RADIO COVERAGE COMPARISON TESTS OF P.25 AND TETRA STANDARDS FOR VOICE TRANSMISSION

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1. Introduction

TELE-COM is a company established in 1991 in Poznań, Poland. The main activities of the company are connected with comprehensive design, deployment and measurements of turnkey radio communication systems (trunked radio, mobile phones, microwave links, WLAN networks, TV and FM stations) and measurements of electromagnetic fields (radio coverage and safety measurements around transmitters, leakage from cable TV networks). TELE-COM also offers consulting services in radio communication and electromagnetic compatibility area. TELE-COM has the ISO 9001 certificate and the measurement laboratory accredited by the *Polish Center for Accreditation*.

Since 1994 TELE-COM has been actively involved in the design and deployment of the trunked radio network used by the power distribution companies in Poland. More than 430 base stations were built in the past 10 years. Due to that fact communication, which is so important for the power industry, has reached a high level. The trunked radio system uses the analog standard MPT 1327 and occupies the bandwidth 410 – 430 MHz. The operator of the network is the *Polish Power Transmission and Distribution Association* (PTPiREE) with the headquarters in Poznań, Poland.

However, the life of the analog systems is coming to its end. They should be replaced by digital systems. The choice of the proper digital standard should be made very carefully. The process of migration will require substantial funds. Moreover, the migration must be done without interrupting the work of all services using the network and long breaks in radio communication.

In the process of system choice two aspects should be taken into consideration:

- there are approx. 430 base stations; the infrastructure (masts, optical and microwave data links, power supplies, etc.) required a lot of money and therefore should be used in the new network,
- the network operator owes more than 50 radio channels (with the raster 12.5 kHz) which can be considered as a big treasure now (the lack of radio spectrum for the new systems). Obtaining the new channels for the digital system can be very difficult and expensive.

The new digital standard should use the above mentioned “resources” as much as possible. In 2003 TELE-COM together with the network operator started some activities concerning the choice of the new digital trunked radio standard.

It was not, or is it now, the intent of the report to discriminate any of the digital radio standards or manufacturers and distributors of the equipment. The *only intent* of this report is to help people responsible for the decisions (management and technical services) to make the choice of the proper digital standard which will meet the needs of their companies.

TELE-COM would like to kindly thank M/A-COM Poland from Warsaw, Poland (the European representative of M/A-COM), and AKSEL from Rybnik, Poland (the representative of Rohill and Motorola), for delivering the equipment for the tests.

2. First steps towards digital radio

An attempt to include the radio network as a part of the new national safety TETRA network (which is to be built within the frame of the F-16 offset project) was made in 2002. The attempt was not successful. However, TELE-COM prepared computer simulations of radio coverage in order to establish the number of base stations (BS) required for the area of Poland. The standard parameters of the TETRA equipment and the design guidelines (published by ETSI) were used.

The simulation showed that the required number of BS was equal to approx. 1200. The same number was obtained by the *National Institute of Telecommunications* in Warsaw which took part in designing the national safety network. Our simulations did not take into account the coverage inside buildings, since power industry employees work in open areas.

The obtained result was in agreement with our expectations. We anticipated that the cliff effect would strongly influence the coverage. The planning criteria published in the ETSI documents may have been tightened to obtain good quality of service. All these factors gave the conclusion: the number of TETRA BS would be approximately 3 times greater than the number of existing analog BS.

The cliff effect is typical for digital radio systems using vocoders. Close to the repeater where we can be assured of a high signal-to-noise ratio and little background noise, conventional FM trunked systems provide a superior voice quality. With the increased background noise the intelligibility of the FM signal decreases gradually.

The vocoder provides a consistent voice quality in both scenarios. As we move towards the edge of the system range (fringe area), the FM quality decreases until a point of unintelligibility is reached. The digital system, however, maintains a consistent performance until the bit error rate (BER) starts to rise and then loss of communication is rather abrupt. The difference between good voice quality and loss of voice can be as little as 2 dB at the receiver input.

The expenditure on the new digital system will be relatively high. In order to confirm whether the simulated coverage is comparable with the measured coverage (direct impact on the expenditure spent by the power industry), the network carrier together with TELE-COM decided to perform field tests of various digital standards.

3. Choice of the standards for testing

After the analysis of existing digital standards TELE-COM decided to choose for further consideration and testing the following standards:

- APCO 25 (P.25),
- TETRA.

Their features defined in the standard documents as well as additional options (standard extensions) offered by equipment manufacturers and distributors make them suitable for the new digital trunked radio network which will be used by the power industry in Poland. The detailed description of both standards is available in written and electronic form.

TELE-COM together with the operator of the analog network PTPiRE organized a series of comparison tests of the existing MPT 1327 standard and the digital standards P.25 and TETRA. During the tests we were using the equipment made by *Alcatel* (MPT 1327), *Motorola*, *Rohill* (TETRA) and *M/A-COM* (P.25).

4. Assumptions for field tests

The main goal of the tests was to measure and compare the *actual* radio coverage of the digital standards P.25, TETRA and the analog one MPT 1327. The coverage influences directly the number of BS required for the whole network, which, in turn, implies the outlay necessary for migration to the new digital standard. The first comparison test between P.25 and MPT 1327 (September 2004, Poznań, Poland) revealed that the actual coverage of the digital system was comparable (equal) with the coverage of the analog system with 430 BS in Poland. Before further tests it seemed possible that the actual coverage for TETRA would be also greater than the simulated one.

The performed tests gave many interesting observations and hints which may be helpful when taking a decision about the new digital radio standard.

