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Objective assessment of the speech quality broadcasted by local Digital Radio in selected locations in Wroclaw

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***Abstract*—The development of digital radio, observed in recent years, and the advantages offered by this medium are resulting in the expansion of the audience. In order to ensure the proper quality of broadcasting, it is necessary to monitor this quality. The assessment based on listening tests is very expensive and organizationally inconvenient. The development of methods for objective evaluation of signals makes it possible to monitor the quality of transmitted content, without the need for troublesome procedures associated with subjective evaluation. The good correlation of subjective evaluation and objective measurements in the transmission of perceptually encoded signals, reported in the literature, may allow for random quality monitoring. The authors decided to test the feasibility of using two objective evaluation methods to assess the quality of the speech signal transmitted on digital radio by comparing the results obtained with the subjective evaluation. The paper presents the results of objective measurements of speech quality transmitted via Digital Audio Broadcasting+ in Wroclaw agglomeration. Measurements have been done in various city sites in order to determine the influence of the location on speech quality. The obtained results of the assessment performed by the use of two methods of testing: PESQ and POLQA, allowed to find a correlation between the objective and subjective results of quality evaluations. The method of objective testing may be used for monitoring the quality of signals in Digital Audio Broadcasting networks especially spoken broadcasts**

***Keywords*—speech quality; DAB; PESQ; POLQA**

I. Introduction

THE first experimental transmission of a radio program in digital technology was made in Poland on September 18, 1995. Unfortunately, digital radio technology was not commercialized in Poland for the next 18 years. In 2013, the European Broadcasting Union recommended the introduction of DAB + Digital Audio Broadcasting technology [1, 2] as soon as possible. In Poland, the digitization of radio began on October 1, 2013. On January 19, 2018, a local DAB multiplex was launched in Wroclaw [3, 4] based on a Single Frequency Network (SFN) system [5, 6, 7].

As digital radio is constantly being improved, the broadcaster is obliged to carry out a number of tests, including quality tests in order to keep the quality as high as possible. From the listener's point of view, the effectiveness of digital radio is assessed by the quality of both music and spoken word broadcasts received. Classical objective quality assessment methods [8], such as SNR or THD+N measurements, do not provide complete information on the sound quality of digital broadcasting. When testing telecommunications networks, an important aspect is the quality of the signal as subjectively perceived by the listener, known as Quality of Experience [9, 10, 11, 12, 13]. For this reason, subjective tests are used – the listening team evaluates the received sounds according to a given scale. Thus, the evaluation is based on the listener's auditory impression. Subjective measurements are still the only way to obtain a reliable result to assess the quality of the speech signal and musical programmes [8]. The study of the quality of speech signals using subjective methods is associated with several difficulties such as long testing times, high costs and the need to organize a large group of listeners. Therefore, it was decided to objectivize the listening tests. It involves replacing the listening team with a computer programme. Perceptual algorithms are designed to evaluate the signal as a human would. As a result, testing time is significantly reduced, less costs are generated, and there is no need to work with a large group of listeners and experts. Therefore, a very important issue is to determine the relationship between the results of subjective and objective measurements of signals transmitted by the DAB+ radio. AI-based methods, such as AutoMOS or WaveNet, can be used to assess speech quality, but they are not yet recommended by ITU-T. In the described experiment, two objective methods recommended by the ITU-T were used, namely PESQ [14] and POLQA [15].

The idea of measuring PESQ (Perceptual Evaluation of Speech Quality), is based on the so-called internal representation which is the theoretical form of the speech signal in the human mind [14, 16, 17]. The reference signal (input signal) is a natural speech signal that generally lasts 8 to 12 s, with samples that last up to 30 s allowed. The evaluated (output) signal is the signal broadcast by the local DAB+ (LocalDAB) radio station. In the first stage, the power and delay between samples are evaluated and, if necessary, an appropriate correction is made. Next, both signals are subjected to a series of transformations that model the various stages of sound processing in the human auditory system, including in particular: specific analysis in the frequency domain and non-linearity of sound intensity processing. Any time shifts of the samples are taken into account in further stages of signal

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processing. In the final stage, a so-called cognitive model is implemented to make a final judgment based on a comparison of the internal representations of the two signals. The final PESQ score is a linear combination of the mean value of the disturbances and the mean value of the asymmetric noise resulting as a product of transmission.

