Drive Test-based Correlation Assessment of QoS Parameters for Exemplary Measurements Scenario in Suburban Environment

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Keywords: Quality of Service (QoS), Quality of Experience (QoE), Video Mean Opinion Score (VMOS), Signal-to-Interference-plus-Noise Ratio (SINR), Reference Signal Received Power (RSRP), Drive Test, Pearson Correlation Coefficient.

Abstract: The development of mobile networks is directly related to developing the telecommunications services market. Introducing new services requires adjusting methods of quality of service (QoS) assessment and management. QoS control measurements in mobile networks are a standard practice carried out by specialized companies for mobile network operators and regulators of the telecommunications market. In this paper, we analyze a selected measurement scenario for a suburban environment in which QoS was evaluated for video transmission from the YouTube service. The Systemics-PAB Group company carried out the measurements for the Polish regulator, the Office of Electronic Communications. The obtained measurement results are the basis for the correlation analysis between the QoS parameters. The analysis results show a strong relationship between the selected parameters, which can be used in modeling and simulation studies.

1 INTRODUCTION

The first mobile networks only provided voice call services. With the development of the next generations of mobile networks, new services have been made available to users, including short message service (SMS), multimedia messaging service (MMS), or broadly understood packet data transmission (Razeghi, 2007; Lloyd-Evans, 2002). Offering new, diverse telecommunications services in subsequent generations of cellular networks forced the development, implementation, and improvement of quality management systems for the provided services (Oodan *et al.*, 2002). In the modern third (3G), fourth (4G), and fifth generation (5G) mobile networks, the concept of quality is usually analyzed in three aspects, i.e., quality of network (QoN), service (QoS), and experience (QoE) (Falkowski-Gilski & Uhl, 2020). In the remainder of the paper, we use the acronym QoS understood as quality in a wide sense.

Correlation is one of the fundamental tools used in the analysis and processing of data and signals, e.g., (Schwarzinger, 2013; Ziółkowski & Kelner, 2016). Correlation analysis allows you to find similarities and relationships between two variables, properties, features, signals, or processes.

Correlation methods are also used in QoS research and methods. For example, (Yu *et al.*, 2021) proposed a novel algorithm of approximate service composition, which is based on QoS correlation. Its task is to determine the optimal path of service delivery.

The work (Li *et al.*, 2019) proposes an innovative approach to service selection that not only considers QoS correlations of services but also accounts for QoS correlations of user requirements. The proposed solution is decentralized, which avoids a single point of failure. The authors of (Li *et al.*, 2019) presented experimental results that showed the effectiveness of the developed solution. A similar approach has been proposed in (Chervenets *et al.*, 2016). On the other hand, simplified service selection methods are described in (Wang *et al.*, 2017; Deng *et al.*, 2016). The solution shown in (Wang *et al.*, 2017) is based on the QoS correlation of requirements. The authors of (Deng *et al.*, 2016) proposed the so-called correlation-aware service pruning (CASP) method.

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The CASP approach is based on managing QoS correlations by accounting for all services that may be integrated into optimal composite services and prunes services that are not the optimal candidate services.

The authors of (Ahmad *et al.*, 2020) conducted a correlation analysis between QoS metrics such as signal strength, average delay, jitter, and average packet loss. This analysis was performed for real-time cellular QoS metrics data, and the authors observed a significant correlation between several QoS parameters. Simultaneously, they indicate that some network emulators, e.g., NetEm (Jurgelionis *et al.*, 2011; Sliwinski *et al.*, 2010), do not consider the fact that some QoS parameters are correlated. In (Kim & Choi, 2010; Bae *et al.*, 2009), the correlations between QoS/QoE metrics in the video signal were analyzed.

In this paper, we analyze the correlation between QoS parameters. The presented results of the analysis are based on a drive-test (i.e., mobile measurements) carried out in a suburban environment for two mobile network operators (MNOs). Tests for video live-streaming from YouTube (YouTube, 2021) were selected for the analysis. This service was carried out using the 3G and 4G standards, i.e., Universal Mobile Telecommunications System (UMTS) and Long Term Evolution (LTE), respectively.

The remainder of the paper is organized as follows. Section 2 presents the test-bed, measurement scenario, and analyzed QoS metrics. Section 3 contains the results of the performed correlation analysis of QoS parameters. In the final part of the paper, we show a summary.