The speech quality was assessed according to the following subjective scale of grades:

- **1**: speech present but unreadable, very high level of noise, deep and long fades,
- **2**: speech readable with considerable effort, voice distorted, strong noise and fades,
- **3**: speech readable with almost no difficulty, voice slightly distorted, easy identification of person's identity, slight noise or fades,
- **4**: speech well readable, pleasant tone, occasional fades and noise,
- **5**: speech perfectly readable, no distortion, noise or fades.

The scale was prepared based on the fact that the speech quality may decide about human's safety and life, so the criteria are rather stringent.

The scale may be compared to the known DAQ scale.

- Grade **1** corresponds to DAQ 1 (unusable, speech present but not understandable),
- Grade **2** corresponds to DAQ 2 (speech understandable with considerable effort, requires frequent repetition due to noise/distortion),
- Grade **3** corresponds to DAQ 3.4 (speech understandable without repetition, some noise/distortion present),
- Grade **4** corresponds to DAQ 4 (speech easily understood, occasional noise/distortion present),
- Grade **5** corresponds to DAQ 5.

The minimum grade required in the power industry network is 3. However, the grades 2+ or 3– (corresponding to DAQ 3 – speech understandable with slight effort, occasional repetition required due to noise/distortion) are also acceptable by the users.

During the tests the link between the base station (the control point) and the mobile radio had been established (if it was possible) and then the speech quality was assessed. The mobile radio was in the measurement vehicle with the roof antenna.

The tests *did not* comprise data transmission. The radio coverage for data transmission is usually smaller than for voice services. The data transmission tests will be performed in the future.

5. Field tests of P.25 and TETRA

The tests were carried out in two phases due to the availability of the equipment. During the first test, which took place in Poznań, Poland (see the map in Fig. 1), the standard P.25 was tested together with MPT 1327. The second test was performed in December 2004 in Gorzów Wielkopolski, Poland. All three systems were tested simultaneously. The second BS localization was suitable for the TETRA system which required two antennas on the mast for space diversity.

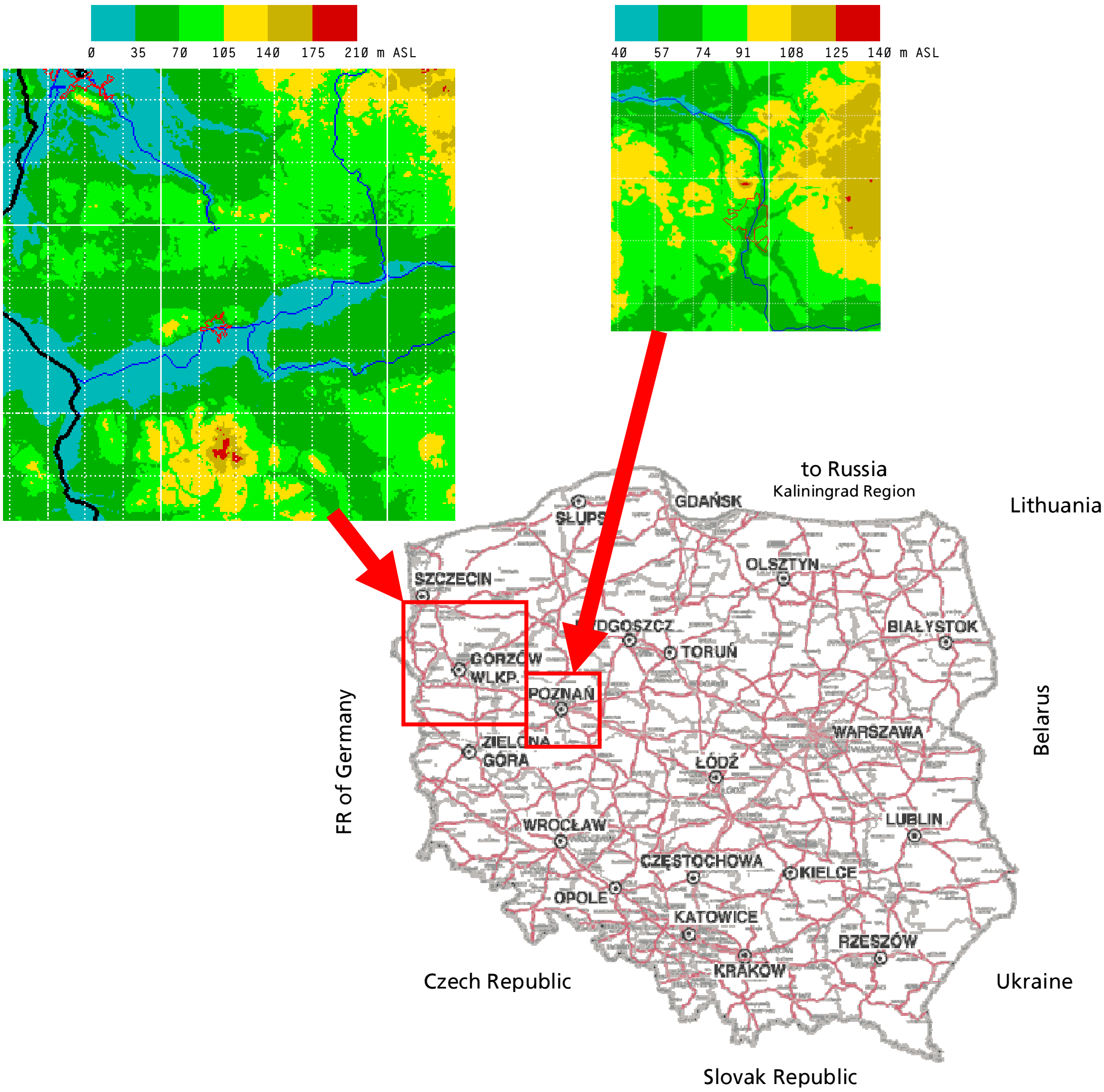

Fig. 1. Localization of BS used in tests (a) and terrain profiles around BS Poznań (b) and BS Gorzów Wielkopolski (c)