The second POLQA method (Perceptual Objective Listening Quality Assessment) used in the experiment is designed to objectively assess the quality of speech transmitted over narrowband (300 Hz to 3,400 Hz), wideband (70 Hz to 7,000 Hz) and superwideband (50 Hz to 14,000 Hz) systems [15, 16, 18, 19]. Please note that, although in super-wideband mode POLQA operates at a sampling rate of 48 ksamples/s, it would be a mistake to apply this method to music signals. For music signals, the standard is the PEAQ (Perceptual Evaluation of Audio Quality) method [20, 21].

The purpose of this study was to determine the quality of the speech signal transmitted in LocalDAB digital radio broadcasting at selected points of the Wroclaw agglomeration using PESQ and POLQA objective methods, allowing one to determine

- the influence of a location on the quality of the transmitted speech signal on a LocalDAB radio,
- the influence of bit rate on the quality of the transmitted speech signal in the LocalDAB radio,
- the effect of the sampling frequency of the test signals on the result of the speech quality measurement,
- a correlation between results of objective measurements and subjective evaluation.

Although the relationship between subjective evaluation and objectively measured signal quality has been noted in the literature [9, 11, 22, 23], to date there are only a few publications that address the evaluation of audio transmission quality in digital radio. In an SFN network, unwanted effects and artefacts in the form of signal distortion are possible, caused, for example, by the overlap of the radiation areas of individual transmitters [4, 6, 7].

The following sections of the article will describe the test signals, the selection of measurement points, and the process of the measurement procedure. Finally, the results of the test will be presented and compared with the results of the subjective quality assessment.

II. RESEARCH METHOD

A. Test material

The test material used in subjective and objective evaluation of speech quality should be based on phonetically balanced sentence lists. An earlier study conducted by the authors [24] was based on audio material created from a recording of spoken broadcasts by the local digital radio station LocalDAB recorded at a single point (Market Square) in Wroclaw. Statements were recorded for several programmes broadcast at different bit rates. Sentence lists were created from several tens of minutes of utterances obtained from broadcasts aired by LocalDAB and subjectively and objectively evaluated using the PESQ method. However, the results of the speech quality assessment were influenced by the manner of pronunciation, expression, and also the accuracy of the speech. In order to obtain more reliable evaluations, phonetically balanced lists read by a man and a woman with correct, careful pronunciation had to be used.

In this experiment, the test material consisted of sets of 10 sentence lists [25] recorded by a man and a woman at a sampling rate of 44,100 samples/s with a resolution of 16 bits. The choice of sampling rate was defined by the standards adopted by the evaluated LocalDAB radio system in the process of preparing the radio material.

Test lists were transmitted at five various bit rates: 32 kbps, 48 kbps, 64 kbps, 96 kbps, and 112 kbps. The test signals were broadcast on five radio channels instead of normal broadcasts, with a bit rate assigned to each radio station.

Measurement points where recordings were made were located in the area of the largest human concentration in the city. The detail of the distribution of measurement points was described in [26].

The test signals were received with a commercial digital radio set Sangean DPR-26 DAB and recorded on the ZOOM H4n PRO recorder. These test signals were broadcasted by LocalDAB for each bit rate consisting of 10 sentence groups, with each group containing 5 sentences. The average duration of one sentence was about 10 seconds. To assess speech quality with the PESQ and POLQA methods, the test material had to be properly prepared according to ITU recommendations [14, 15]. For this purpose, the test signal group containing 10 sentences was divided into 10 files containing 1 sentence. Such a base was created for each measurement point and for each bit rate. In addition to the database of test signals (emitted by LocalDAB), a database of original (undistorted) signals was also created as a reference in the objective measurements.

B. Objective measurement method

Speech signal quality measurements were made using two objective methods: PESQ and POLQA, using the Voice Quality Testing (VQT) program from GL Communication Inc. The VQT program is designed to objectively assess speech quality in various types of telecommunications networks. Measurements with the PESQ algorithm follow the recommendations of ITU-T P.862, while the POLQA algorithm follows ITU-T P.863. The VQT program analyzes the degraded files and provides a comparison of the test file with the reference one.

