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Within its scope of powers and responsibilities, Czech Telecommunication Office (hereinafter referred to as "the Office") performs measurement and evaluation of data parameters of electronic communications networks. The measurement and evaluation of data parameters of mobile networks are specified in a Methodology entitled

Methodology for measurement and evaluation of data parameters of mobile electronic communications networks, version 2.3, which is published and applied by the Office in the case of inspection measurements of the coverage by means of a drive test or stationary measurement.

The measurements are performed using Office's own measuring devices (terminals) with clearly defined parameters in mobile networks. The measuring methods applied are based on BEREC guidelines BoR (14) 117: *Monitoring Quality of Internet Access Services in the Context of Net Neutrality and* BoR (17) 178: *Net Neutrality Regulatory Assessment Methodology. The methodology is also consistent with the* ITU-T Y.1540 *standard*: *Internet protocol data communication service – IP packet transfer and availability performance parameters.*

I. Introduction

The purpose of this document (hereinafter referred to as "Methodology") is to describe and unify the procedure for the measurement and evaluation of the data parameters of mobile electronic communications networks, namely in terms of the quality of the end user access to the internet access service and, as the case may be, to other services. The Methodology is related in particular to the following documents: *Designation of the basic parameters and measurement of the quality of the internet access service*, *Statement of the Office on the selected issues of access to open internet and European net neutrality rules*, and General Authorization No. VO-S/1/08.2020-9 laying down conditions for the provision of electronic communications services. The Methodology is in accordance with BEREC Guidelines BoR (20) 112: *Implementation of the Open Internet Regulation*.

A necessary condition for the measurement and evaluation of the data parameters of mobile electronic communications networks is the availability of network sources (IP addresses, ports, services) and the related transparency of network paths (in accordance with net neutrality).

The document fully respects or acknowledges international standards ITU-T Y.1540 and ITU-T Y.2617, and international recommendation CEPT ECC report 231: *Mobile coverage Obligations* and CEPT ECC report 312: *Measuring and Evaluating Mobile Internet Access Service Quality*. The document is also related to the following Office's documents *Procedure to measure the data transmission speed of mobile networks in accordance with the LTE standard* and *Calculation and measurement for the purposes of inspecting the coverage of the territory by signals of mobile broadband data networks*.

II. Definition of the measuring sides and the network under test

1. Measuring server

Measuring server (MS) shall mean the measuring side which in the case of data download provides the opposite side (terminal) with services (data) upon request. In general, measuring server is a device connected to the internet at a point with available connectivity to the internet exchange. The measuring server should have sufficient performance and independence of the data connection so that sufficient throughput and guarantee of the data parameters is ensured, even in the case of multiple connections of the measuring devices (terminals) at a time. Measuring server is a part of the Measuring System of Electronic Communications (hereinafter referred to as “MSEK”) managed by the Office. MSEK has connectivity with sufficient capacity to the internet exchange NIX.CZ including transit connectivity for filtering the exchange of routing information in the internet exchange NIX.CZ, or the exchange of routing information in a foreign internet exchange.

2. Measuring device (terminal)

Measuring device, terminal (MT) shall mean the measuring side which in the case of data download functions as the recipient of the service (data). Measuring device shall mean a terminal with the respective service software and measuring tools which are capable of performing measurements according to the applicable guidelines of the Office and whose computing and network performance is high enough that it does not affect negatively the measurement results. During the measuring process, the measuring device must be capable of monitoring and recording the set of data parameters of mobile electronic communications networks, exporting them in a format suitable for machine processing or other kind of further processing, and subsequently making it possible to transfer such measured values to the central storage of the MSEK or store them in internal memory.

3. Network under test

Network under test (NUT) shall mean such sequence of transmission nodes where a connection exists between every two consecutive transmission nodes and, at the same time, the first transmission node is MT and the last transmission node is MS. The electronic communications network measured is a network that is a part of the network under test to which the measuring device (terminal) was connected during the measurement. The basic measuring interval is 1 second. The following parameters are always evaluated for this basic measuring interval, unless specified otherwise.

III. Definition of the set of parameters

When defining the set of data parameters, the Office relied mainly on the requirement for comprehensibility of individual parameters from an ordinary end user’s point of view. The Office also considered which parameters are presented by the service providers in their offers of the internet access service with regard to Regulation (EU) 2015/2120 (hereinafter referred to as “Regulation”) and the related Statement of the Office on the selected issues relating to open internet access and European net neutrality rules and General Authorization No. VO- S/1/08.2020-9 which defines the conditions of the contractual guarantee of the download and upload speed, including the occurrence of significant discrepancies in the performance of internet access service according to Article 4 (1) (d) of the Regulation.

The Office selected the below-specified parameters from possible data parameters, recommended to monitor various aspects of the quality of the internet access service obtained by measurement with TCP and UDP protocols, or their combinations. An inseparable part is the set of identification parameters clearly defining the place and time of the measurement of data parameters of mobile electronic communications networks including the information on the measuring device, the internet access service measured, definition of mobile network coverage, and its radio parameters.

1. TCP measurement

The Office has decided, with regard to the relevance for normal users (with respect to the commonly executed subscriber contracts for provision of the internet access service and the need for comprehensibility), to cover three basic data parameters which determine the quality of the internet access service, namely TCP throughput (upload; $\mathrm{TCP\ aTR_{up}}$), TCP throughput (download; $\mathrm{TCP\ aTR_{down}}$), and round-trip delay or, more precisely, latency, ($\mathrm{Delay(avg)}$).

1.1. TCP throughput of the data flow (upload)

TCP throughput (upload), $\mathrm{TCP\ aTR_{up}}$ is data transmission speed in the direction from the end user to the internet access service provider corresponding to the transport layer of the ISO/OSI model (L 4) and using the connection-oriented TCP protocol. This is therefore the actually achieved upload speed ($\mathrm{SDR_{up}}$).

1.2. TCP throughput of the data flow (download)

TCP throughput (download), $\mathrm{TCP\ aTR_{down}}$, is data transmission speed in the direction from the internet access service provider to the end user corresponding to the transport layer of the ISO/OSI model (L 4) and using the connection-oriented TCP protocol. This is therefore the actually achieved download speed ($\mathrm{SDR_{down}}$).

1.3. Delay (RTT)

Round-trip Delay, or also referred to as round-trip time (RTT), is a time elapsed between sending of the first bit of the TCP segment and receipt of the last bit corresponding to the confirmation of the TCP segment, most often expressed in milliseconds.

2. UDP measurement

The qualitative parameters providing information on the ability of the network to provide end subscribers with other advanced services, for example real-time services in the form of VoIP, etc., use UDP protocol on the transport layer of the ISO/OSI model (L4). We use it to determine the uplink data speed, downlink data speed, IP packet transfer delay $IPTD$, IP packet delay variation $IPDV$, IP packet loss ratio $IPLR$, and, as the case may be, IP packet error ratio $IPER$. These qualitative data parameters are generally associated with elementary functionality at the network layer of the ISO/OSI model (L3).

2.1. Data speed (uplink)

Data speed (uplink), $\mathrm{UDP\ aTR_{up}}$, can be imagined as data transmission speed in the direction from the end user to the internet access service provider corresponding to the network layer of the ISO/OSI model (L 3). The process of measurement and designation of the data speed (uplink) should be based on the ITU-T Y.1540 standard.