2 DRIVE TEST

The correlation assessment of the QoS metrics was carried out based on measurements in 3G (UMTS) and 4G (LTE) mobile networks in Poland. The drive tests were made by Systemics-PAB Group company on behalf of the Office of Electronic Communications (UKE), the Polish telecommunications market regulator (Kruszewski & Malinowski, 2022). The measurements were carried out in suburban areas, near Warsaw in the fourth quarter of 2021. Our analysis is based on data for the selected scenario, i.e., video live-streaming from the YouTube service. Benchmarking video streaming services was performed with a dedicated mobile application. The following sections describe the test-bed, scenario, and measured QoS parameters.

2.1 Measurement Test-bed

The QoS measurements were made by the Systemics-PAB Group company using the professional Rohde & Schwarz test-bed. The measurement system included SwissQual Diversity Smart Benchmarker Rel. 20.3 based on measuring terminals with SwissQual QualiPoc software (Kruszewski & Malinowski, 2022).

In tests, the Samsung Galaxy S20 + 5G (SM-G986BDS) measuring terminals were utilized. These terminals support the carrier aggregation technology and all bands used by MNOs in Poland.

A passive scanner, Rohde & Schwarz TSME6, was used for measuring the QoS metrics that represented the quality and power of radio signals. The scanner supports all frequency bands used in mobile networks.

Figure 1 shows part of the test-bed mounted in the rear trunk of the car. The measuring terminals were placed in special housings in the roof box at a height of about 1.8 m.

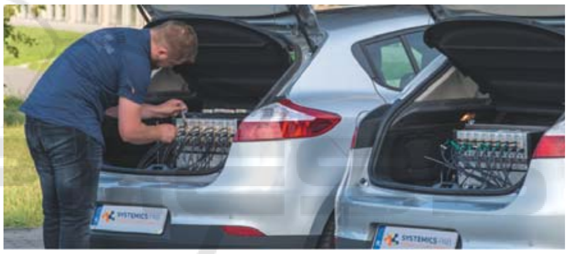

Figure 1: Test-bed mounted in the rear trunk (R&S, 2016).

2.2 Measurement Scenario

The research was conducted in the vicinity of Piaseczno and Góra Kalwaria towns, south of Warsaw, from November 29 to December 14, 2021. During the measurements, tests for voice calls and data transfers were performed. Data transfer tests included the YouTube live-stream, Hypertext Transfer Protocol (HTTP) browsing, and transfer. In this paper, we only analyzed data for the YouTube test for which three scenarios were performed:

- The G1 scenario played two-minute YouTube videos with 10-second intervals between videos.
- The G2 scenario consisted of playing a 60-second movie three times, followed by a 1-second preload ping. Then, there was a resection pause for 10 seconds.
- The G3 scenario consisted of playing a 10-second movie ten times, followed by a 2-second preload ping. Then, there was a resection pause for 10 seconds.