To perform the measurement, one needs to select the appropriate algorithm (PESQ or POLQA) and upload two signal files: the original one and the tested one (emitted by LocalDAB in this case). The program, after performing calculations, returns the result in the form of a numerical, verbal and graphical evaluation.

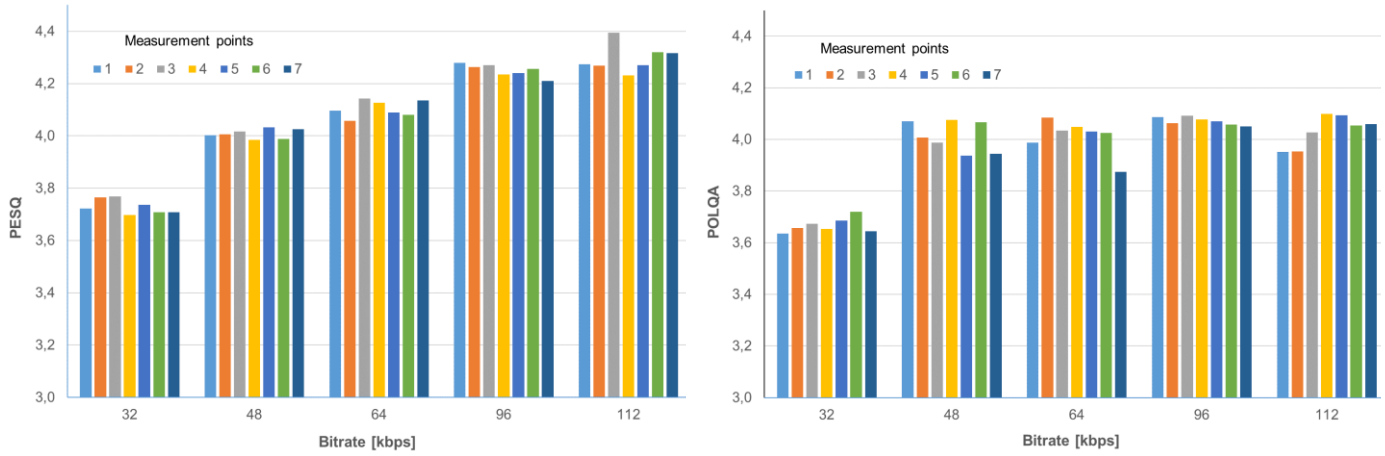
In the presented work, speech quality assessment was carried out using POLQA and PESQ methods for speech samples recorded at 7 measurement points. For each location, quality measurements were made for five bit rates: 32, 48, 64, 96 and 112 kbps. The sampling frequency for both methods (PESQ and POLQA) was set at 16 kHz. Additionally, for the POLQA algorithm sampling frequencies 8 kHz and 48 kHz were used. Then all the results were subjected to statistical analysis.

The first step of the analysis was to assess the probability of obtaining a questionable measurement result. For this purpose, the Chauvenet criterion was used [27]. The next step was to determine the significance of the results based on the Student's t-test and one-way ANOVA analysis of variance, using the F-Snedecor test.