2.2. Data speed (downlink)

Data speed (downlink), $\mathrm{UDP\ aTR_{down}}$, can be imagined as data transmission speed in the direction from the internet access service provider to the end user corresponding to the

network layer of the ISO/OSI model (L 3). The process of measurement and designation of the data speed (downlink) should be based on the ITU-T Y.1540 standard.

2.3. Round-trip IP packet delay

Round-trip IP packet delay, IPTD, can be imagined as a result of measurement of the time delay between sending and receipt of a packet. It is usually a measurement of “round-trip” delay due to the use of synchronization only on the side of the measuring device, which corresponds to the time elapsed between sending of the packet from the end user to the provider of the internet access service and receipt of the back-sent packet in the direction from the service provider to the end user.

2.4. IP packet delay variation

IP packet delay variation, IPDV, often described also as delay variation or jitter, can be imagined as a difference between the reference time of delivery of the packet ($\mathrm{rp_k}$) and the actual time of delivery thereof ($\mathrm{p_k}$) on the side of the internet access service provider or on the side of the end user, i.e. using the “end-to-end” measurement method. IP packet delay variation can be expressed as follows:

$$\mathrm{IPDV} = \sum_{k=1}^{K} |\mathrm{p_k} - \mathrm{rp_k}| \,; [\mathrm{s}; \mathrm{s}, \mathrm{s}], \tag{1}$$

2.5. IP packet error ratio

IP packet error ratio, $IPER$, can be imagined as the ratio between all delivered error packets and the total number of all packets sent to the internet access service provider or to the end user, i.e. using the “end-to-end” measurement method. IP packet error ratio can be expressed as follows:

$$\mathrm{IPER} = \frac{\sum_{\mathrm{n}=1}^{\mathrm{N}} \mathrm{E_n}}{\sum_{\mathrm{n}=1}^{\mathrm{N}} \mathrm{S_n}} \cdot 100; [\%; -, -], \tag{2}$$

where $\mathrm{E_n}$ refers to the n-th error packet and $\mathrm{S_n}$ refers to the n-th sent packet.

If the measuring device is unable to distinguish error packets (the physical interface circuits discard the received packet evaluated as error and do not pass it to higher communication layers for processing), only the packet loss ratio, which also includes these discarded error packets, is evaluated.

2.6. IP packet loss ratio

IP packet loss ratio, $IPLR$, can be imagined as the ratio between all undelivered (lost) packets and the total number of all packets sent to the internet access service provider or to the end user, i.e. using the “end-to-end” measurement method. IP packet loss ratio can be expressed as follows:

$$\mathrm{IPLR} = \frac{\sum_{\mathrm{n}=1}^{\mathrm{N}} \mathrm{L_n}}{\sum_{\mathrm{n}=1}^{\mathrm{N}} \mathrm{S_n}} \cdot 100; [\%; -, -], \tag{3}$$

where $\mathrm{L_n}$ refers to the n-th lost frame and $\mathrm{S_n}$ refers to the n-th sent frame.

3. Set of identification parameters

The set of identification parameters, as an inseparable part of the measuring process, defines in a clear manner the place and time of the measurement of the data parameters of mobile electronic communications networks including the information on the measuring terminal. The set of identification parameters includes the exact time of measurement which consists of the date and exact time of the start of the measuring process, exact time of the start of individual tests, and duration of the measuring process and individual tests, including the exact time of completion of the measuring process, and it also includes the exact position of the measuring terminal defined in the form of a GNSS coordinate supplemented, if

applicable, with the specific address location if known. This set also includes data identifying conclusively the measuring device and its measuring interface which was connected during the measurement process to the mobile electronic communications network measured and defines the types of coverage evaluation (drive test, stationary).

3.1. Exact time of measurement

Exact time of measurement includes the date and exact time of the start and end of the measuring process according to the Methodology, including the exact time of start of individual tests as well as the duration of the entire measuring process including individual tests. To determine the exact time, we recommend using an internal or external GNSS module of the measuring device used. If the GNSS module is not available, it is possible to use internal clock of the measuring device for the determination of the time.

The date of the measuring process according to the Methodology must be written in the following format: DD month YYYY, for example 01 January 2020. The required accuracy of the time of the start and end of the measuring process, time of start of individual tests, and duration of the entire measuring process including duration of individual tests is in seconds, and the resulting information must be in the following format: HH:MM:SS, for example 12:08:58.

3.2. Exact position of the measuring device

The exact position of the measuring device represents a uniquely identified place where the measuring device was placed during the measuring process according to the Methodology. To determine the exact position, we recommend using an internal or external GNSS module of the measuring device used. If the GNSS module is not available, it is possible to enter the position of the measuring device manually. We also recommend indicating the specific address location of the place of measurement if known.

The GNSS coordinates must be given in the defined reference coordinate format (WGS-84) in degrees, for example 50.1106225N, 14.4996508E. If the identification is known, the specific address location of the place of measurement must be provided in the following format: Street, street No., Postcode, Municipality/City, for example, Sokolovská 58/219, 190 00 Praha.

3.3. Identification of the measuring device

Identification of the measuring device and interface represents a set of data identifying conclusively the measuring device in the form of a mobile terminal identification number (IDMT), including the provision of an identifier of a specific part of the mobile electronic communications network with the identification of a specific channel, which was connected to the measured electronic communications network during the measurement process. We recommend providing also IDMT to uniquely identify the measuring chain.

This information also includes the name of the measured technology and the name of the measured internet access service, the name of the provider, its place of residence, including the company identification No. (IČO), as well as data based on the Regulation and the related Statement of the Office on the selected issues relating to open internet access and European net neutrality rules and General Authorization No. VO-S/1/08.2020-9 which defines the conditions of the contractual guarantee of the data download and upload speed, including the occurrence of significant discrepancies in the performance of internet access service according to Article 4(1)(d) of the Regulation.

3.4. Coverage definition (squares, address points)

Measurements performed in mobile networks shall be evaluated depending on the type of measurement. In the case of drive test, the coverage measurement is evaluated in measured squares. The measured square is a given normalized square with the exact position and orientation with the size of 100 x 100 meters or 50 x 50 meters according to the *Tender for Granting of the Rights to Use Radio Frequencies to Provide a Public Electronic*

Communications Network in the 800 MHz, 1800 MHz and 2600 MHz Frequency Bands or according to the *Invitation to Tender for Granting of the Rights to Use Radio Frequencies to Provide Electronic Communications Networks in the 700 MHz and 3400–3600 MHz Frequency Bands*. Each square is provided with an identifier (SquareID). The attribute of the measured square is the affiliation to a municipality and district, the size of population in the given square, and information on whether the square is part of a motorway or railway corridor. The measured square serves as the smallest unit to evaluate the coverage of an area.