5.1. First test (P.25 and MPT 1327)

The simulated radio coverage around BS for the analog system MPT 1327 is shown in Fig. 2. The blue line is the border of the town. The grey color means the simulated area of good coverage. The diameter of the red circle equals 50 km. The simulated contour is similar with the actual contour (experimental verification done by many users of the analog system).

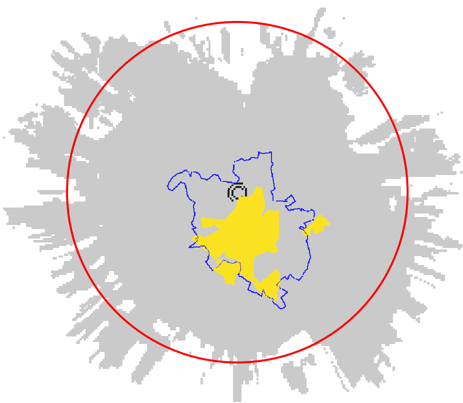

Fig. 2. **Simulated** radio coverage for analog systems around BS in Poznań

Before the tests TELE-COM simulated the predicted coverage for P.25 using the design criteria obtained from M/A-COM. The comparison of the simulation results is presented in Fig. 3. The coverage for P.25 is slightly smaller than for MPT 1327. It was a confirmation of the hypothesis that the coverage of digital systems was smaller than for analog systems.

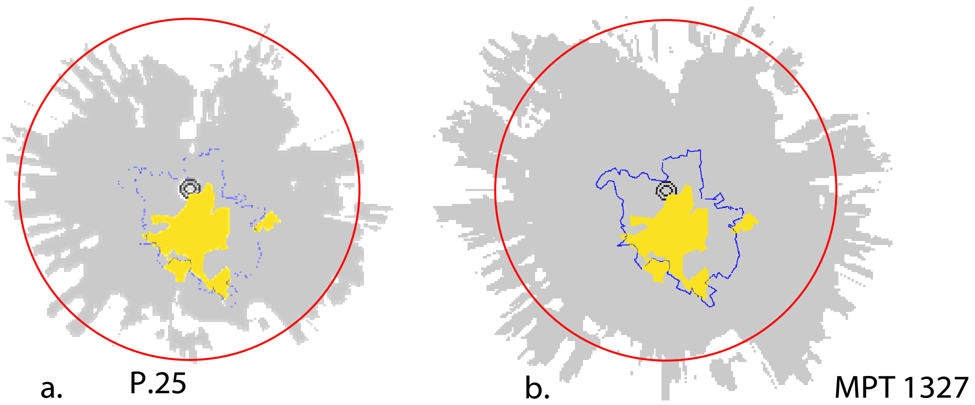

Fig. 3. Comparison of **simulated** coverage for P.25 and MPT 1327 around BS in Poznań

However, the measurements gave the results shown in Fig. 4 and 5. Red dots mean the test points where the speech quality was equal to or better than 3. Grey dots describe the test points with lower quality or without any radio contact.

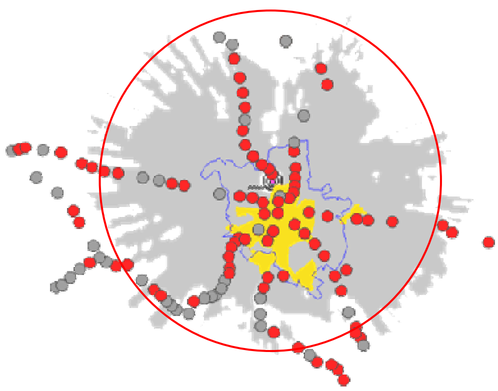

Fig. 4. Test results for P.25 placed on the simulated coverage contour for that system

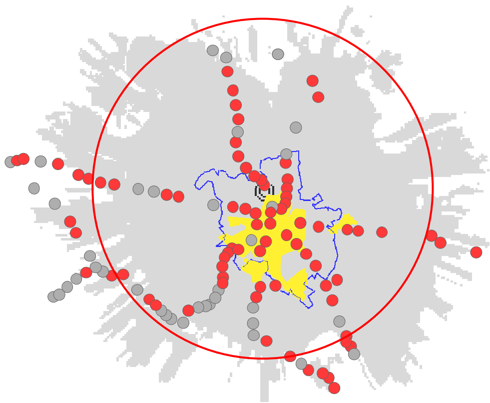

Fig. 5. Test results for P.25 placed on the simulated coverage contour for MPT 1327 (currently used analog standard)

As one can see, the actual coverage is larger than the simulated one. It seems that the design criteria suggested by the manufacturer are very stringent. The most important result of the test is the comparison of the actual coverage for P.25 with the simulated or actual coverage of the MPT 1327 system, shown in Fig. 6. We can formulate a conclusion that the actual coverage of P.25 is practically the same (for lowland terrain) as the coverage of the analog system MPT 1327. The red dots inside the simulated contour where the voice transmission was not possible in P.25 do not contradict the conclusion, because in those points the transmission was not possible also in the analog system. Of course, during the test both systems used the same BS and mobile antenna and the radiated powers were equal.

