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

Methodology for measurement and evaluation of data parameters of electronic communication networks, version 2.1, which is published and applied by CTU in the case of inspection measurements in fixed or semi-fixed networks.

The measurements are performed using Office's own measuring devices (terminals) with clearly defined parameters, in fixed as well as in semi-fixed networks. The measurement methods applied are based on the following IETF recommendation RFC 6349: *Framework for TCP Throughput Testing* and on the ITU-T Y.1564 standard: *Ethernet service activation test methodology*.

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 fixed or semi-fixed (FWA) electronic communication 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: Determination of the basic parameters and measurement of the quality of the internet access service, Statement of the Czech Telecommunication Office on selected issues of access to open internet and European net neutrality rules, and General Authorisation No. VO-S/1/08.2020-9 amending General Authorisation 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* and is based on the recommendation IETF RFC 6349 and also on standard ITU-T Y.1564 including technical specification MEF 23.2: *Carrier Ethernet Class of Service*.

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

The document fully respects or acknowledges international recommendations IETF RFC 1191, RFC 8201 RFC 2544, RFC 2681, RFC 2697, RFC 2923, RFC 3393, RC 4443, RFC 4656, RFC 4821, RFC 4898, RFC 5136, RFC 5357 and RFC 7323, and also international standards

ITU-T Y.1563, ITU-T Y.1564, ITU-T O.150, ITU-T Y.2617, as well as recommendation CEPT ECC (15)03, including technical specifications MEF 10.4 and 23.2.

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

1. Measuring server

Measuring server (MS) shall mean the measuring side which provides the opposite side with services (data) upon request in the case of data download. 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. The measuring server is a part of the Measuring System of Electronic Communication (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 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 functions as the recipient of the service (data) in the case of data download. Measuring device shall mean a terminal with the respective service software and measuring tools which is 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. The measuring device must be capable of monitoring and recording the basic and extended set of data parameters of fixed and semi-fixed electronic communication networks, exporting them in a standardized 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 during the measuring process.

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.

III. Definition of the set of data parameters

When defining the set of data parameters, the Office relied mainly on the requirement for comprehensibility of the 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 the Regulation (EU) 2015/2120 of the European Parliament and of the Council (hereinafter referred to as “Regulation”) and the related Statement of the Czech Telecommunication Office on selected issues relating to open internet access and European net neutrality rules and General Authorisation 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 the internet access service according to Article 4(1)(d) of the Regulation.

The Office selected the below-specified parameters in the form of a basic and advanced set of possible data parameters, recommended for monitoring various aspects of the quality of the Internet access service, including a set of identification parameters clearly defining the place and time of the measurement including the information on the measuring device and the internet access service measured.

1. Set of basic data parameters

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 delay or, more precisely, latency, ($\mathrm{Delay(avg)}$).

1.1. TCP throughput (upload)

TCP throughput (upload), $\mathrm{TCP\ aTR_{up}}$, can be imagined as data transmission speed in the direction from the end user to the provider of the internet access service corresponding to the transport layer of the ISO/OSI model (L 4) and using the connection-oriented TCP protocol. The process of measurement and determination of the TCP throughput (upload) of the NUT should comply with the process of measuring TCP throughput derived from recommendation IETF RFC 6349, whereas the resulting value of $\mathrm{TCP\ aTR_{up}}$ can be expressed as follows:

$$\mathrm{TCP\ aTR_{up}} = \frac{\mathrm{TCP\ RWND_{up}} \cdot 8}{\mathrm{Delay(avg)_{up}}}; [\mathrm{b/s; B, s}]. \tag{1}$$

This is therefore the actually achieved upload speed ($\mathrm{SDR_{up}}$).

1.2. TCP throughput (download)

TCP throughput (download), $\mathrm{TCP\ aTR_{down}}$, can be imagined as data transmission speed in the direction from the provider of the internet access service to the end user corresponding to the transport layer of the ISO/OSI model (L 4) and using the connection-oriented TCP protocol. The process of measurement and determination of the TCP throughput (download) of the NUT should comply with the process of measuring TCP throughput derived from IETF recommendation RFC 6349, whereas the resulting value of $\mathrm{TCP\ aTR_{down}}$ can be expressed as follows:

$$\mathrm{TCP\ aTR_{down}} = \frac{\mathrm{TCP\ RWND_{\ down}} \cdot 8}{\mathrm{Delay(avg)_{down}}}; [\mathrm{b/s; B, s}]. \tag{2}$$

This is therefore the actually achieved download speed ($\mathrm{SDR_{down}}$).