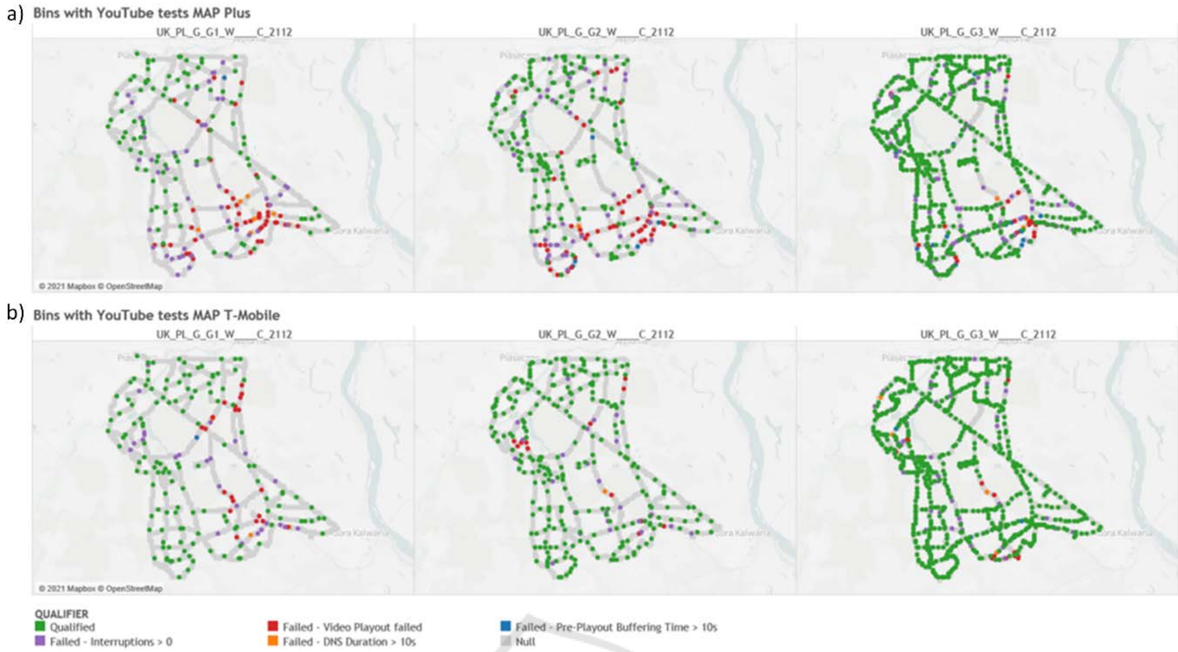

Figure 2: Maps with measurement points (bins) in YouTube test for a) MNO no. #1 and b) MNO no. #2 (Kruszewski & Malinowski, 2022).

It is worth emphasizing that the concept of a measurement point (bin) used in this paper should refer to a specific section of the measurement route (as well as the time interval) in which a single test was carried out for the analyzed scenario.

The tests were conducted for two MNOs providing telecommunications services in Poland, marked as MNO no. #1 and #2 – for formal reasons, the data has been anonymized. In the case of MNO no. #1, the video transmission service from YouTube was provided using two technologies, 3G (UMTS) and 4G (LTE). In the case of MNO no. #2, all transmissions were made using LTE.

Figure 2 illustrates a situational map with plotted measurement points (bins) for three scenarios (G1, G2, and G3) and two MNOs (Kruszewski & Malinowski, 2022). A green bin means that the test has been qualified as correct, while other colors indicate different errors that occurred during the test. In our analyzes, only the results corresponding to the green bins (‘*Qualified*’) were used, i.e., where the QoS metric values were determined.

2.3 Measured QoS Metrics

During the measurements, for each measurement point (bin), various parameters were determined regarding the MNO, time and place of measurement, used technology (i.e., UMTS or LTE), the average vehicle speed (*AvgSpeed*), and QoS parameters, including:

- VMOS – video mean opinion score – a subjective metric representing video quality; the parameter value is determined in the range from 1 to 5, with an accuracy of 0.1;
- AR – average resolution of video related to the number of pixels (p) in the film frame level – parameter representing video quality; its value is determined in the range from 360p to 1080p (i.e., Full High Definition);
- RSCP – reference signal code power – parameter representing radio signal power in dBm, designated only for UMTS technology;
- EC/IO – downlink carrier-to-interference ratio – parameter representing radio signal quality in dB determined for UMTS technology;
- RSRP – reference signal received power – parameter representing radio signal power in dBm, designated only for LTE technology;
- SINR - signal-to-interference-plus-noise ratio – parameter representing radio signal quality in dB determined for LTE technology.

A description of the last two mentioned metrics is presented in (Afroz *et al.*, 2015). In this case, the authors show also their measurement results in the LTE network.

3 CORRELATION ASSESSMENT

3.1 Correlation Metrics

In our analyzes, we use the Pearson correlation coefficient (PCC) defined as

$$PCC = \rho(X,Y) = \frac{\mathrm{E}\{(X-\mu_X)(Y-\mu_Y)\}}{\sigma_X \sigma_Y}, \qquad (1)$$

where $X=\{x_i\}$ and $Y=\{y_i\}$ represent sets of two analyzed parameters, $\mathrm{E}\{\cdot\}$ is the expectation operator, μ_X, μ_Y, σ_X, and σ_Y represent mean values and standard deviations of X and Y, respectively, i.e.,

$$\mu_X = \mathrm{E}\{X\},\ \sigma_X = \sqrt{\mathrm{E}\{(X-\mu_X)^2\}},$$
$$\mu_Y = \mathrm{E}\{Y\},\ \sigma_Y = \sqrt{\mathrm{E}\{(Y-\mu_Y)^2\}}. \qquad (2)$$

PCC is used to assess the correlation between two QoS metrics or the correlation of the average vehicle speed (*AvgSpeed*) with the selected QoS parameter.