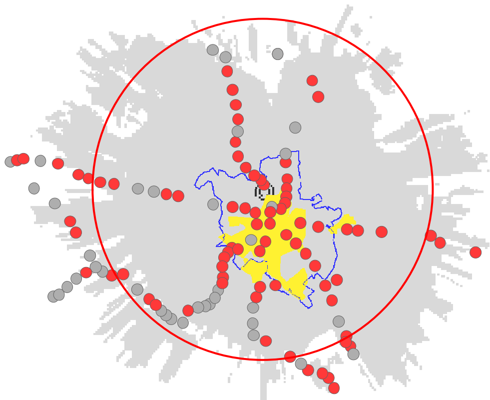

Fig. 6. Test results for P.25 over the simulated coverage contour for MPT 1327.
Black dots mean the transmission quality equal to or higher than 3.

5.2. Second test (P.25, TETRA and MPT 1327)

The second test was carried out in Gorzów. The terrain around Gorzów is difficult for the proper radio coverage due to many hills and forests (see Fig. 1 c). The second reason of choosing this localization was the fact that it was possible to use two antennas simultaneously.

Fig. 7. BS of P.25 system made by M/A-COM and of TETRA made by Rohill

Equipment

In Gorzów we additionally installed BS of the P.25 system made by M/A-COM and BS of the TETRA system made by *Rohill* (Fig. 7).

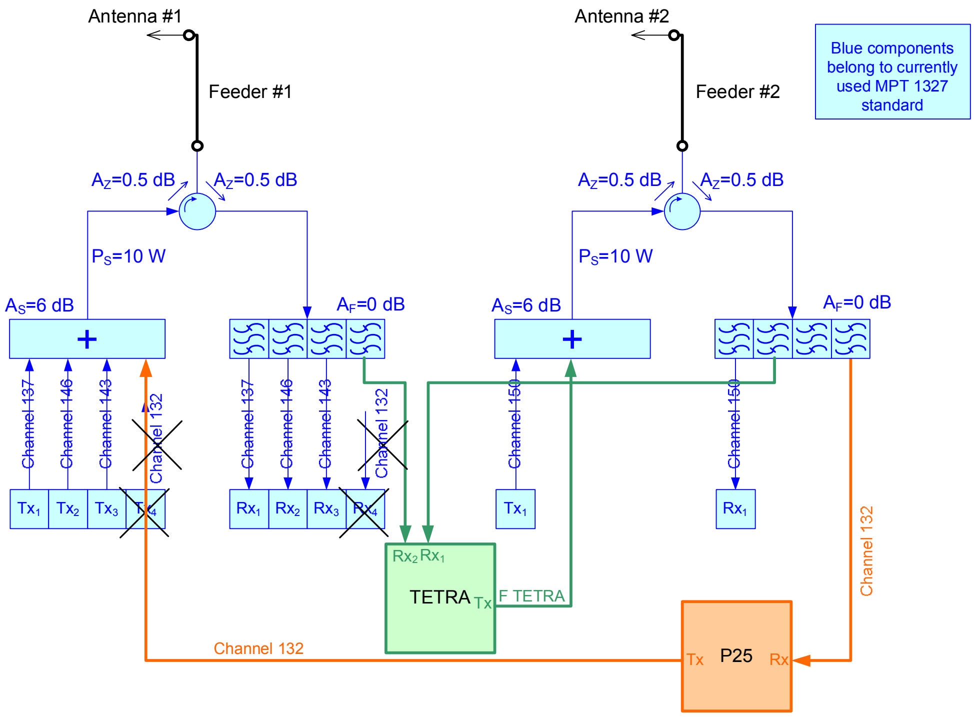

Fig. 8. Connection diagram of the test equipment

The antenna tower in Gorzów supports two antennas, which are 3.2 m apart, used for transmission and reception of radio signals. The equipment was connected according to the diagram shown in Fig. 8. Since the TETRA system requires space diversity, both antennas were connected to the TETRA BS receiver. During installation of the new base stations the output powers were equalized. The output power of the TETRA transmitter was 6.5 W, and the power of the P.25 transmitter 6 W (0.35 dB of difference). The output power of the MPT 1327 was 8.5 W (1.5 dB higher than 6 W available from the P.25 transmitter).

The equality of the powers radiated from the antenna was verified in the field by measuring with a spectrum analyzer the received output power at the terminals of the vehicle antenna.

Inside the measurement vehicle there were the following mobile terminals:

- TETRA - MTM 700 (made by Motorola) with the output power 3 W,
- P.25 - M7100 (made by M/A-COM) with the output power 10 W,
- MPT - 1327 MXD 9226 (made by Alcatel) with the output power 10 W.

Additionally, the handheld radios 7100 P (P.25, made by M/A-COM, output power 1 W/4 W) and MPT 700 (TETRA, made by Motorola, output power 1 W) were used, especially in the urban area in Gorzów. All terminals were programmed to work in the radio channels currently used in Gorzów.

On the roof of the measurement vehicle there were two monopole antennas (gain +4 dB ref. to quarter-wave whip) matched to the frequency band designated for the radio network (410…430 MHz). One antenna was connected to the spectrum analyzer, and the second one was switched between the radios used in the test. In this way the conditions of the measurements were equal for all the radio systems. The geographical coordinates of the test points were obtained from a GPS receiver. The equipment was powered from the vehicle's 12 V DC internal source.