1.3. Delay

When using TCP, Delay can be viewed as a time elapsed between the sending of the first bit of the TCP segment and the receipt of the last bit corresponding to the confirmation of the TCP segment. The process of measurement and determination of the delay of the NUT should correspond to the process of measuring TCP throughput derived from IETF recommendation RFC 6349, whereas the resulting value of delay should be defined in the form of $\mathrm{Delay(avg)}$:

$$\mathrm{Delay(avg)} = \frac{1}{\mathrm{t}} \sum_{\mathrm{i}=0}^{\mathrm{N}-1} \mathrm{Delay_i}\, ; [\mathrm{s; s, s}], \tag{3}$$

where $\mathrm{Delay_i}$ refers to individual values of Delay which are continuously measured with a period of 1 s during the test, and parameter t refers to the total duration of the test. The value of

$\mathrm{Delay(avg)}$ can also be derived from the value of TCP Buffer delay (BD) metric and the default value of $\mathrm{Delay(baseline)}$ which corresponds to the minimum measured value of the NUT delay not burdened by the established TCP session.

2. Set of advanced data parameters

The set of advanced data parameters is based on the set of basic data parameters and includes, in addition, qualitative data parameters, namely information rate (uplink; $\mathrm{IR_{up}}$) and information rate (downlink; $\mathrm{IR_{down}}$) which characterize the available bandwidth at a given measuring point for both directions of data communication, frame delay (FTD), inter-frame delay variation (IFDV), and frame loss ratio (FLR). In general, these qualitative data parameters are closely related to the elementary functionality of the network and therefore are relevant when performing a stress test (activation analysis). Unlike the set of basic data parameters which correspond to the TCP of the transport layer of the ISO/OSI model, the advanced qualitative data parameters correspond to the link layer of the ISO/OSI model and therefore are closely related to the structure of the Ethernet II frame, whereas the protocol used during the process of measurement on the transport layer of the ISO/OSI model is the connectionless UDP protocol. The qualitative data parameters can provide, in addition to the information on the actual bandwidth at the relevant point, key information on the ability of the network to provide the end users with other specific services, for example real-time services in the form of IPTV, VoIP, etc.

2.1. Information rate (uplink)

Information rate (uplink), $\mathrm{IR_{up}}$, can be imagined as data transmission speed in the direction from the end user to the provider of the internet access service corresponding to the link layer of the ISO/OSI model (L 2), relying on the structure of the Ethernet II frame. The process of measurement and determination of the information rate (uplink) of the NUT should be based on standard ITU-T Y.1564. The maximum achievable value of the information rate IR is limited by the maximum number of FPS frames, which can be transferred per second, which can be expressed as follows:

$$\mathrm{FPS} = \frac{\mathrm{NBR}}{(\mathrm{IFG + Preambule + MAC\ DST + MAC\ SRC{+}Ethertype + 802.1Q\ (802.1ad) + MTU + FCS}) \cdot 8}; [1/\mathrm{s}; \mathrm{b/s}, \mathrm{B}], \quad (4)$$

where NBR refers to the data transfer rate corresponding to the physical layer of the ISO/OSI model (L 1). The resulting maximum information rate (upload) can be expressed as follows:

$$\mathrm{IR_{up}(max)} = \mathrm{MTU} \cdot 8 \cdot \mathrm{FPS}; [\mathrm{b/s}; \mathrm{B}, 1/\mathrm{s}]. \quad (5)$$

2.2. Information rate (downlink)

Information rate (downlink), $\mathrm{IR_{down}}$, can be imagined as data transmission speed in the direction from the provider of the internet access service to the end user corresponding to the link layer of the ISO/OSI model (L 2), relying on the structure of the Ethernet II frame. The process of measurement and determination of the information rate (downlink) of the NUT should be based on standard ITU-T Y.1564. The resulting maximum information rate (downlink) can be expressed as follows:

$$\mathrm{IR_{down}(max)} = \mathrm{MTU} \cdot 8 \cdot \mathrm{FPS}; [\mathrm{b/s}; \mathrm{B}, 1/\mathrm{s}]. \quad (6)$$

