-9*	*-8*	*-88.16*	*-47*	*-69*	*16*	*12*	*21*

Acknowledgeent:
4G/5G real data was kindly provided by Mr. Philipp Svoboda, a enior scientist working at TU Wien (www.tuwien.at), with a research focus on the performance aspects of mobile cellular technologies. The authors would like to extend their gratitude and acknowledgements for his valuable support.

REFERENCES

1- Shakir, Z., Mjhool, A.Y., Al-Thaedan, A. et al. Key performance indicators analysis for 4 G-LTE cellular networks based on real measurements. Int. j. inf. tecnol. (2023).
2- Santos, R. "Machine learning techniques using key performance indicators for the configuration optimization of 4G networks." (2018).
3- Eyceyurt, Engin, and Josko Zec. "Uplink throughput prediction in cellular mobile networks." International Journal of Electronics and Communication Engineering 14.6 (2020): 149-153.
4- El-Saleh, Ayman A., et al. "Measurements and Analyses of 4G/5G Mobile Broadband Networks: An Overview and a Case Study." Wireless Communications and Mobile Computing 2023 (2023).
5- Mostafa, Ali, Mustafa A. Elattar, and Tawfik Ismail. "Downlink Throughput Prediction in LTE Cellular Networks Using Time Series Forecasting." 2022 International Conference on Broadband Communications for Next Generation Networks and Multimedia Applications (CoBCom). IEEE, 2022.
6- Fernandez, Gustavo A. "Machine Learning for Wireless Network Throughput Prediction." (2023).
7- Eyceyurt, Engin, Yunus Egi, and Josko Zec. "Machine-Learning-Based Uplink Throughput Prediction from Physical Layer Measurements." Electronics 11.8 (2022): 1227.
8- Al-Thaedan, Abbas, et al. "Downlink throughput prediction using machine learning models on 4G-LTE networks." International Journal of Information Technology (2023):1-7.
9- Shakir, Zaenab, Abbas Al-Thaedan, Ruaa Alsabah, Ali Al-Sabbagh, Monera Elhashmi M. Salah, and Josko Zec. "Performance evaluation for RF propagation models based on data measurement for LTE networks." International Journal of Information Technology 14, no. 5 (2022): 2423-2428.
10- Raida, Vaclav, Philipp Svoboda, and Markus Rupp. "Constant rate ultra short probing (CRUSP) measurements in LTE networks." 2018 IEEE 88th Vehicular Technology Conference (VTC-Fall). IEEE, 2018.
11- Raida, Vaclav, et al. "Deriving cell load from RSRQ measurements." 2018 Network Traffic Measurement and Analysis Conference (TMA). IEEE, 2018.
12- Raida, Vaclav, et al. "Repeatability for spatiotemporal throughput measurements in LTE." 2019 IEEE 89th Vehicular Technology Conference (VTC2019-Spring). IEEE, 2019.
13- Alho, Lauri, et al. "Machine learning based mobile network throughput classification." 2021 IEEE Wireless Communications and Networking Conference (WCNC). IEEE, 2021.
14- Motlagh, Naser Hossein, et al. "Quality of Monitoring for Cellular Networks." IEEE Transactions on Network and Service Management 19.1 (2021): 381-391.
15- Krasniqi, Fidel, Liljana Gavrilovska, and Arianit Maraj. "The analysis of key performance indicators (KPI) in 4G/LTE networks." International Conference on Future Access Enablers of Ubiquitous and Intelligent Infrastructures. Springer, Cham, 2019.
16- Egi, Yunus, et al. "An efficient approach for evaluating performance in LTE wireless networks." Proceedings of the International Conference on Wireless Networks (ICWN). The Steering Committee of The World Congress in Computer Science, Computer Engineering and Applied Computing (WorldComp), 2017.
17- Elsherbiny, Habiba, et al. "4g lte network throughput modelling and prediction." GLOBECOM 2020-2020 IEEE Global Communications Conference. IEEE, 2020.
18- Skocaj, Marco, et al. "A KPI-Based Self-Optimization Algorithm for Inter-Frequency Handover in 4G/5G Networks." 2021 Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit). IEEE, 2021.
19- Imoize, Agbotiname Lucky, Kehinde Orolu, and Aderemi Aaron-Anthony Atayero. "Analysis of key performance indicators of a 4G LTE network based on experimental data obtained from a densely populated smart city." Data in brief 29 (2020): 105304.
20- Oje, A. A., and S. O. Edeki. "KPI measurement on the 4G network within the University of Ilorin." Journal of Physics: Conference Series. Vol. 1734. No. 1. IOP Publishing, 2021.
21- Raida, Vaclav, et al. "On the stability of rsrp and variability of other kpis in lte downlink-an open dataset." GLOBECOM 2020-2020 IEEE Global Communications Conference. IEEE, 2020.
22- Imoize, Agbotiname Lucky, et al. "Updating analysis of key performance indicators of 4G LTE network with the prediction of missing values of critical network parameters based on experimental data from a dense urban environment." Data in Brief 42 (2022): 108240.
23- Maposa, Darlington. "Evolving 4G KPIs to improve end user QoE for 4G LTE broadband systems." (2016).
24- Song, Guochao, et al. "KPI/KQI-driven coordinated multipoint in 5G: Measurements, field trials, and technical solutions." IEEE Wireless Communications 25.5 (2018): 23-29.
25- Zhang, Yan, et al. "Path loss prediction based on machine learning: Principle, method, and data expansion." Applied Sciences 9.9 (2019): 1908.
26- Cho, Yeon-Jea, et al. "AI-enabled wireless KPI monitoring and DiagnosisSystem for 5G cellular networks." 2019 International Conference on Information and Communication Technology Convergence (ICTC). IEEE, 2019.
27- Alshamsi, Hazza Saif Saeed. UE Based Performance Evaluation of 4G LTE Network. Diss. Florida Institute of Technology, 2019.
28- Jung, Alexander. Machine Learning: The Basics. Springer Nature, 2022.
29- Ericsson training student book, "LTE Mobility and Throughput - KPI Analysis & Optimization Workshop", Ericsson AB, LZT1381950 R1A ,2017.
30- Raida, Dipl-Ing Vaclav. Data-Driven Estimation of Spatiotemporal Performance Maps in Cellular Networks. Diss. University of Bologna Vienna, 2021.
31- Soós, Gábor, et al. "Practical 5G KPI measurement results on a non-standalone architecture." Noms 2020-2020 IEEE/IFIP network operations and management symposium. IEEE, 2020.
32- Trinh, Hoang Duy. "Data analytics for mobile traffic in 5G networks using machine learning techniques." (2020).