The control point near BS in Gorzów (where there was the second person assessing the speech quality received from the mobile terminals) was equipped with MXD 9226 (MPT 1327 – Alcatel), MTM 700 (TETRA – Motorola) and M7100 (P.25 – M/A-COM) and is presented in Fig. 9. All the radio systems were tested simultaneously so as to remove the influence of the changing wave propagation caused by the weather.

Fig. 9. Control point with mobile terminals

Static field tests

The test points were chosen close to the public roads in various types of terrain (rural, suburban, urban, forests, hills, valleys, open area, etc.). After the vehicle had been stopped, the crew started to establish contact between the car and the control point. After establishing the connection, the speech quality was assessed separately for the downlink direction (the crew of the car was listening to the control point) and for the uplink direction (the control point was listening to the car). The speech quality was influenced not only by the propagation, but also by the quality of the microphones, loudspeakers and audio amplifiers of the terminals. During the test it occurred that the mobile terminal of the P.25 system, which was installed in the vehicle, gave a slightly worse quality than other P.25 terminals. It surely influenced the quality of the P.25 system assessed in the control point. Next it was observed that the speech distortion in the digital systems had a different character than in the analog system.

The speech quality was tested in 169 points. The points from 158 to 169 were placed in Gorzów and were tested only with the handheld radios. The points had been chosen by the local power industry workers who had troubles to establish a radio connection from these points using the analog system. This is the reason why MPT 1327 was not tested in these points.

The TETRA mobile terminal has the output power 3 W, while the BS transmitter has the output power 6.5 W. Sometimes it was an asymmetry between the downlink and uplink: the signal from BS *was* correctly detected in the field, but the signal from the mobile terminal *was not* detected by BS. In order to equalize the test conditions for both digital systems, in the test points with TETRA asymmetry there was always an attempt to establish contact using a handy P.25 radio with the output power of 4 W or even 1 W. The radio was connected to the roof antenna. The difference between 3 W and 4 W is equal to 1.25 dB, so one can assume that the described mode of operation of the P.25 system is quite similar to the operation of the TETRA system with a mobile terminal.

Discussion of results

All the numeric results were placed in a table. However, it is better to visualize them in the form of maps with black dots showing the test points where the quality was equal to or higher than a given grade (2 or 3 – red points on the maps). The points in magenta squares (□) are the points with TETRA asymmetry where it was possible to establish contact in the P.25 system with the power of 4 W or 1 W.

There are two maps for each digital system: the first one with the quality equal to or better than 3 and the second one with the quality equal to or better than 2. Although grade 3 has been recommended as the minimum quality in the power industry network, sometimes it is possible to make contact with grade 2 (DAQ 3). The maps are presented in Fig. 10 – 13. The layout for all maps is the simulated coverage of MPT 1327 (gray patch). Fig. 14 and 15 show the results for test points in Gorzów (urban area).

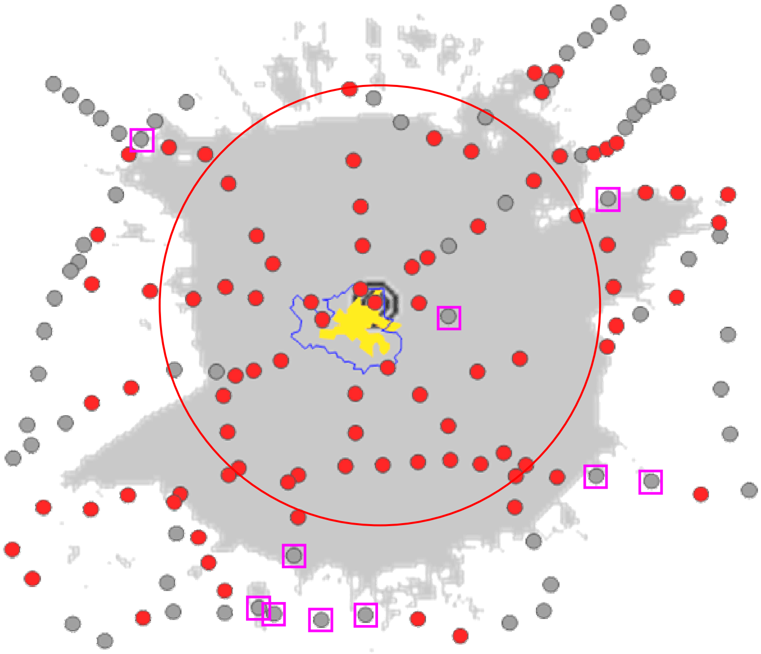

Fig. 10. Measured coverage of TETRA with speech quality equal to or higher than 3