In the case of parameters for which $PCC > 0.5$, the linear regression using the least squares method and the deviation of the measurement results in relation to the obtained line were determined.

3.2 Preparation of Measurement Data

In the YouTube tests performed by Systemics-PAB Group, total bins (i.e., measurement points) were equal to 5566 and 6060 bins for MNOs no. #1 and #2, respectively. In the case of MNO no. #1, video transmissions using the UMTS and LTE technologies were performed for 339 (6.1%) and 5227 bins (93.9%), respectively. For further analysis, only the data with the '*Qualified*' status were used, which means that the test was successful, and the values of all analyzed metrics were determined. In the case of MNO no. #1, video transmission tests were successful with UMTS and LTE for 60.2% and 89.4%, respectively. In the case of MNO no. #2, video transmission tests were finished successfully in LTE technology for 93.3%.

Correlation analyzes were carried out for three data sets, i.e., MNO#1-UMTS, MNO#1-LTE, and MNO#2-LTE.

3.3 Correlation between QoS Parameters

Using the prepared data from tests in UMTS technology, the PCCs between the four QoS metrics described in Section 2.3 were determined. For the MNO#1-UMTS dataset, RSCP, EC/IO, AR, and VMOS were used. The determined PCC values are included in Table 1.

Table 1: PCCs between QoS metrics for MNO#1-UMTS.

Metric	RSCP	EC/IO	AR	VMOS
RSCP	1.000	0.580	0.242	0.148
EC/IO		1.000	0.395	0.243
AR			1.000	0.546
VMOS				1.000

The obtained results show a significant correlation between RSCP and EC/IO ($PCC = 0.58$) and also between VMOS and AR ($PCC = 0.546$). For these parameter pairs, the measurement results are illustrated in the graphs in Figures 3 and 4, respectively. In addition, linear regressions have been determined, which are marked in red.

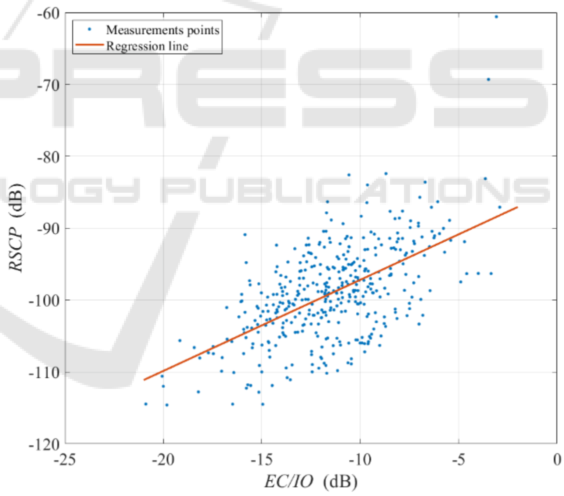

Figure 3: RSCP versus EC/IO for MNO#1-UMTS.

The following equation describes regression line between RSCP and EC/IO:

$$RSCP(\mathrm{dB}) = 1.267 \cdot EC/IO(\mathrm{dB}) - 84.5\ \mathrm{dB} \qquad (3)$$

The spread of the empirical RSCP values in relation to the value determined by the line is defined by the standard deviation, which is $\sigma_{RSCP} = 5.4$ dB .

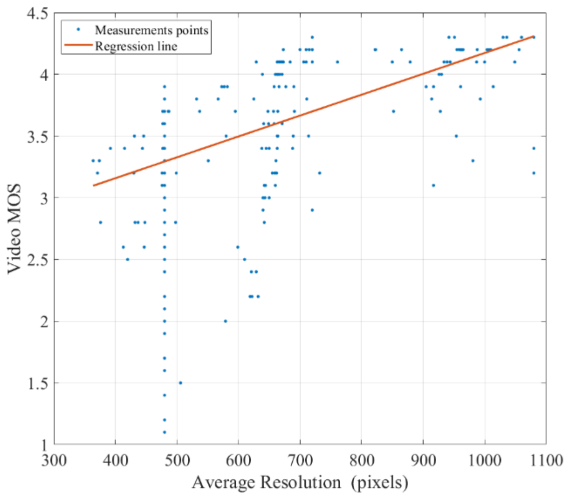

Figure 4: VMOS versus AR for MNO#1-UMTS.