2.3. Frame delay

Frame delay, FTD, can be imagined as a result of measurement of the time delay of the NUT between the sending and receipt of the Ethernet frame. It is usually a “round-trip” type of measurement (RTT) due to the use of synchronization only on the side of the measuring device (terminal), which corresponds to the time elapsed between the sending of the first bit of the frame from the end user to the provider of the internet access service and the receipt of the last bit of the back-sent frame in the direction from the service provider to the end user. Frame delay (generally, the $k$frame) of the RTT type can be expressed as follows:

$$\mathrm{FTD_k(RTT)} = t_2 - t_1 \leq 2 \cdot T_{max}; [s; s, s, s], \quad (7)$$

where t_1 represents the time of sending of the first bit of the $k$frame and t_2 represents the time of receipt of the last bit of the same $k$frame on the measuring device (terminal) , whereas T_{max} is the maximum value of frame delay which, when exceeded, results in the frame being declared as lost.

2.4. Inter-frame delay variation

Inter-frame delay variation, IFDV, often described also as delay fluctuation or jitter, can be imagined as a difference between the reference time of delivery of the Ethernet frame (c_k) and the actual time of delivery thereof (d_k) on the side of the provider of the internet access service or on the side of the end user, i.e. using the “end-to-end” measurement method. Inter-frame delay variation can be expressed as follows:

$$\mathrm{IFDV_k} = |d_k - c_k|; [s; s, s], \quad (8)$$

where $c_k = d_j + \Delta t$, $k > j$ and Δt is the interval between the sending of the jth and kth Ethernet frame.

2.5. Frame loss ratio

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

$$\mathrm{FLR} = \frac{\sum_{n=1}^{N} L_n}{\sum_{n=1}^{N} S_n} \cdot 100; [\%; -, -], \quad (9)$$

where L_n refers to the n-th lost frame and 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 fixed or semi-fixed electronic communications networks including the information on the measuring device (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 the individual tests, and duration of the measuring process and the individual tests, including the exact time of completion of the measuring process, and it also includes the exact position of the measuring device (terminal) defined in the form of a GPS coordinate, plus, if applicable, the specific address location if known. This set also includes information identifying conclusively the measuring device (terminal) and its measuring interface (physical port) which was connected during the measurement process to the fixed or semi-fixed electronic communications network measured, including IP addresses.

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, including the exact time of start of each test, as well as the duration of the entire measuring process including the individual tests. To determine the exact time, we recommend using an internal or external GPS module of the measuring device (terminal) used. If the GPS module is not available, the internal clock of the measuring device (terminal) can be used to determine the time, while it is assumed that the calibration date of the measuring device (terminal) will be observed.

The date of the measuring process must be entered in the following format: DD month YYYY, for example 01 January 2021. The required accuracy of the time of the start and end of the measuring process, time of start of each test, and the duration of the entire measuring process including the duration of the individual tests is in seconds, and the resulting information must be in the following format: HH:MM:SS, for example 08:03:24.

3.2. Exact position of the measuring device

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

GPS coordinates must be in the following format: xx.xxxxxxxN, yy.yyyyyyyE, 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 No., Postcode Municipality/City, for example, Sokolovská 58/219, 190 00 Praha.

3.3. Identification of the measuring device (terminal) and its interface

Identification of the measuring device (terminal) and its interface represents a set of data identifying conclusively the measuring device (terminal) in the form of ID chassis MT and ID of the measuring module MT including the information on the measuring interface which was connected during the measurement process to the termination or hand-over point (device) or, more precisely, to its interface with the fixed or semi-fixed electronic communications network measured. We recommend providing also ID of the chassis MS and ID of the measuring module MS for unique identification of the entire measuring string.

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 registered office, including the company identification number (IČO), as well as data based on the Regulation and the related Statement of the Czech Telecommunication Office on selected issues relating to open internet access and European net neutrality rules and General Authorisation 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 the Internet access service according to Article 4(1)(d) of the Regulation.

IV. Measurement process

This section defines the procedures and techniques of measurement of data parameters of fixed or semi-fixed electronic communications networks to make it possible to verify the actual achievable values thereof. The procedures and techniques of the 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 or, more precisely, whether it is a basic or advanced set of data parameters.