In the case of stationary measurements in mobile networks, the measurement is most often evaluated at the so-called address point. Which is a point representing an address location (a place in an area to which an address can be unambiguously assigned in relation to the building). This type of measurement can be used to evaluate population coverage according to the *Invitation to Tender for Granting of the Rights to Use Radio Frequencies to Provide Electronic Communications Networks in the 700 MHz and 3400–3600 MHz Frequency Bands.* Population coverage will be evaluated at the above-mentioned address points, the exact location of which will be obtained from the database of the Czech State Administration of Land Surveying and Cadastre (ČÚZK). The numbers of inhabitants at individual address points are designated on the basis of data provided by the Czech Statistical Office (ČSÚ) from the latest available census data.

4. Set of radio parameters

Upon measurement of data parameters, it is also necessary to measure radio parameters of the signal, to assess the impact on network data parameters. Limit values of radio signals for individual types (frequency bands) of mobile networks are designated according to valid ETSI standards and 3GPP specifications and are listed in Table 1. To objectively assess the signal coverage, the radio parameters of the signals are measured, namely Reference Signal Received Power (RSRP) and Signal to Interference + Noise Ratio (SINR). The limit values for all measured frequency bands are shown in the following table. The listed limit values apply under the same conditions as they are designated for the reference signal power. These values of measured parameters are provided for the height of the measuring antenna 1.5 m off railway corridors, where the assumed height of the antenna is 4.5 m above the surrounding ground surface.

Table 1: Limit values of radio signals for individual frequency bands of mobile networks

Frequency band	RSRP for unpopulated territories [dBm]	RSRP for populated territories [dBm]	RSRP for road corridors [dBm]	RSRP for railway corridors [dBm]	SINR [dB]
700 MHz	-118	-109	-118	-114	-5
800 MHz	-118	-109	-118	-114	-5
900 MHz	-118	-109	-118	-114	-5
1800 MHz	-118	-107	-118	-113	-5
2100 MHz	-118	-106	-118	-113	-5
2600 MHz	-118	-105	-118	-112	-5
3400–3800 MHz	-118	-100	-118	-109	-5

IV. Measurement process

This section defines the procedures and techniques of measurement of data parameters of mobile electronic communications networks in such a manner so as to make it possible to verify the actual and, as the case may be, maximum achievable value of the data parameters measured. The procedures and techniques of measuring process differ according to which set of data parameters is to be monitored in terms of various aspects of quality of the internet access service, what is the purpose of the measurement, and whether it is a drive test measurement or stationary measurement.

1. Requirements necessary for carrying out the measurement

In general, the measurement of data parameters of mobile electronic communications networks is conditional upon correct function of the first four layers of the ISO/OSI model, i.e. from the physical up to the transport layer. Before starting the measurement, it is necessary to make sure and verify the functionality and other parameters on the required layers of the ISO/OSI model. In addition, it is necessary to check the availability of a sufficiently accurate GNSS position as well as a network access card (SIM), which allows the use of all data services without any data limits.

The measuring antenna for measurement of the coverage while driving (drive test) must be positioned during the measurement in such a way so as to minimize influences, if any, of the measuring vehicle on the measurement performed. The parameters of the antenna used, as well as the parameters of the cabling, must be known and must allow conversion to standard height and antenna gain. Measurements can be performed with a standardised terminal with an integrated antenna when the condition of placement in a suitable space is met.

2. Measuring tools

There are a number of measuring tools that are capable of performing measurements of the set of data parameters defined in this Methodology. These measuring tools must be implemented in each of the two measuring sides where one acts as a client and one as a server. Both the measuring server and the terminal (client) must be properly equipped in terms of software and communication protocols so that they can function as counterparties and the measuring server can serve multiple measurements performed at a given time. A prerequisite for successful measurement is to ensure that the packets sent are not fragmented in the network during transmission, but at the same time they must be as large as possible. For the purposes of one measurement of the parameters specified in this Methodology, ≥1 open TCP or UDP sessions are assumed between the measuring terminal and the measuring server. The measuring software on both the measuring server and terminal must be able to open a sufficient number of ports for the required connections. Port numbers must be chosen according to the type of connection (TCP, UDP) such as to prevent blocking of any of the open connections anywhere in the path between the measuring terminal and the measuring server. Furthermore, it is necessary to consider the performance of both measuring sides such as to prevent degradation of the measurement. When using the end user's technology, e.g. for indicative measurements, it is always necessary to consider the nominal performance of the equipment, loading with common applications as well as age of the equipment. For the measurement of mobile networks, two available tools for measurement of network performance mentioned in the following two subchapters 2.1 and 2.2 will be used.

2.1. Iperf3

Iperf or, more precisely, its version Iperf3, is an open-source tool for indicative measurement of network performance, which is available for platforms such as OS Windows,

OS Linux and FreeBSD. It is based on the client/server principle and supports a wide range of parameters associated with timing, buffering and protocols such as TCP, UDP, SCTP running over IPv4 or IPv6. iPerf3 is a tool that can measure delay and throughput using multiple parallel connections at once. The result of each test is a set of selected data parameters, such as: throughput, packet loss ratio and the like. The main features of the tool include:

- TCP:
  - Measurement of the current throughput of the data flow in one, the other or both directions between the client and the server (measuring points), usually in Mbps.
  - Setting the size of MSS (maximum segment size).
  - Support for changing the TCP window size through the buffer, setting the number of TCP sessions, etc. as needed.
- UDP:
  - The client can create a UDP stream with a defined transmission speed.
  - Possibility of measurement of packet loss ratio and packet delay.

2.2. FlowPing

FlowPing is a freely available tool under GNU GPLv3 licence, and similarly to Iperf, it enables network performance testing such as basic service performance tests or network throughput tests. FlowPing is partially similar to Ping, but instead of ICMP, it works with UDP in the client/server mode. Unlike Iperf, FlowPing allows you to create tests with variable size of generated traffic. This feature provides room for testing network throughput and the associated quality of real-time services, such as video streaming, where it is possible to generate, for example, interfering traffic together with a given stream and it is possible to observe the influence of individual set test parameters on video quality and, at the same time, monitor parameters such as network throughput or packet loss ratio.

3. Drive test

Drive test is carried out continuously while the measuring car is traveling along a pre-selected path, the measured parameters being divided into individual measuring intervals of 1 second, as specified in section II. Upon measurement of data parameters of mobile networks, we recommend the maximum speed of the measuring car to be 40 km/h in the case of measurements in a municipality and 90 km/h in the case of measurements on a motorway or express roads. For measurements taking place at higher speeds (motorways, railway corridors), measurements in both directions of the given linear structure are assumed in order to obtain a sufficient number of measured points or repeated measurements in the desired direction. In the case of measurement of railway corridors, the maximum speed of the train on which the measurement takes place using this Methodology is not limited. Drive test is designed primarily for:

- measurement of the coverage of municipalities,
- measurement of the coverage of motorways (linear structures), or other types of roads according to the requirements,
- measurement of the coverage of railway corridors (linear structures),
- checking the fulfilment of the auction conditions (the so-called development criteria),
- identifying problematic areas,
- dealing with end customers' complaints.

The travel path of the measuring vehicle upon measurement of data parameters during the drive test in a municipality must be such that the largest possible number of inhabitants of the given municipality is covered, due to the distribution in the squares measured (section III.).