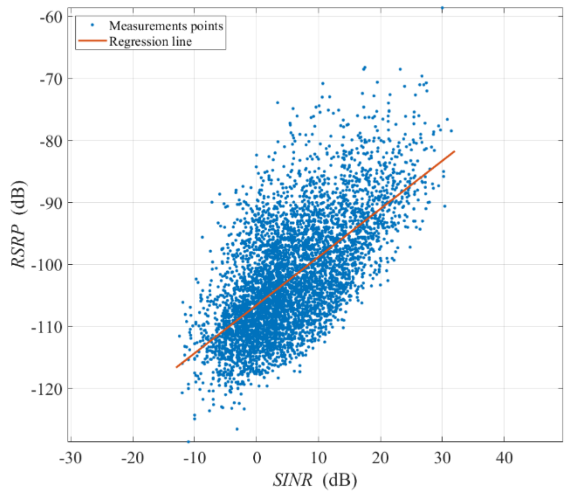

Figure 5: RSRP versus SINR for MNO#1-LTE.

In the case of the relationship between VMOS and AR for MNO#1-UMTS, the regression line is defined as

$$VMOS = 0.0017 \cdot AR(\mathrm{p}) + 2.5\,. \tag{4}$$

In this case, the deviation of the VMOS results is equal to $\sigma_{VMOS} = 0.5$.

Table 2 shows the results of the correlation analysis for MNO#1-LTE. In the case of LTE technology, RSRP and SINR were determined instead of the RSCP and EC/IO metrics, respectively.

Table 2: PCCs between QoS metrics for MNO#1-LTE.

Metric	RSRP	SINR	AR	VMOS
RSRP	1.000	0.647	0.369	0.269
SINR		1.000	0.405	0.298
AR			1.000	0.637
VMOS				1.000

The obtained results show that for MNO#1-LTE, analogously to MNO#1-UMTS, signal parameters (i.e., quality – SINR and power – RSRP) and quality video (i.e., AR and VMOS) are correlated with each other (i.e., *PCC* > 0.5). These parameters are illustrated in Figures 5 and 6, respectively.

The regression line between RSRP and SINR for MNO#1-LTE is given by the equation:

$$RSRP(\mathrm{dB}) = 0.776 \cdot SINR(\mathrm{dB}) - 106.5\ \mathrm{dB} \tag{5}$$

In this case, the standard deviation of RSRP relative to the regression line is $\sigma_{RSRP} = 7.0\ \mathrm{dB}$.

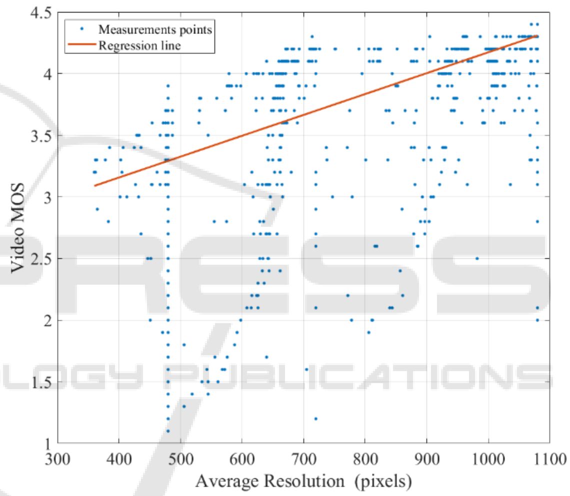

Figure 6: VMOS versus AR for MNO#1-LTE.

The regression line for AR and VMOS metrics and MNO#1-LTE is as follows:

$$VMOS = 0.0017 \cdot AR(\mathrm{p}) + 2.5 \tag{6}$$

and the deviation of VMOS is equal to $\sigma_{VMOS} = 0.4$.

An analogous analysis of measurement data was performed for the MNO#2-LTE set. PCCs are shown in Table 3 and in Figures 7 and 8 for RSRP(SINR) and VMOS(AR), respectively.

The obtained results indicate the correlation between SINR and RSRP parameters and a slightly lower correlation between AR and VMOS (i.e., *PCC* = 0.446) than in the case of MNO#1-LTE.

Table 3: PCCs between QoS metrics for MNO#2-LTE.