III. RESULTS AND DISCUSSION

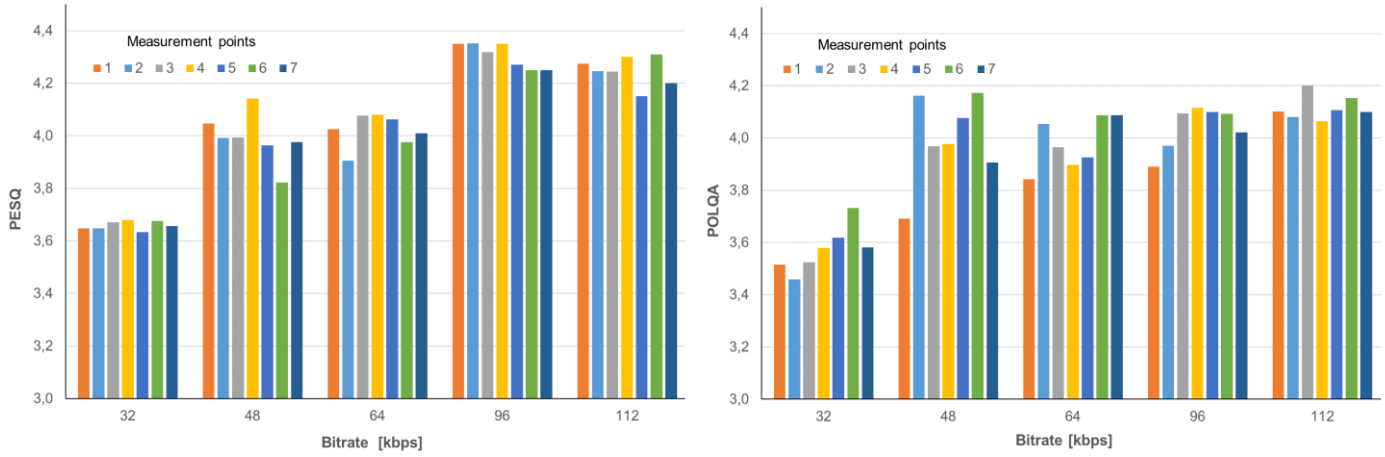
A. Effect of receiving location on speech signal quality

The first aspect was to see if the location of the measurement point, has an impact on the quality of the speech signal emitted by a LocalDAB radio. Objective measurements were made using PESQ and POLQA methods separately for male and female voices. The results obtained for the male voice are shown in Figure 1, and for the female voice in Figure 2. To compare these results obtained by the PESQ and POLQA methods, signals with a sampling frequency of 16 kHz were calculated.



(**a**) (**b**)

Fig. 1. Averaged values of the quality assessment of the male speech signal broadcast on LocalDAB radio in all of receiving points in the area of Wroclaw for 5 bit rates obtained by the method (a) PESQ, (b) POLQA..



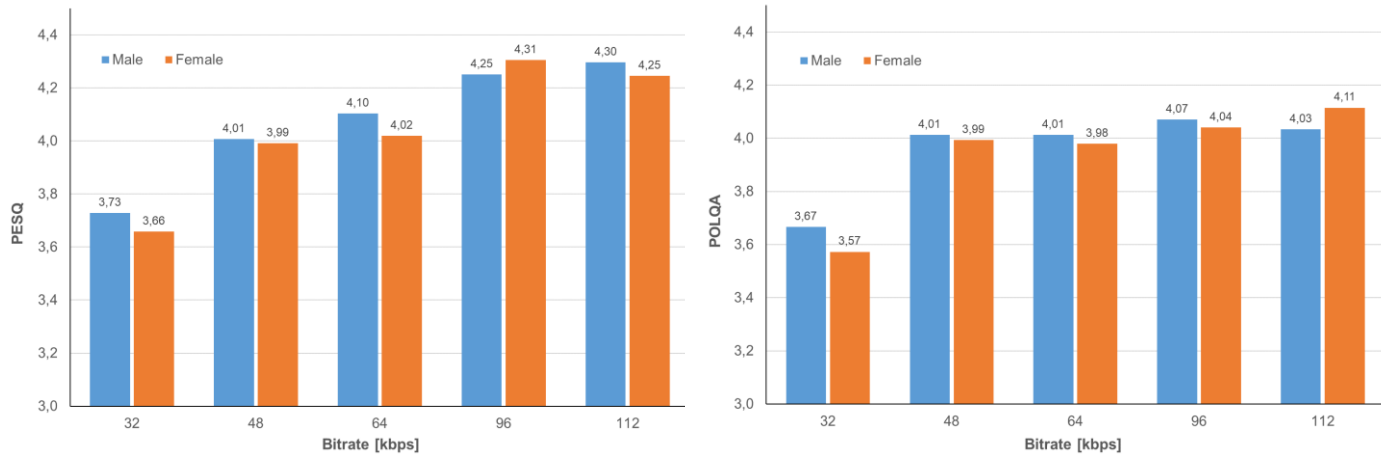
(**a**) (**b**)

Fig. 2. Averaged values of the quality assessment of the female speech signal broadcast on LocalDAB radio in all receiving points in the area of Wroclaw for 5 bit rates obtained by the method (a) PESQ, (b) POLQA.