When performing a drive test, it is assumed that UDP is used for measurement with the FlowPing tool to verify the minimum speed (uplink or downlink), or in combination with TCP to verify the maximum throughput. TCP throughput (upload) or TCP throughput (download) or, in other words, uplink or downlink data speed is measured without measurement of the given parameters simultaneously on one measuring terminal. The IP packet transfer delay parameter, *IPTD,* is measured simultaneously with the above-specified parameters. When requesting the measurement of a specific part of a mobile network, the measuring terminal must allow the locking of a specific technological variant or the locking of a specific channel of the mobile electronic communications network. The measurement takes place primarily on business days between 7 am and 10 pm, unless the nature of the measurement requires otherwise. A detailed description of the measurement of a mobile electronic communications network for the purpose of checking data parameters is provided in the following chapter 5 of this Methodology.

Measurement records performed by the software in the measuring terminal must be made so as to allow their subsequent machine processing, evaluation and map visualization.

4. Stationary measurement

At a specific address point or, as the case may be, the required position, a stationary measurement is performed for the period of designated measuring intervals according to the type of measurement (measurement of the actual transmission speed or measurement of the occurrence of significant discrepancies), if local conditions permit stationary measurements, in particular with regard to road safety and traffic regulations. This type of measurement is designed primarily for:

- dealing with end customers' complaints,
- checking the fulfilment of the auction conditions (the so-called development criteria),
- long-term monitoring of the given location.

When performing stationary measurement, measurement with TCP, measurement with UDP, or measurement of all the above data parameters simultaneously is assumed (section III). Upon measurement of the actual transmission speed, the assumption is measurement of TCP throughput (download) or TCP throughput (upload) or both consecutive parameters on one measuring terminal. The round-trip delay (RTT) parameter is measured simultaneously with the above parameters. In the case of UDP measurement, the goal is to determine the downlink or uplink data transmission speed or both consecutive parameters on one measuring terminal. The IP packet transfer delay parameter $IPTD$, IP packet delay variation $IPDV$, IP packet error ratio $IPER$ and IP packet loss ratio $IPLR$ are measured simultaneously with the above parameters. When requesting the measurement of a specific part of a mobile network, the measuring terminal must allow for the locking of a specific technological variant or the locking of a specific channel of the mobile electronic communications network. The measurement takes place primarily on business days between 7 am and 10 pm, unless the nature of the measurement requires otherwise. A detailed description of the measurement of a mobile electronic communications network for the purpose of checking data parameters is provided in the following chapter 5 of this Methodology.

Measurement Records performed by the software in the measuring terminal must be also made so as to allow for their subsequent machine processing, evaluation and map visualization.

5. Measuring process

The measuring processes are different in cases where the measurement is performed using the TCP and UDP.

When performing measurement of TCP throughput (upload; $\mathrm{TCP\,aTR_{up}}$), TCP throughput (download; $\mathrm{TCP\,aTR_{down}}$) and round-trip delay (RTT), this Methodology specifies the procedure for the measurement of wireless communications networks. The TCP settings have a fundamental effect on the measurement results and must be carefully considered. The measuring tool must allow the setting of different numbers of TCP sessions based on the measurement need. It is also important to calculate the required buffer size (BS) and the size of the receiver window (RWND) on the side of the measuring terminal (for measurement of the download parameter) or on the side of the measuring server (for measurement of the upload parameter), or on both sides for parallel measurement of both parameters (upload, download), or, as the case may be, alternating measurement of both parameters. TCP sets a low current RWND value at start up, which increases rapidly (in the case of error-free transmission) up to the maximum value. Taking this factor into account, it is only necessary to start measuring the transmission speed with a certain delay after the start of the transmission. When performing a drive test, in particular at higher speeds (motorways, railway corridors), it is recommended to set a lower default window size (typically 32 kB) to ensure a more stable connection under dynamically changing conditions.

In case the measurement is performed using the UDP – these are parameters defined in section IV, chapter 2, namely uplink speed, downlink speed, IP packet transfer delay $(IPTD)$, IP packet delay variation $(IPDV)$, IP packet error ratio $(IPER)$ and IP packet loss ratio $(IPLR)$ – it is necessary to set the size of the data flow with regard to the expected network throughput so as to prevent network overload, which can affect the stability of the data connection.

5.1. Measurement of a set of data parameters using the drive test with UDP

Measurements in mobile electronic communications networks when the measuring device (terminal or external antenna of the terminal) is placed on the roof of the measuring vehicle corresponds to drive test. This method of measurement of a set of data parameters must be used for the purpose of drive-testing the data parameters of existing and newly deployed networks. Measurement of data parameters by means of a drive test is performed using the UDP in order to determine the coverage at the minimum transmission speed (e.g. to check compliance with the development conditions from auctions), or by simultaneous UDP and TCP measurements to determine the immediate achievable throughput of the network (approaching the maximum speed under given conditions, on a given path, at a given time, at a given speed of movement and load of the network).

5.1.1. Sequence of measurements

When performing a drive test, a set of data parameters measured by the UDP is used, where it is recommended to select only one measured parameter out of the above (upload (uplink) or download ($\mathrm{downlink}$) data speed). Where necessary, these parameters can be measured simultaneously. It is recommended to perform repeated drive tests on linear structures (in both directions) with sufficient time diversity (e.g. annually).

The measuring process should consist of the following steps:

- Step 1 – test of the availability of the measured mobile network consisting in the verification of the possibility of connection to the measured mobile network;
- Step 2 – selecting the required data parameter (upload data speed (uplink), download data speed (downlink)) measured throughout the measurement in the selected section

of the path. The measurement time depends on the area and type of measurement, see section IV, chapter 3.

5.2. Stationary measurement using TCP

The following procedure describes a sequence of steps that are necessary for obtaining correct measurement results. If this procedure is not adhered to the result of the measurement might be distorted by incorrect settings of the measuring sides (mainly in terms of their download and upload capacities, respectively).

Two measured parameters are specified in the given type of measurement – TCP throughput (download) and TCP throughput (upload). Based on these parameters, they are compared with:

- Estimated maximum speed $(\mathrm{R_{odmax}})$ is a realistically achievable maximum speed for a given service in a given location in real operating conditions, in places with a sufficient signal power outside buildings;
- Advertised speed $(\mathrm{R_{inzer}})$ is a speed corresponding to the internet access service speed identified by the internet service provider when concluding a contract with the end user.

To assess the stability of the data speed, the following parameters are defined: significant continuous discrepancy and regularly recurring discrepancy. Significant continuous discrepancy from $\mathrm{R_{inzer}}$ (downlink or uplink) shall mean such a discrepancy which results in a continuous decrease in the performance of the internet access service, i.e. a decrease in the actually achieved TCP throughput below 25% of the value of the advertised speed in an interval longer than 40 minutes. Regularly recurring discrepancy from $\mathrm{R_{inzer}}$ (downlink or uplink) shall mean such a discrepancy at which there are at least five decreases in the actually achieved speed (AAS) corresponding TCP throughput designated by measurement below 25% of the value of $\mathrm{R_{inzer}}$ in an interval of more than or equal to 2 minutes in a time range of 60 minutes.

5.2.1. Sequence of measurements

Measurement in mobile electronic communications networks in terms of the location of the measuring device (terminal) corresponds to stationary measurement. For all measurements at a stationary point it is recommended to perform repeated measurements with sufficient time and operational diversity. It is recommended to perform three main independent measurements, including compliance with sufficient time diversity.