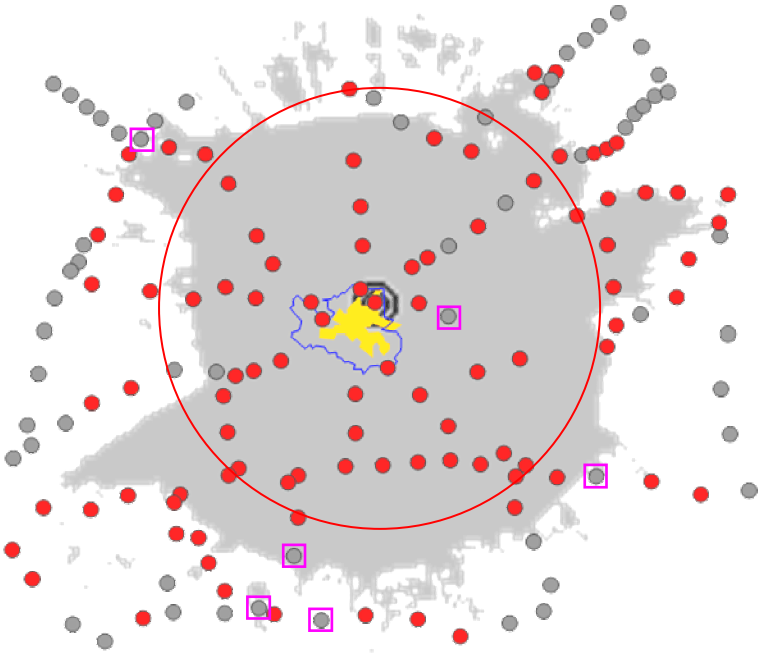

Fig. 11. Measured coverage of TETRA with speech quality equal to or higher than 2

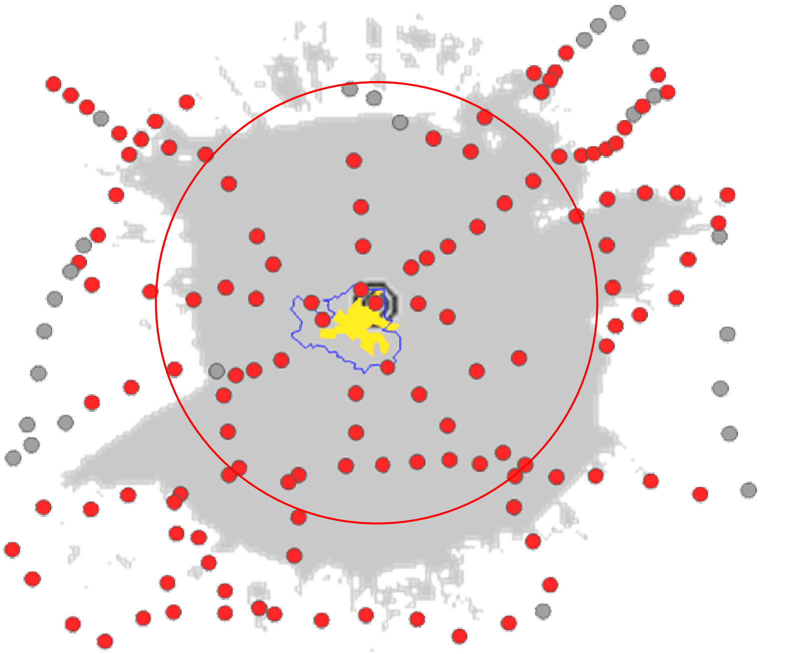

Fig. 12. Measured coverage of P.25 with speech quality equal to or higher than 3

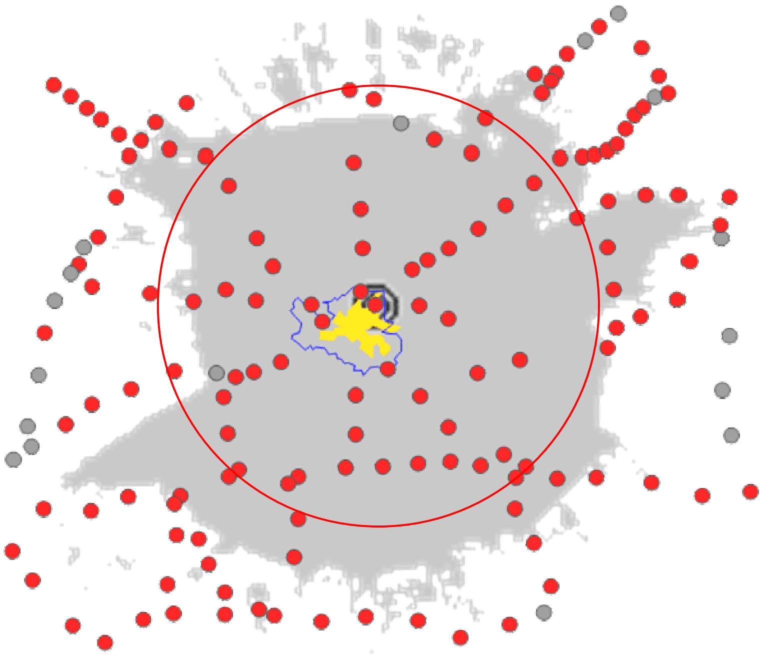

Fig. 13. Measured coverage of P.25 with speech quality equal to or higher than 2

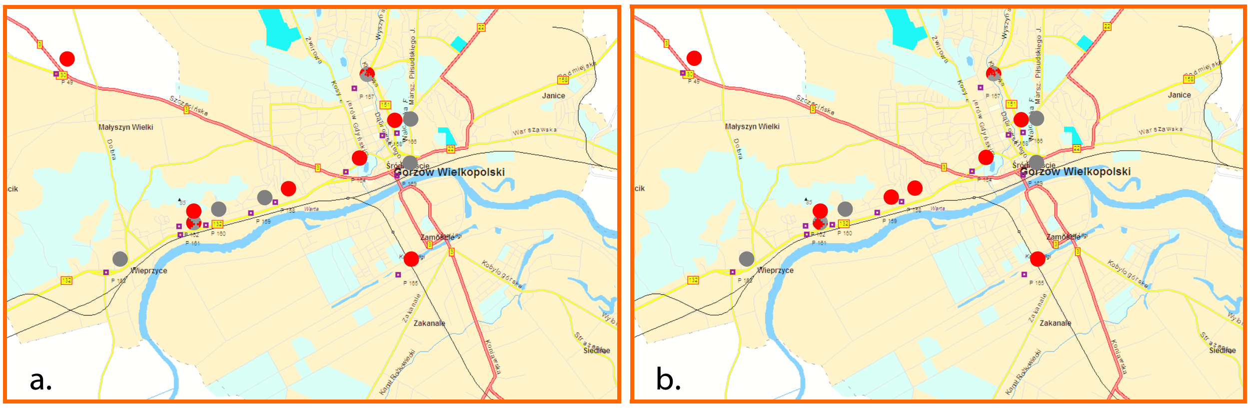

Fig. 14. Test results for points in Gorzów for **TETRA**
a.: grade 3 or better; b.: grade 2 or better