In general, the measurement of data parameters of fixed or semi-fixed 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, whereas prior to launching the measurement, it is necessary to check their functionality and, as appropriate, also the capacity of the network under test, and other parameters on the second layer of the ISO/OSI model. The recommended steps before the start of the measuring process are as follows:

- Prior to starting determining the parameters of the measurement concerned, it is recommended to check with a packet capturing program (Wireshark), what is actually going on at the network interface (what the actual TCP RWND is, whether there are repeated packet transfers, and whether or not TCP RWND is exhausted during the transfer, etc.).

- Use the *tracert (traceroute)* command and IP address of the MS to diagnose the route via individual demarcation points to MSEK, if allowed by active network elements.
- Check whether or not the traffic is prioritized based on IP address of the standard (generally known) or reference measuring servers. It is therefore advisable to perform the initial measurement of TCP throughput against the reference measuring server.
- A good approach is also checking the fulfilment of net neutrality rules, i.e. whether or not the traffic of a certain service is prioritized. In this case, whether, for example, there is prioritization of the ports which require greater capacity of the network under test. A special case may be prioritization of ports which are used by CTU's measuring devices (terminals). In such case, of course, the result would be substantially distorted.
- If it is very likely that traffic is deliberately prioritized toward standard measuring servers, either based on the IP address or port, it is necessary to perform a comparative measurement according to the above steps. If the results of the standard measurement and the comparative measurement significantly differ it is necessary to report this in the measurement results report accordingly.

1. Measurement of a set of basic data parameters

The following procedure describes a sequence of steps that are necessary for obtaining correct measurement results. Before the measurement procedure specified in section 1.5 which only covers the measurement of TCP throughput itself, sections 1.1 through 1.3 describe the necessary conditions which must be fulfilled before the measurement according to section 1.5. If this procedure is not adhered to, the result of the measurement might be distorted by the incorrect settings of the measuring sides (mainly in terms of their download and upload capacities, respectively).

1.1. Introductory arrangements and risks

The TCP protocol cannot be used for reliable measurement of non-functional electronic communications networks (i.e. networks which are exposed to high packet/frame loss ratio or high packet/frame delay variation). According to IETF recommendation RFC 6349, the threshold of 5% packet loss and packet delay variation of 150 ms can be used as a reference value. These or higher values already indicate a defect or emergency status of the network (e.g. overloading, insufficient network capacity, or the application of traffic management measures); in such cases, it is necessary to choose an alternative method of measuring the basic data parameters according to Annex 1. Furthermore, it is not possible to measure reliably networks where the parameters change relatively quickly in time (parameters according to sections 1.2 and 1.3). In addition, it is necessary to ensure compliance with and respecting the following arrangements:

- Availability of services on one port may not mean availability of services on other ports. It is therefore advisable to add a comparative test of measurement of the ports – availability of known ports (TCP/UDP), to the test of TCP throughput according to section 1.5.
- Independence of measurement must be ensured at each point of measurement (test) – it means that during each measurement, no other data stream which is not a part of the measurement may be implemented at the termination point of the network (device). This is especially true for terminal equipment devices that, in addition to interfaces that conform to IEEE 802.3 (Ethernet, interface RJ-45/SFP/SFP+), also have the option of wireless connection according to the IEEE 802.11 standard, which must be deactivated during the measurement process.

1.2. Identification of MTU

Identification of MTU of the network under test is of essence for correct set-up of the measuring system such as to prevent fragmentation and so that it is possible to measure the capacity of the network under test as accurately as possible; in other words, the following must apply:

$$\mathrm{MTU\ (TCP\ TTD)} = \mathrm{MTU\ (NUT)};\ [\mathrm{B};\ \mathrm{B}]. \tag{10}$$

Several methods can be used for identification of MTU of the network under test; the methods differ from each other mainly by the network area in which they can be deployed. The following methods can be used for correct identification of MTU of the network under test:

- identification according to IETF recommendation RFC 1191,
- identification according to IETF recommendation RFC 1981,
- identification according to IETF recommendation RFC 4821.

The following sections 1.2.1 through 1.2.4 briefly describe the individual methods of identification of MTU of the network under test; for details see the relevant IETF recommendations RFC.