<u>Sequence for measuring the actual TCP throughput</u>

The measuring process consists of the following steps:

- Step 1 – test of availability of the measured mobile network (consisting in verification of the possibility of connection to the measured mobile network) at a specific address point or, as the case may be, at a required position;
- Step 2 – measuring the required data parameter (upload, download) for the selected time, but at least 600 measuring intervals (10 minutes);
- Step 3 - the procedure according to the previous steps can be repeated.

<u>Sequence to verify the significant continuous discrepancy and regularly recurring discrepancy</u>

The measuring process should consist of the following steps:

- Step 1 – test of availability of the measured mobile network (consisting in verification of the possibility of connection to the measured mobile network) at a specific address point or, as the case may be, at a required position;
- Step 2 – measuring the required data parameter (upload, download) for the selected time, but at least 3,600 measuring intervals (60 minutes);
- Step 3 - the procedure according to previous steps can be repeated.

5.2.1.1 Input parameters of the sequence of measurements of a set using TCP

The input parameters of the measurement sequence must be based on the parameters presented by the electronic communications service providers in their offers of the internet access service with regard to the Regulation and the related Statement of the Office on the selected issues relating to open internet access and European net neutrality rules and General Authorization No. VO-S/1/08.2020-9 which defines the conditions of the contractual guarantee of the download and upload speed, including the occurrence of significant discrepancies in the performance of internet access service according to Article 4(1)(d) of the Regulation. When defining the input parameters, the characteristics of the access technology were also taken into account.

Pursuant to the Regulation, the Office provided two definitions of speeds related to the provision of the internet access service in mobile networks. In the case of data download and upload, the following definitions of speeds apply to each direction separately:

- Advertised speed ($\mathrm{R_{inzer}}$) – speed corresponding to download speed and upload speed which the internet service provider presents in its commercial communication, including advertising and marketing, in connection with the promotion of internet access service offers, and with which it identifies the internet access service when concluding a contract with the end user. The value of the advertised speed is not greater than the estimated maximum speed. The value of the advertised speed corresponds to TCP throughput of the transport layer according to the ISO/OSI reference model. The unit is numeric values in bits per second (e.g. kbps or Mbps).

- Estimated maximum speed ($\mathrm{R_{odmax}}$) – data download and upload speed is realistically achievable maximum speed for a specific service at a given location in real operating conditions, at a place with a sufficient signal power outside buildings. The value of the maximum speed corresponds to TCP throughput of the transport layer according to the ISO/OSI reference model. The unit is numeric values in bits per second (e.g. kbps or Mbps).

5.3. Stationary measurement using UDP

TCP measurement can be expanded by adding UDP measurement, specifically measurement of data upload (uplink) and download (downlink) speed which characterize the available network capacity at a given measuring point for both directions of data communication, plus IP packet transfer delay $IPTD$, IP packet delay variation $IPDV$, IP packet error ratio $IPER$ and IP packet loss ratio $IPLR$ – however, it is necessary to adjust the size of the data flow with regard to the expected network throughput so that there is no excessive network congestion, which can affect the stability of the data connection.

5.3.1. Sequence of measurements

As in the case of the procedure for performing measurement using TCP, it is recommended to perform repeated measurements with sufficient time and operational diversity. It is therefore recommended to perform three main independent measurements, including compliance with sufficient time diversity.

<u>Sequence for measuring the actual transmission speed</u>

The measuring process consists of the following steps:

- Step 1 – test of the availability of the measured mobile network (consisting in the verification of the possibility to connect to the measured mobile network) at a specific address point or, as the case may be, at a required position;

- Step 2 – measuring the required data parameter (upload data speed (uplink), download data speed (downlink)) measured for a selected period of at least 600 measuring intervals (10 minutes);
- Step 3 - the procedure according to previous steps can be repeated.

It is also possible to use the basic service performance test according to ITU-T Y.1540 which is suitable for verification of qualitative data parameters such as IP packet transfer delay (*IPTD*), IP packet delay variation (*IPDV*), IP packet error ratio (*IPER*) and IP packet loss ratio (*IPLR*), whereas in the case of IP packet transfer delay and IP packet delay variation it is their resulting average values. The result of the measuring process within the basic service performance test can be used to verify the defined values of individual parameters of the categories. Upon measurement of the actual throughput (bandwidth), it is necessary to take into account the header of the network layer (L 3).

6. Evaluation of the measurement

The evaluation of measurements is performed differently for drive tests (coverage of municipalities, coverage of motorways and other roads, coverage of railway corridors) and for stationary measurements. Measured data of all types of scenarios is visualized in maps in the form of color-coded measured squares (points) in order to publish the achieved measurement results. Map visualizations distinguish individual operators (connection providers). In addition, it is possible to select for visualization the individual technologies and the used frequency bands in which the measurement took place.

6.1. Evaluation of drive tests

In terms of evaluation of squares measured by means of a drive test, we distinguish the following types of measured squares:

- Non-measured square – a square where no measurement according to this Methodology has taken place;
- Measured square – a square where the measurement was performed up to 50 meters from its centre according to this Methodology, regardless of the measurement result or the parameters obtained;
- Successfully measured square – a square where the measurement was performed up to 50 meters from its centre according to this Methodology, with at least n intervals, where parameter $n \geq 2$;
- Covered measured square – is such successfully measured square where the limit conditions set, for example, by development criteria of the auctions are also met;
- Non-covered measured square – a square where a successful measurement took place, but requirements for the Covered measured square were not met.

Upon repeated measurement of a previously measured square, the results of the original measurement are replaced with the results of the new measurement for the sake of relevance of the presented data. The evaluation of the coverage of the population of a given municipality is designated on the basis of data from measured squares in the territory of the given municipality or on the basis of data from measured address points according to the development criteria of the auction for the relevant block allocation. Covered address point shall mean a point that falls within the covered measured square. To evaluate the coverage of motorways, expressways and railway corridors (so-called linear structures), division of road routes into short sections in which the measured parameters are averaged is used.

6.2. Evaluation of stationary measurement

The same rules are used for the evaluation of stationary measurements as described in the chapter dealing with the evaluation of coverage or non-coverage of the measured square, but these results are not combined with the results of drive tests and are assigned only to a specific location (address point) with the detected GNSS position regardless of the existing network of measured squares. For stationary measurements, repeated measurements at the same location are expected, e.g. at different times of the day according to this Methodology. All obtained parameters for repeated measurements performed at the same location during the same period are averaged, and the values thus obtained are tested, from the point of view of the decision on coverage or non-coverage, against the conditions specified in the previous chapter 6.1 concerning the coverage of the measured square.

6.3. Evaluation of measurement of a set of data parameters

With respect to the fact that evaluations of the measurement according to the respective set of data parameters of mobile electronic communications networks measured can significantly differ also with respect to the exercise of the Office's powers, the detailed visualization information on each case (scenario) is provided in the relevant annex hereto.

7. Security considerations

Because the measurement of the data parameters uses also UDP on the transport layer of the ISO/OSI model, the behaviour of the measuring process can be perceived by network operators (providers) as an attempt to carry out a DoS or a DDoS attack. Therefore, measurement using UDP may require coordination with the internet connection provider.