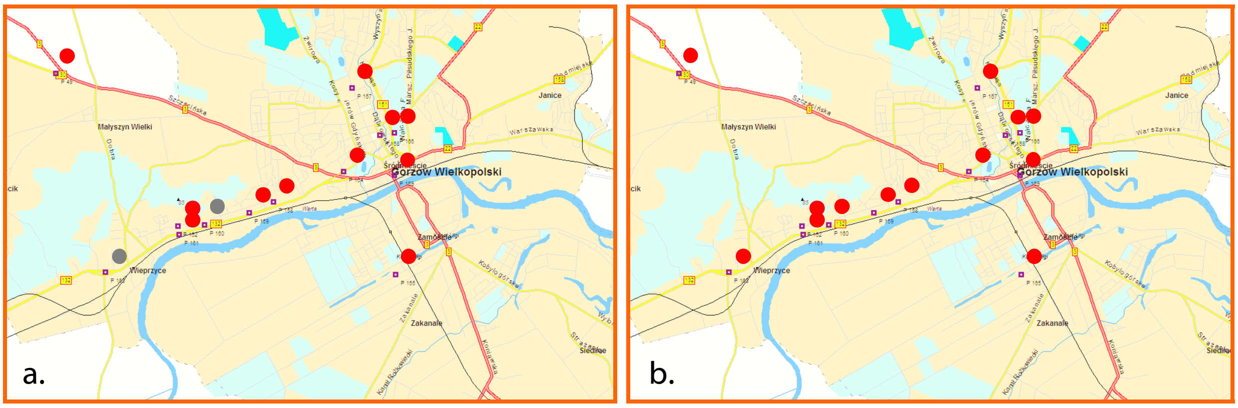

Fig. 15. Test results for points in Gorzów for **P.25**
a.: grade 3 or better; b.: grade 2 or better

Basing on the test results, TELE-COM has formulated several observations.

Observation 1

The comparison of the results shows that the coverage of P.25 is larger than the coverage of TETRA. The P.25 coverage is virtually the same as the coverage of the analog system MPT 1327. This conclusion confirmed the observation made during the first test in Poznań. One should remember that both digital systems worked with the output power 1.5 dB lower than the power of the analog system. Moreover, TETRA was using space diversity (additional gain approx. 2 dB).

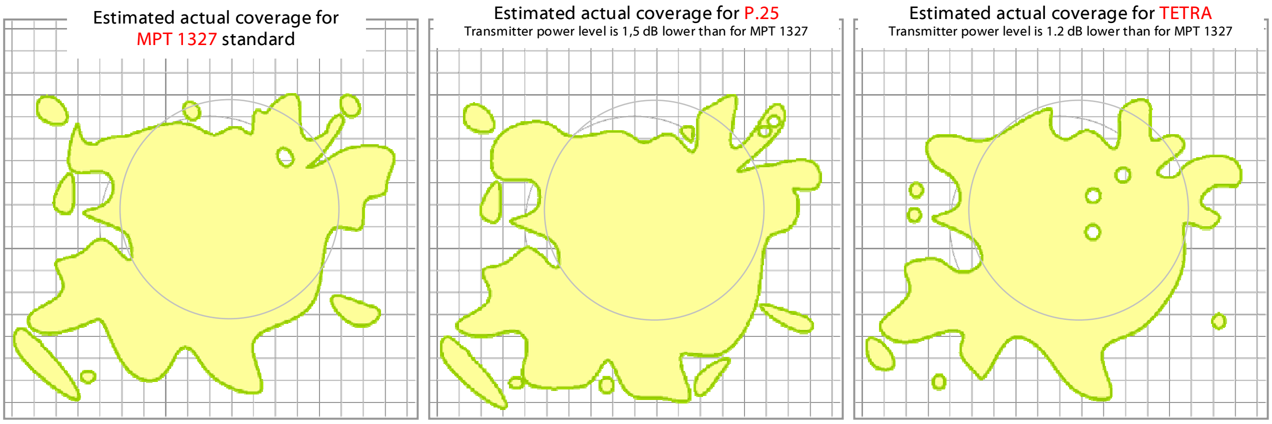

Fig. 16. Estimated coverage (grade 3 or better) for MPT 1327 (a), P.25 (b) and TETRA (c)

The maps with the estimated coverage contour for grade equal to or better than 3 (based on the measurement results) are shown in Fig. 16. The area is divided into 5×5 km squares.

In certain situations independent from the network designers, it is not possible to assure radio contact with good quality. However, even a contact with bad quality is better than no contact at all. This is why the maps with the estimated coverage for grade 2 or better are shown in Fig. 17.