After rejecting the results that did not meet the Chauvenet criterion, the ANOVA tests were performed for the results obtained at all measurement points, for each bit rate separately. The test was carried out at a significance level of $\alpha = 0,05$. The results of the statistical analysis referred to the POLQA method were consistent with the results obtained by the PESQ method and indicated that there is no influence of the location of reception of the radio signal on the quality assessment in the group of female and male voices ($p = 0,063$, and $p = 0,077$, respectively).

B. Effect of bit rate on speech signal quality

The next stage of the analysis was concerned with the effect of bit rate on the quality of the speech signal. Five bit rates were examined: 32, 48, 64, 96 and 112 kbps. Although the first stage of the study has showed that the location of the recordings does not affect the measurement result, so for each bit rate the PESQ and POLQA results collected at the various receiving points have been averaged over the sites, for male and female voices. The results obtained using the PESQ method are shown in Figure 3a, while those using the POLQA method are shown in Figure 3b. As in III *A* section, in order to compare the results obtained by the PESQ and POLQA methods, signals with a sampling frequency of 16 kHz were calculated.



(a) (b)

Fig. 3. Averaged values of the quality assessment of the male and female speech signal broadcast on LocalDAB digital radio depending on the bit rates obtained by the (a) PESQ, (b) POLQA method.

Statistical analysis of the results based on an ANOVA test showed that for both the PESQ and POLQA methods, the difference in scores starting from a bit rate of 48 kbps is not significant (p = 0,057). Although differences can be observed in the results obtained by the PESQ method for the bit rate of 48, 64 kbps and 96 and 112 kbps, however, the analysis by Student's t-test at α = 0.05 showed that these differences are statistically insignificant (p = 0,087). For the results obtained by the POLQA method from 48 kbps to 112 kbps, no differences have been observed, and these findings apply to both male and female speech.

C. *Effect of sampling rate on speech signal quality*

In this stage of the study, Voice Quality Testing software was used, allowing measurement by the POLQA method for signals sampled at 8kHz, 16kHz and 48kHz. Measurements were made with male and female voices.

Speech quality assessment results obtained using the POLQA for sampling rates of 8 kHz (blue bar), 16 kHz (orange bar) and 48 kHz (grey bar) are shown in Figure 4a and b for both voices.

Statistical analysis of the significance of the differences in the results obtained by POLQA methods for speech signals sampled at different frequencies was performed using Student's t-test at a significance level of α = 0.05. In the case of the results obtained using the POLQA method, it was shown that the differences are statistically significant between the results obtained for speech signals sampled at 48 kHz and the others, that is, 8 kHz and 16 kHz (p = 0,008). Statistical analysis of signals sampled at 8 kHz and 16 kHz showed that for the female speaker, for all bit rates, the differences are statistically insignificant (p = 0,101). For the male voice, only for the bit rate of 32 kbps the differences are statistically significant (p = 0,04), while for the others it is insignificant (p = 0,519).