7.1. Measurements in the networks with IPv6 and NAT

With respect to the possibility to encapsulate TCP and UDP in an IPv6 packet, significant differences in the measurement of TCP throughput can occur between IPv6 and IPv4 today in the electronic communications network with native IPv6 support. It is therefore advisable to check whether IPv6 connectivity is available, and if so, perform the measurement even in a situation where the TCP and UDP session will be encapsulated in IPv6 packets.

7.2. Measurements in the environment of non-public IP addresses and stateful firewalls

If, for some reason, the initiation of downstream network session in the direction server (MS) → client (MT) is impossible, it is necessary to use such measuring tool that enables reverse initiation of network session upon measurement of download direction. This situation may occur, e.g. in electronic communications networks with NAT or with a set stateful firewall which, for example, blocks the TCP segment with SYN attribute (establishment of session) from the outside.

7.3. Procedure in the event of an error

If a problem (e.g. a problem when establishing a data connection) or an evident error occurs during the measurement, it is necessary to proceed adequately. The operator of the measuring device (terminal) should try to determine the cause of the given problem, eliminate it if possible and, if applicable, subsequently perform a repeated measurement.

V. Terms, definitions and abbreviations

3GPP – organisation for creating mobile networks standards

BS – buffer size

ČÚZK – (CZ) State Administration of Land Surveying and Cadastre

ČSÚ – Czech Statistical Office

Delay – is the time period between sending the first bit of TCP segment and receiving the last bit of the corresponding TCP segment confirmation

Delay(avg) – the average Delay value during a TCP data flow throughput test

DoS, DDoS – a type of attack on web services or sites which aims to block the access of other users to the targeted service

ETSI – European Telecommunications Standards Institute

GNSS – Global Navigation Satellite System

IČO – Company registration number is a unique eight-digit identification number of a legal person, natural person conducting business or a organisational unit of the state

IDMT – identification number unequivocally identifying a mobile measuring terminal

$IPDV$ – inter-packet delay variation or jitter

IPLR – IP packet loss ratio is a ratio of all undelivered (lost) packets to the overall number of all sent packets

IPER – Packet error rate is a ratio of all delivered erroneous packets to the overall number of all sent packets towards Internet access service provider or towards the end-user

IPERF – network performance testing tool

$IPTD(RTT)$ – the time elapsed between sending a packet from the end-user towards the Internet access service provider and receiving the sent packet back from the IAS provider towards the end-user

IPv x, IPv x – version of Internet protocol

ISO/OSI – reference model ISO/OSI set by ISO as the main part of the effort to standardize OSI computer networks

ITU – International Telecommunication Union, a specialized UN agency dealing with issues of information and communication technologies

L x (layer x) – a specific layer of the ISO/OSI model

LTE – 4th generation mobile network standard (4G)

MS – measuring server

MSEK – Measuring System of Electronic Communications, an important information system of the Office

MT – measuring terminal

NAT (network address translation) – a way of adjusting the network traffic

NUT (network under test) – marks the tested transmission line

R_{inzer} – advertised speed, i.e. the download and upload speed used by the Internet access service provider in their business announcements, incl. advertisements and marketing, in relation with promotion, sale and delivering the given service

R_{max} – maximal speed, i.e. the highest possible speed for download or upload

R_{odmax} – estimated highest speed, i.e. the maximal achievable speed of download and upload provided by the service provider

RSRP – Reference signal received power

RTT – round-trip delay time of a packet sent from the end-user towards the measuring server and back for the Internet access service, usually expressed in *ms*, called also Delay

RWND (receive window) – marks the TCP window size on the receiving side (the measuring terminal)

SDR – the actually achieved speed, i.e. the current speed in a particular moment

SIM – identification card of a subscriber based on 3GPP TS 51.011 standard used to identify a subscriber in a mobile network

SINR – Signal to Interference plus Noise Ratio

SquareID – Identifier of a measured square

t – a time duration of test in general

TCP – Transmission Control Protocol is a transport layer protocol in a series of TCP/IP protocols used in the Internet network

TCP aTR – the current value of TCP data flow throughput corresponding to the ISO/OSI model transport layer

UDP – UDP is a network layer protocol in a series of protocols used in the Internet network

UDP aTR - the current value of UDP data flow throughput corresponding to the ISO/OSI model transport layer

WGS – 84 – geodetical standard

VI. Annexes

1. Maps and evaluation

The annex shows the possible outputs from the measurements defined by the Methodology for measurement and evaluation of the data parameters of mobile electronic communications networks. Fig. 1 shows the evaluation of measurements according to the *Tender for Granting of the Rights to Use Radio Frequencies to Provide a Public Electronic Communications Network in the 800 MHz, 1800 MHz and 2600 MHz Frequency Bands.* It is an evaluation into measured squares of 100 x 100 m, where each measured square of the given size contains measurement points (circular shape) according to which the measured square is color-coded. Fig. 2 and Fig. 3 show the evaluation of measurements according to the *Invitation to Tender for Granting of the Rights to Use Radio Frequencies to Provide Electronic Communications Networks in the 700 MHz and 3400–3600 MHz Frequency Bands.* It is an evaluation into measured squares of 50 x 50 m, where each measured square of the given size contains measurement points (circular shape, Fig. 2) according to which the measured square is color-coded. Fig. 3 contains evaluation of measurements at address points (square shape). The evaluation of the coverage of squares and address locations (points) is described by this Methodology in section IV, chapter 6. Fig. 4 shows the evaluation of the measurements of the coverage of linear structures which are evaluated into individual sections of the given size according to the above-mentioned tenders. The evaluation according to section IV, chapter 6.2 is shown in Figures 5 and 6, where the same rules apply to the evaluation of coverage in the map (Fig. 5) as for the evaluation of drive tests (Fig. 1, 2 and 3). In the case of stationary measurement, the measurement is presented in the table (Fig. 6), where the measured values (actual transmission speed, radio parameters) are presented in graphic form.