Metric	RSRP	SINR	AR	VMOS
RSRP	1.000	0.657	0.228	0.157
SINR		1.000	0.246	0.156
AR			1.000	0.446
VMOS				1.000

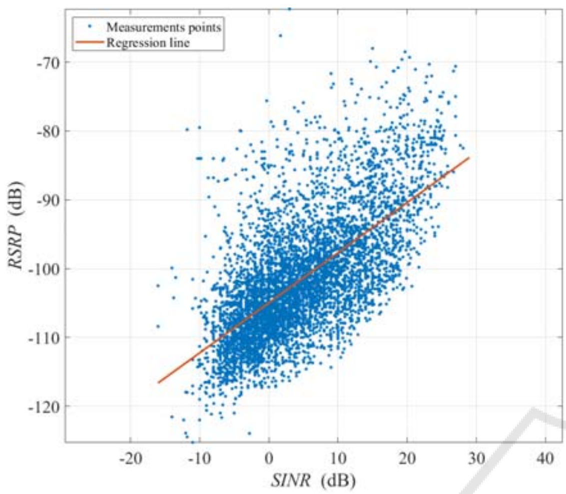

Figure 7: RSRP versus SINR for MNO#2-LTE.

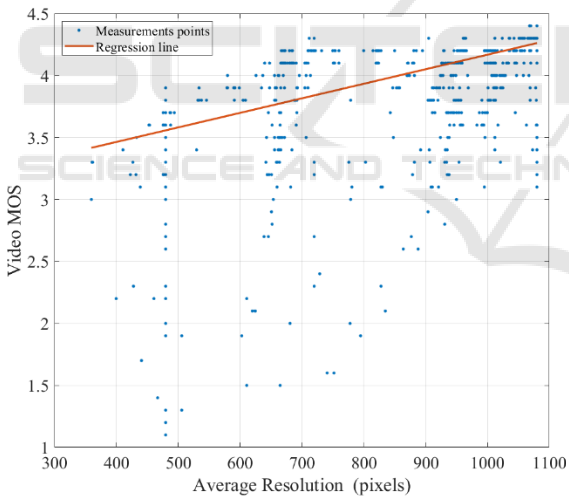

Figure 8: VMOS versus AR for MNO#2-LTE.

The regression line between RSRP and SINR for MNO#2-LTE is as follows:

$$RSRP(\mathrm{dB}) = 0.728 \cdot SINR(\mathrm{dB}) - 105.0\ \mathrm{dB} \qquad (7)$$

and the RSRP deviation is $\sigma_{RSRP} = 6.5$ dB.

For MNO#2-LTE, the regression line between VMOS and AR is described by the formula:

$$VMOS = 0.0012 \cdot AR(\mathrm{p}) + 3.0 . \qquad (8)$$

In this case, the standard deviation of VMOS is $\sigma_{VMOS} = 0.3$.

Based on the obtained results, we can see that the signal parameters represent power (i.e., RSCP and RSRP for UMTS and LTE, respectively) and quality (i.e., EC/IO and SINR for UMTS and LTE, respectively) are strongly correlated with each other. For the three analyzed data sets, there are $PCC > 0.5$. Therefore, regression lines could be derived for these QoS metrics. It is worth noting that the deviation of the results of the parameter representing the signal strength (i.e., RSCP or RSRP) is about 10% of its variability range, e.g., for MNO#1-LTE, $\sigma_{RSRP} = 7.0$ dB, while the RSRP varied from -128.6 dBm to -58.6 dBm, which gives a change range of 70 dB. Thus, the regression line describes the relationship between these QoS metrics relatively well. The obtained equations can be used to determine the power parameter based on the signal quality parameter using the normal distribution with an appropriate standard deviation.

For the video quality parameters, $PCC > 0.5$ is for the two sets, i.e., MNO#1-UMTS and MNO#1-LTE, while for MNO#2-LTE, PCC was slightly below 0.5. In these cases, the regression lines were also determined. For MNO#1-UMST and MNO#1-LTE, line equations are described with identical coefficients. The difference is for the VMOS standard deviation values – for UMTS, it is slightly greater than for LTE. In the case of MNO#2-LTE, the regression line coefficients are slightly different to MNO#1-LTE, while VMOS deviation is the smallest. The obtained regression lines make it possible to determine the approximate or model VMOS value based on the average resolution adjusted to the current link throughput in the radio channel.