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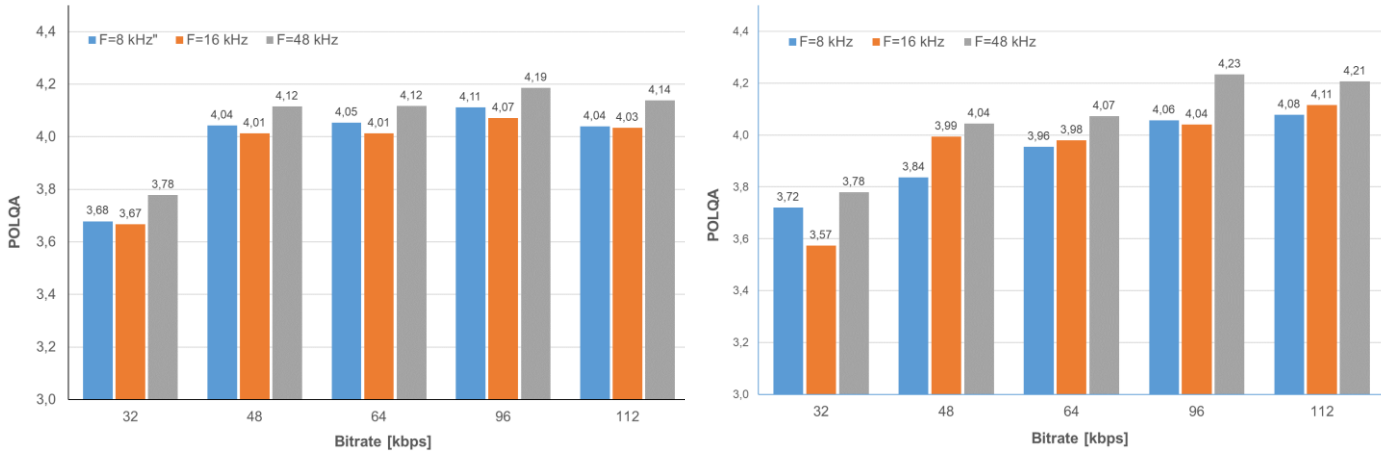
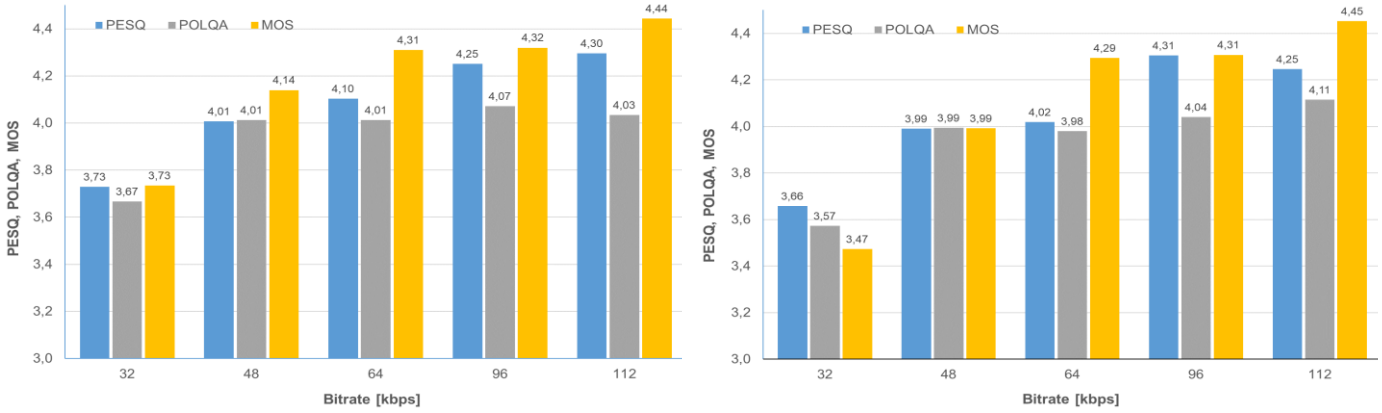


(a) (b)

Fig. 4. Averaged values of the quality assessment of the male (a) and female (b) speech signals broadcast on LocalDAB digital radio depending on the bit rates obtained by the POLQA method for signal prepared with 8, 16 and 48 kHz as sampling frequencies.

D. *Comparison with subjective evaluation of speech signal quality*

Subjective evaluation of the quality of the speech signal was performed using the Absolute Category Rating (ACR) method with 30 listeners ranging in age from 18 to 30 years, and on a five-point MOS scale (Mean Opinion Score) scale [14] with the same sound material used in objective measurements. The test signals were presented in the laboratory and the acoustic conditions of the listening room met the standards included in the ITU Recommendation P.800. A detailed description of the whole performance of the test can be found in the paper [26]. A comparison of the results of subjective (MOS) and the objective measurements (PESQ and POLQA) is shown in Figure 5.



(**a**) (**b**)

Fig. 5. Averaged values of the quality assessment of the male (a) and female (b) speech signal broadcast on LocalDAB digital radio depending on the bit rates obtained by PESQ (blue bars), POLQA (gray bars) and MOS (subjective measurements - yellow bars) methods..