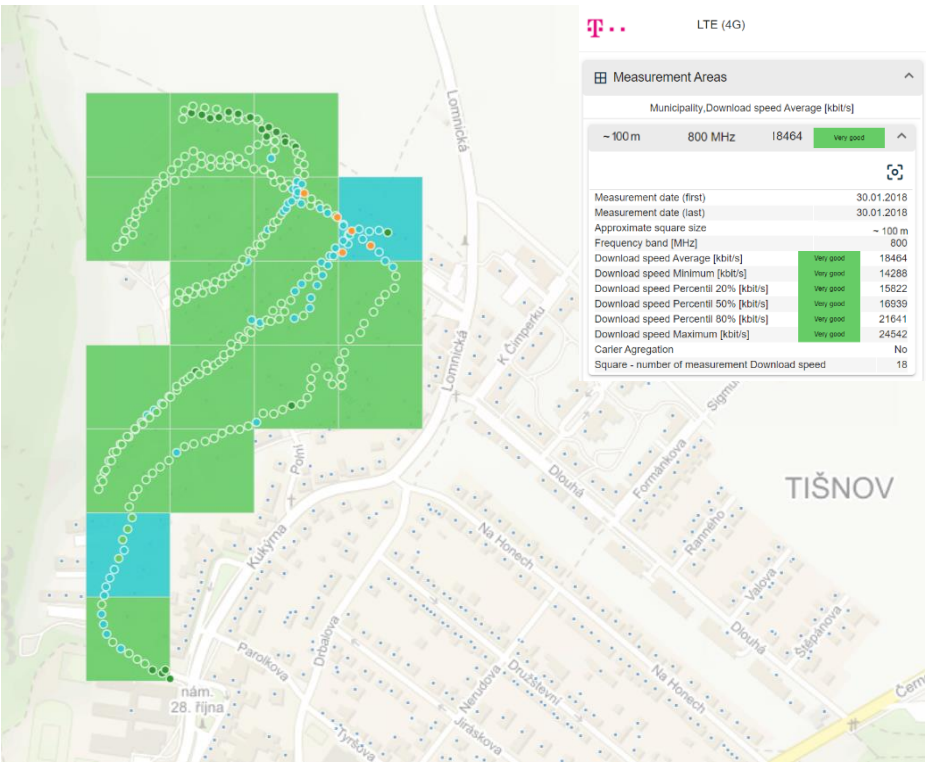


Fig. 1: Visualization of measurements (to measured squares 100 x 100) of the coverage of a municipality by means of a drive test at the data speed (downlink) of the relevant frequency bands.

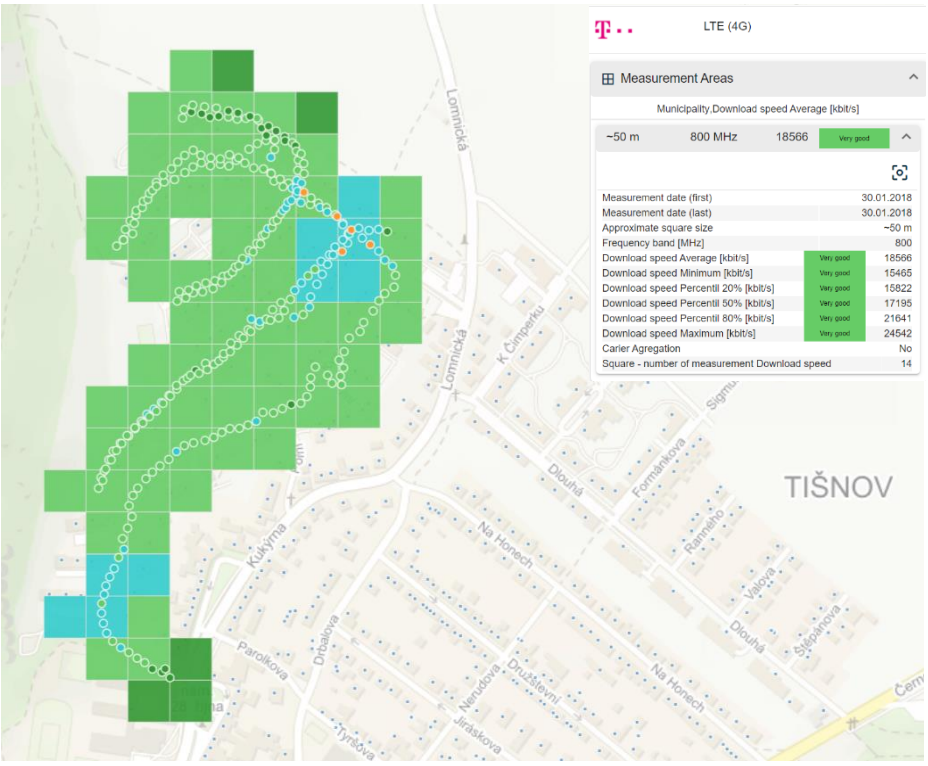


Fig. 2: Visualization of measurements (to measured squares 50 x 50 with display of measured points) of the coverage of a municipality by means of a drive test at the data speed (downlink).

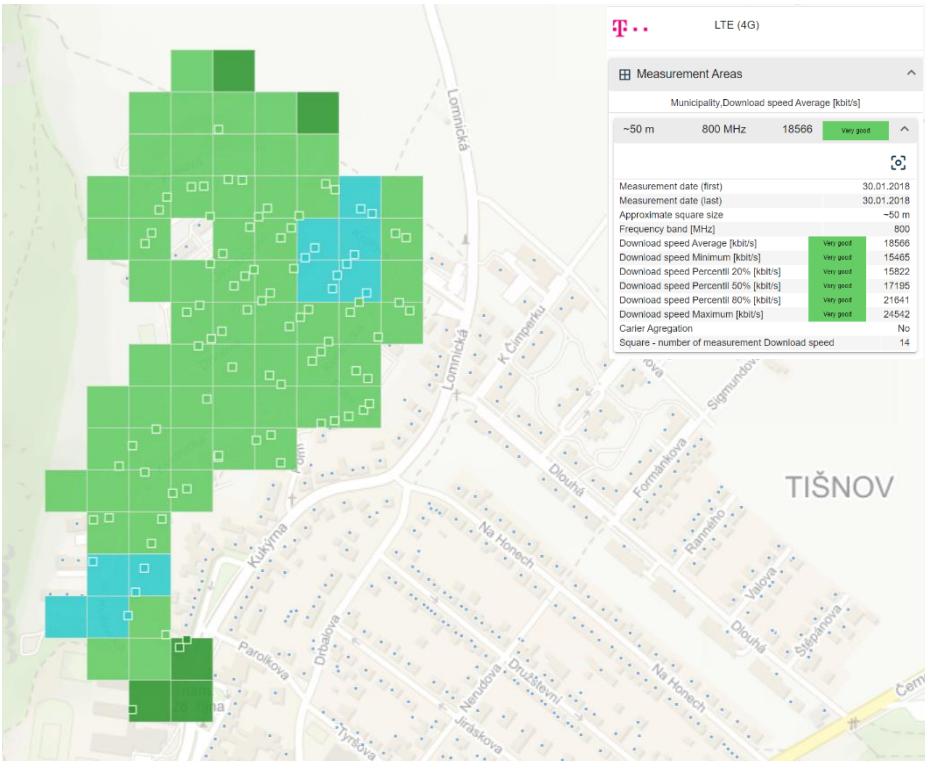


Fig. 3: Visualization of measurements (to measured squares 50 x 50 with display of the address places measured) of the coverage of a municipality by means of a drive test at the data speed (downlink).