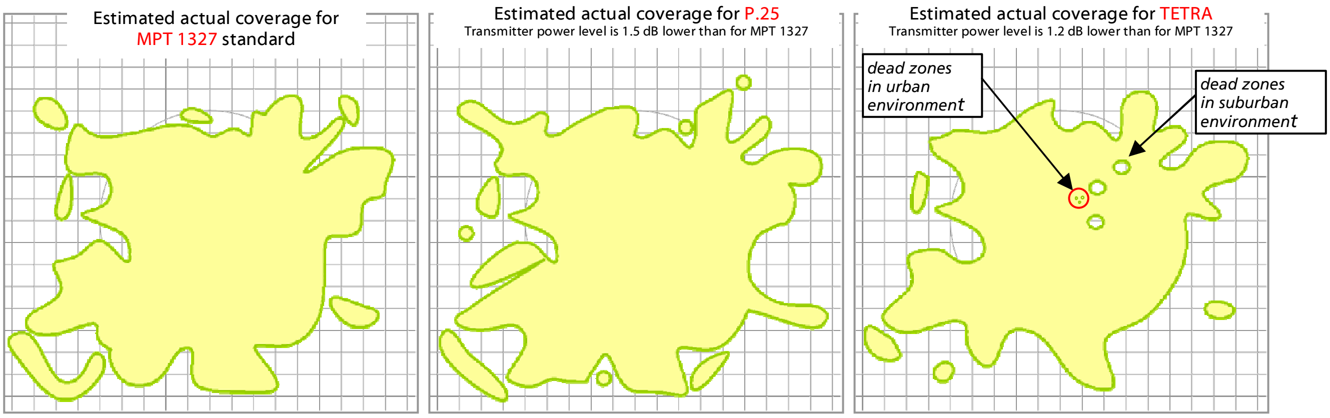

Fig. 17. Estimated coverage (grade 2 or better) for MPT 1327 (a), P.25 (b) and TETRA (c)

Observation 2

In many places with transmission asymmetry in the TETRA system it was possible to establish a good quality contact in the P.25 system using the output power 4 W or even 1 W, sometimes without the rooftop antenna. This phenomenon is reflected in the dead zones inside the main coverage contour for TETRA in Fig. 16c and 17c. It is worth remembering that TETRA was using space diversity.

Observation 3

The phenomenon described above was confirmed also during the dynamic tests when the measurement vehicle was traveling between test points. The TETRA system is much more sensitive to hard propagation conditions (high path attenuation) due to foliage or hills. During the dynamic tests the TETRA system was often asymmetric, while it was usually possible to establish contact in P.25 with 4 W or even 1 W of the output power in the same propagation conditions.

Observation 4

The speech quality for TETRA was the best from all tested systems (in the points where it was possible to establish contact using TETRA). Voice distortions in the P.25 system are typical for digital systems (digitalization effect – it is sometimes not easy to identify the speaker) and stronger than for TETRA. Despite this effect the transmission is readable and clear in P.25.

Observation 5

The cliff effect described in Chapter 3 is stronger than for P.25. The speech quality in P.25 decreases gradually similar to the deterioration in analog systems.

Observation 6

During the talk in the TETRA system, after listening to the sender, one should push the PTT button, wait for an acoustic signal and then talk (respond). If the radio signal is strong, the time between pushing the PTT button and hearing the acoustic signal is negligibly small. When the signal is weak, the time rises up even to 5 s. It is a very annoying effect which makes the dialog very difficult. The talking person usually does not know if the correspondent can hear him at all (no link), if the link was broken during the contact or if the correspondent is simply waiting for the acoustic signal or thinking about the answer. The described effect is highly undesirable, especially during the exchange of short messages (which are quite typical in practice).

Observation 7

When the analog FM signal was present in the channel used by the P.25 system (co-channel interference), the P.25 terminal was receiving the analog signal despite the simultaneous digital transmission. When the FM signal disappeared, the detection of the digital signal was correct. The effect can be important in case of co-existence of the FM system and the P.25 system.

Observation 8

The test crew noticed that the threshold level required for good communication in TETRA was higher than for P.25 and MPT 1327.

Observation 9

The test results for the points in Gorzów (urban area) show the considerable advantage of P.25 over TETRA (see Fig. 14 and 15). The signal indicator on the TETRA handy terminal display was usually showing quite a high level, however it was not possible to establish contact.

Observation 10

The TETRA system is somewhat uncomfortable in use. It was noticed by the TELE-COM crew and confirmed also by the power industry workers in Gorzów responsible for radio communication.

6. Conclusions

Taking into consideration the results of the tests conducted in Poznań and Gorzów TELE-COM has formulated the following conclusions:

- Radio coverage for P.25 is greater than for TETRA (lowlands with hills),
- Radio coverage for P.25 is the same as the coverage of MPT 1327,
- Establishing contact in urban terrain is easier in the P.25 system than in the TETRA system,
- Speech quality is better in TETRA*,
- The comfort of system use, consisting of many various components, is higher for P.25,
- The exchange of BS from analog to digital is simpler for P.25 (the same channel raster, the same feeders, antennas, combiners, etc.) and does not require either new 25 kHz channels and space diversity antennas or the new channel allocation and checking of internal electromagnetic compatibility of the system.

* The official statement of M/A-COM Poland concerning the TELE-COM tests: *M/A-COM Poland company announces that the worse quality of the voice received from the radio installed in the measurement vehicle was the result of the use the older version of the hand held controller (HHC). This version of HHC was adapted to the analog transmission only. In currently installed controllers HHC the electroacoustic channel is modified in order to improve the voice quality for digital transmission.*