Comparing the results obtained, it can be seen that for the male voice, the MOS values are higher than PESQ and POLQA, while for the female voice only for the speed of 32kbps the MOS value is lower, and in other cases the MOS values are higher than the objectively measured indicators. Table 1 shows the difference between the MOS values and the PESQ and POLQA values separately for male and female speech signals sampled at 16 kHz. Additionally, the difference between MOS and POLQA for a sampling frequency of 48 kHz is included in the table I. The results of the presented data analysis allow concluding that, in general, the subjective measurement results converge most closely with the PESQ values. The exception is the 32 kbps rate for the female voice when there is the smallest difference in subjective and objective measurements for the POLQA measurement.

The results obtained supported by statistical tests indicated that the objective measured quality of the speech signal transmitted via LocalDAB radio within the agglomeration of Wroclaw city does not depend on the locations of the measurement points. This fact converges with the conclusions drawn from the analysis of the results of subjective measurements [26] as well as the measurement of radio-wave propagation [28].

Analyzing the effect of bit rate on the speech quality, it can be said that the presented results of objective measurements are consistent with the results of subjective assessment performed in Wroclaw agglomeration [26], that for bit rates ≥ 64 kbps, PESQ values exceed the value of 4.0, what means that the speech quality may be assessed as good, according to ITU-T recommendation P.800 as well as the other criteria assumed by other researchers [29, 30]. It should also be noted that a subjective assessment of speech signals has been addressed mostly on speech intelligibility which suggests that the mode of evaluation is based on a single-factor criterion, other than in the case of multimedia evaluation [23, 31].

TABLE I
THE DIFFERENCES IN RESULTS OF A SUBJECTIVE (MOS) AND OBJECTIVE (PESQ, POLQA) MEASUREMENTS FOR MALE AND FEMALE VOICES.

Bit rate	32 kbps	44 kbps	64 kbps	96 kbps	112 kbps
MOS – PESQ (Male - 16 kHz)	0.006	0.132	0.206	0.069	0.147
MOS - PESQ (Female - 16 kHz)	-0.186	0.001	0.275	0.002	0.206
MOS - POLQA (Male - 16 kHz	0.068	0.127	0298	0.249	0.409
MOS - POLQA (Female - 16 kHz)	-0.100	0.002	0.314	0.267	0.338
MOS - POLQA (Male - 48 kHz)	-0.043	0.024	0.193	0.134	0.306
MOS - POLQA (Female - 48 kHz)	-0.306	-0.052	0.221	0.074	0.246

Regarding the effect of the sampling rate observed for POLQA method, differences can be noted between the results obtained for a speech signal sampled at 48 kHz and the results obtained for the other sampling rates (8 kHz and 16 kHz). When comparing the results of objective and subjective measurements, it can be seen that a similar trend exists in the evaluation of speech signal quality for both methods. In the performed studies, very good convergence of objective and subjective results was obtained for the PESQ method for bit rates ≥ 64 kbps although the results obtained by the POLQA also show good agreement with the subjective evaluation for this method (48 kHz). Therefore, it can be assumed that, on the basis of the presented studies, it is possible to use objective methods

of PESQ or POLQA in assessing speech quality for a simple monitoring method of broadcast quality.

CONCLUSION

Based on the results obtained, it can be concluded that the objective-measured quality of the speech signal transmitted through LocalDAB radio within the agglomeration of Wroclaw city does not depend on the location of the measurement points. For the sampling rate values used for preparing the test signals, it was found that this parameter does not affect the obtained results for lower sampling frequencies (8 kHz and 16 kHz). However, the higher value of sampling frequency (48 kHz) used in the POLQA makes significant differences from the results obtained for the lower sampling rates.

The verification of the effectiveness of the objective method of assessing speech quality is possible by a subjective evaluation. When comparing the results of objective and subjective measurements, one can see a similar trend in the evaluation of speech signal quality. In the studies carried out, a very good convergence of objective and subjective results was obtained for the PESQ method for bit rates <64 kbps, although the results obtained by the POLQA also show a good agreement with the subjective evaluation of the POLQA method (48 kHz). Thus, it can be assumed that the studies presented in this paper confirmed the validity of using objective PESQ or POLQA methods in assessing speech quality as simple methods to monitor quality for digital radio applications.

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