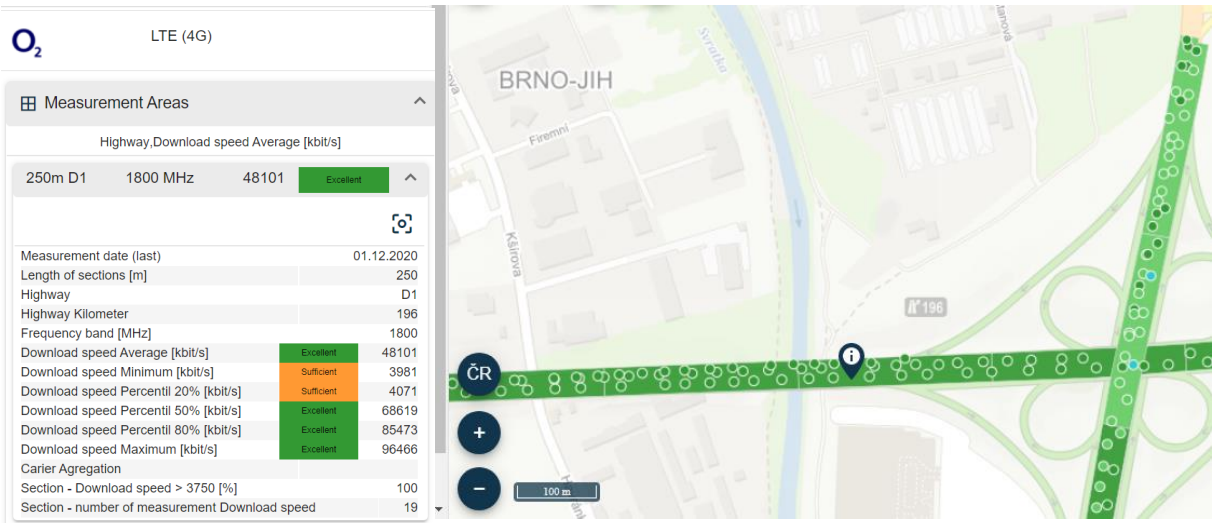


Fig. 4: Visualization of measurements of the coverage of a linear structure (section of the D1 motorway) by means of a drive test at the data speed (downlink).

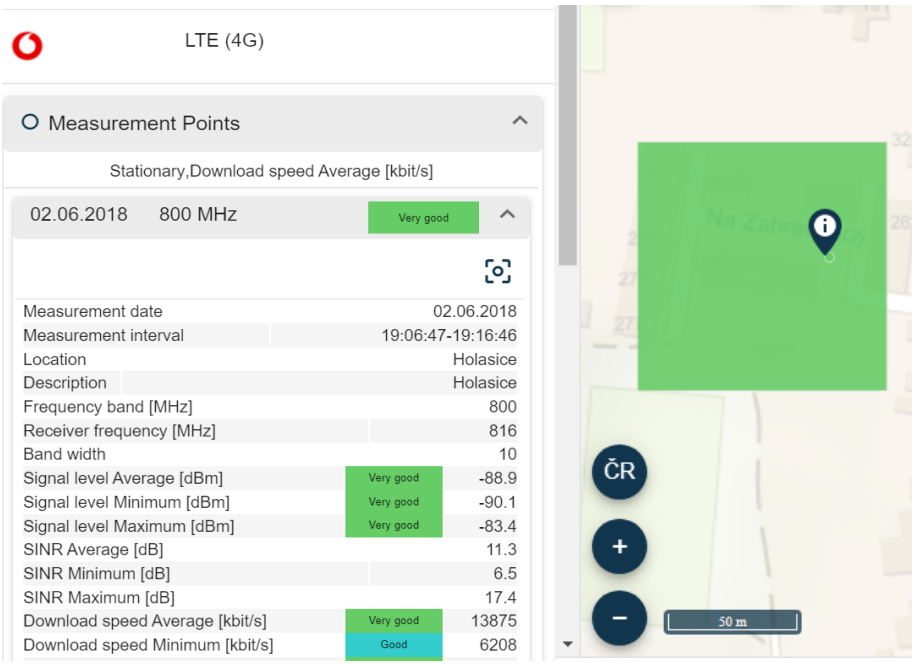
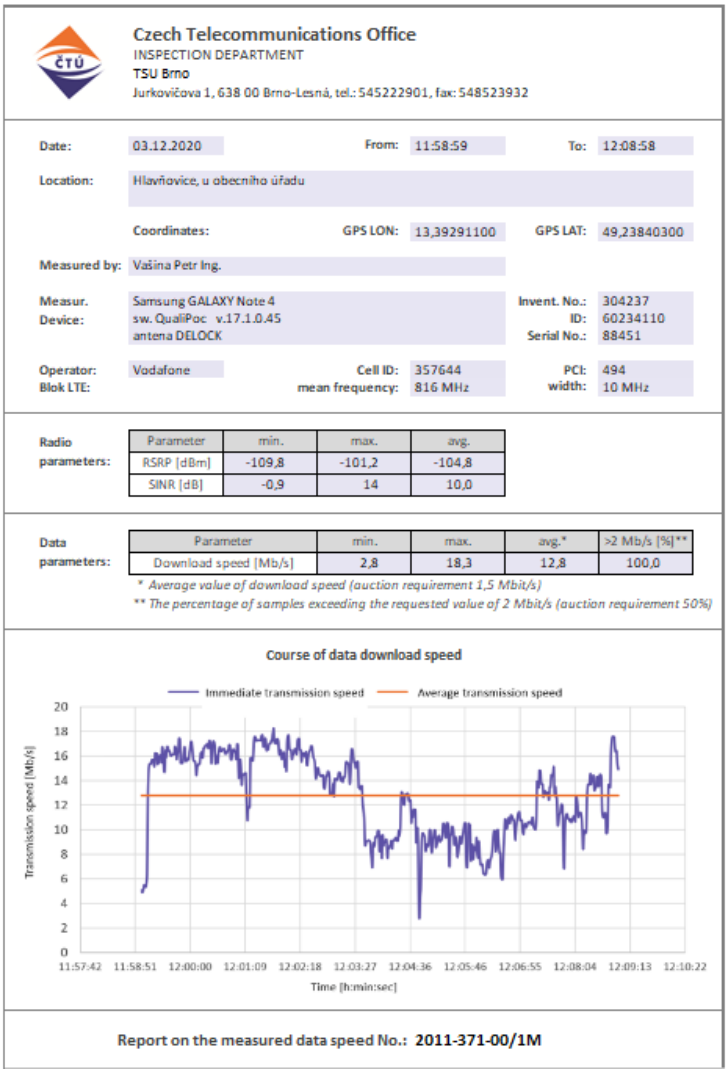


Fig. 5: Visualization of stationary measurement in a municipality at data speed (download) in the map.



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TSU Brno
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Date:	03.12.2020	From:	11:58:59	To:	12:08:58
Location:	Hlavňovice, u obecního úřadu				
Coordinates:		GPS LON:	13,39291100	GPS LAT:	49,23840300
Measured by:	Vašina Petr Ing.				
Measur. Device:	Samsung GALAXY Note 4 sw. QualiPoc v.17.1.0.45 antena DELOCK			Invent. No.: ID: Serial No.:	304237 60234110 88451
Operator: Blok LTE:	Vodafone	Cell ID: mean frequency:	357644 816 MHz	PCI: width:	494 10 MHz

Radio parameters:

Parameter	min.	max.	avg.
RSRP [dBm]	-109,8	-101,2	-104,8
SINR [dB]	-0,9	14	10,0

Data parameters:

Parameter	min.	max.	avg.*	>2 Mb/s [%]**
Download speed [Mb/s]	2,8	18,3	12,8	100,0

** Average value of download speed (auction requirement 1,5 Mbit/s)*
*** The percentage of samples exceeding the requested value of 2 Mbit/s (auction requirement 50%)*

Course of data download speed

Report on the measured data speed No.: **2011-371-00/1M**

Fig. 6: Measurement Record with evaluation of stationary measurement of the actual transmission speed – stationary measurement.