1.2.1. Identification according to IETF recommendation RFC 1191

The IETF recommendation RFC 1191 offers the easiest and fastest method of determination of MTU for IPv4. It is about using the characteristics of IPv4 packets with fixed selection of the size of MTU and with a set attribute $\mathrm{DF}=1$ (do not fragment). If the set value of MTU is too high for the respective network under test or, more precisely, for a certain network element on the route, the network element will discard the IP datagram and will reply back to the sender with an ICMP message that the datagram cannot pass through and that the fragmentation option is blocked using the DF attribute. This method can only be used in situations where the administrator of the network under test is not blocking the use of ICMP messages within the network and the network elements actually send these ICMP messages in that situation.

1.2.2. Identification according to IETF recommendation RFC 8201

IETF recommendation RFC 8201 offers a similar principle of identification of MTU for IPv6 as recommendation RFC 1191. Due to the essence of the IPv6 protocol, however, it is not possible to use the settings of the bit of the attribute $\mathrm{DF}=1$. When this option is missing the method uses the principle of sending an ICMPv6 message (with content "*packet too big*" according to IETF RFC 4443) through the network element which is not able to transfer the packet of that size. From this message, it is possible to identify clearly the maximum size of MTU of the respective network element. Nevertheless, this method can only be used in situations where the administrator of the network under test is not blocking the use of ICMPv6 messages within the network and the network elements actually send these ICMPv6 messages in that situation.

1.2.3. Identification according to IETF recommendation RFC 4821

This procedure deals with situations where for some reason (section 1.2.4) it is not possible to use the previous two procedures for identification of MTU. These are in particular cases where for some reason the option of sending ICMPv4 or ICMPv6 messages is blocked. Windows and Linux operating systems make it possible to use the implementation of the standardized technique of PMTUD (*Path MTU Discovery*) using the "*black hole detection*" (BHD) option.

1.2.4. Problems with the determination of the size of MTU of the network under test

Problems with the determination of the size of MTU of the network under test are covered by the IETF recommendation RFC 2923.

1.3. Measurement of delay (Delay)

When using TCP, Delay can be viewed as a time elapsed between the sending of the first bit of the TCP segment and the receipt of the last bit corresponding to the confirmation of the TCP segment. It is thus a round-trip delay (RTT) characteristic of connection-oriented data transmission. Measurement of delay, as well as the identification of MTU, can be performed in multiple ways which differ in terms of accuracy and robustness. It is recommended that the initial measurement be performed in the process of the test interval. Within the test interval, it is recommended to use measurement to determine the value of parameter $\mathrm{Delay(baseline)}$, which corresponds to the smallest measured value of the delay unloaded by the established TCP session.

The parameter $\mathrm{Delay(baseline)}$ will be applied when determining the TCP metrics of BD, but it is also necessary for the subsequent calculation of the subsequently defined parameters such as BDP, $\mathrm{TCP\ RWNDmin}$, and also the size of the so-called socket buffers. The resulting values will be subsequently used to ensure the sufficient capacity of the data receiver as well as data transceiver prior to the measurement.

1.3.1. ICMP (ping tool)

The use of ICMP or, more precisely, ping tool can be considered an adequate method of estimating the value of delay, provided that the datagram size is taken into account. Nevertheless, with respect to the nature of ICMP, it is not possible to describe this method as sufficiently accurate (problems on the part of network elements, prioritization of QoS), and therefore it is not recommended and the result of the ping tool can be referred to as an indicative value of the delay (Delay).

1.3.2. Use of extended MIB statistics

The use of statistics available in MIB for the measurement of the value of delay (Delay) is provided in IETF recommendation RFC 4898.

1.3.3. Use of suitable tools

It is appropriate to use iPerf, FTP or other tools based on the principle of capturing packets from the test TCP sessions to measure delay (Delay). It is important to realize that results based on SYN → SYN-ACK messages at the beginning of a TCP session should not be used to measure the value of the delay (Delay).

1.3.4. Use of the TWAMP protocol

The most robust and suitable method for measuring delay is to proceed according to recommendation RFC 5357 where the use of TWAMP protocol for the measurement is recommended.

1.4. Determining the bandwidth value (BB)

Before measuring the TCP throughput itself, it is necessary to measure the lowest value of the bandwidth of the network under test (*Bottleneck Bandwidth*) or determine its value on the basis of the terms of the contractual guarantee of download and upload speeds according to Article 4(1)(d) of the Regulation during the administrative process. In the case of fixed or semi-fixed electronic communications networks, the value of the BB parameter corresponds to the contractually defined value of the maximum speed of the internet access service. From the point of view of the ISO/OSI model, according to IETF recommendation RFC 6349, the value of BB corresponds to the physical layer (L 1) during the measurement process and it is therefore necessary to recalculate it through the knowledge of the value of MTU from the contractually specified value, which corresponds to the transport layer (L 4).