Moreover, the results obtained in the tables show a specific correlation between AR and the radio signal parameters at the level of $0.22 < PCC < 0.41$. Therefore, the regression lines for such cases may allow the estimation of AR values based on the signal parameter (e.g., SINR or RSRP) measurements or vice versa, which may find practical application.

3.4 Impact of Velocity on QoS Parameters

Figure 9 shows the velocity distribution for the three analyzed data sets. We can see that measurements in suburban areas were usually carried out at speeds below 40 km/h, while driving at speeds above 50 km/h took place outside the built-up area.

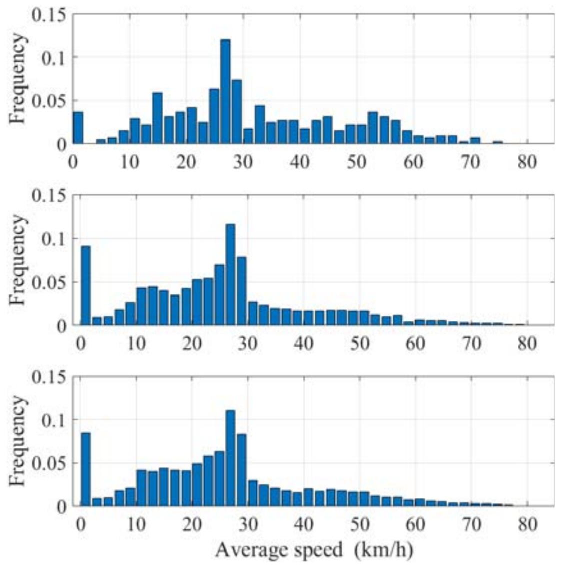

Figure 9: Average speed distribution for (a) MNO#1-UMTS, (b) MNO#1-LTE, and (c) MNO#2-LTE.

In the conducted analysis, we decided to check whether there is a correlation between the average vehicle speed and the QoS metrics. The determined PCCs are included in Table 4.

Table 4: PCCs between QoS metrics and average speed.

Metrics	MNO#1-UMTS	MNO#1-LTE	MNO#2-LTE
RSCP	0.014		
EC/IO	0.031		
RSRP		0.069	–0.004
SINR		–0.001	0.018
AR	0.046	–0.021	–0.039
VMOS	0.068	–0.026	–0.030

The obtained results indicate a negligible influence of speed on the analyzed QoS metrics. The practice of using data transmission in mobile networks while traveling by vehicles (e.g., car, train, etc.) shows that at high speeds, the use of this service type is problematic. On the other hand, the obtained results do not indicate a significant impact of speed on the QoS. Thus, we conclude that the vehicle speed may have a more substantial effect on session breakup during video transmission or reconnection between the mobile terminal and base station. In this paper, we do not analyze the dataset that was qualified as '*Failed*' (only '*Qualified*' data was analyzed).

4 CONCLUSIONS

In this paper, we have presented a correlation analysis of QoS metrics determined in the measurement campaign near Warsaw for two MNOs. The study considered a scenario with the YouTube live-stream service. The determined PCCs for the parameter pairs indicated a strong relationship between the signal parameters – radio signal power and quality, and between the video quality metrics, i.e., AR and VMOS. Regression lines for these pairs and metrics deviations were determined. We also assessed the impact of car speed on the QoS metrics. In this case, the obtained PCC values do not show a strong correlation between them.

It is worth noting that the percentage of measurements considered for analysis for LTE was about 90%, while for UMTS is only about 60% (see Section 3.2). In the UMTS case, the rejection of a significant amount of data may result from the fact that older generation solutions (UMTS) cope worse than LTE technology with user mobility (i.e., Doppler effect mitigation), ensuring continuity of broadband transmission, especially when user handover between the next base stations. Hence, the trend, noticeable in numerous MNOs, consisting of the 3G technology abandonment and the use of its spectral resources in favor of efficient 4G and 5G seems to be justified. On the other hand, the smaller number of measurement data used for the UMTS correlation analysis should insignificantly affect the reliability of the obtained results, which are close to the LTE results.

In the near future, the authors are planning to analyze other scenarios carried out in the measurement campaign and assess the possible influence of vehicle speed on session interruption. The obtained results of the analysis will be used in the method of assessing mobile networks in terms of QoS/QoE performance assessment developed by the authors (Zmysłowski & Kelner, 2022).

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