If the value of BB is unknown, it is necessary to use one of the measurement methods by means of a connectionless protocol (e.g. UDP) to determine BB. It is advisable to perform the measurement in both directions, in particular if it concerns an asymmetrical technology of the electronic communications network. It is recommended to perform the measurement repeatedly, i.e. in different time intervals and at off-peak hours such as to achieve relevant values and that the values are as little as possible affected by local or time-variable fluctuations of the availability of network sources. It is also necessary to keep in mind that BB is affected not only by the capacity of the network under test of the given data connection but also, for example, by unsuitable terminal equipment device with inadequate performance, or by the use of an access method which is unsuitable at the location in question (e.g., wireless network with high interference, setting a slow transfer mode, insufficient bandwidth, or even unsuitable encryption). To measure BB, it is possible to use several methods according to the IETF recommendations:

- Measurement of BB according to IETF RFC 2544;
- Measurement of BB according to IETF RFC 5136.

1.4.1. Measurement of BB according to IETF RFC 2544

This measurement method is suitable for a qualified estimate of BB, but it is necessary to keep in mind that this method of measurement of BB has been designed for testing network elements in laboratory conditions and its use outside laboratory conditions is not recommended.

1.4.2. Measurement of BB according to IETF RFC 5136

This is a measurement according to IETF recommendation RFC 5136 which focuses on measurement in actual conditions, and therefore, a measurement according to this recommendation should become the standard method for estimating BB. Unfortunately, this recommendation does not contain any specific procedures how BB should be measured; it only defines general mathematical calculations, and therefore its applicability today is minimal.

1.5. Mathematical apparatus

Prior to the measurement of TCP throughput, it is necessary to perform the required calculations and set the important parameters which include BDP, buffer size BS, and the size of $\mathrm{TCP\ RWND}$. For these calculations it is necessary to use the acquired value of $\mathrm{Delay(baseline)}$ or, more precisely, the initial value of the delay measured according to the methods mentioned in section 1.3 of the measurement process, as well as the set BB parameter according to section 1.4 of the measurement process.

1.5.1. Calculation of BDP

BDP shall be calculated from the acquired values $\mathrm{Delay(baseline)}$ and BB, or:

$$\mathrm{BDP} = \mathrm{Delay(baseline)} \cdot \mathrm{BB};\ [\mathrm{b};\ \mathrm{s},\ \mathrm{b/s}]. \tag{11}$$

1.5.2. Calculation of the buffer size BS

The buffer size (BS) needs to be set according to:

$$\mathrm{BS} \geq \mathrm{BDP};\ [\mathrm{b};\ \mathrm{b}]. \tag{12}$$

1.5.3. Setting the size of $\mathrm{TCP\ RWND}$

The setting of the size of $\mathrm{TCP\ RWND}$ window on the data receiver side is based on the value of parameter $\mathrm{TCP\ RWNDmin}$ which can be determined using the following relation:

$$\mathrm{TCP\ RWNDmin} = \frac{\mathrm{BDP}}{8};\ [\mathrm{B};\ \mathrm{b}]. \tag{13}$$

General setting of BS and $\mathrm{TCP\ RWND}$ to a high value can lead, when the values of BB are low, to overloading of the buffer of the network element, which will generate a large number of segments in the first phase in the direction to the measuring device (terminal), which the network equipment cannot send over BB, and therefore packets will be thrown away unnecessarily due to the network element buffer size.

1.5.4. Single or multiple TCP session

The decision whether a single TCP session or multiple TCP sessions should be used in the measurement depends on the size of BDP or, more precisely, on the value of $\mathrm{TCP\ RWNDmin}$, in relation to the set value of the $\mathrm{TCP\ RWND}$ window on the data receiver side (e.g. $64\ \mathrm{kB}$). The target of the use of multiple TCP sessions is maximally credible coverage of the entire capacity of the network under test. If it is true that:

$$\mathrm{TCP\ RWNDmin} > \mathrm{TCP\ RWND}; [\mathrm{B}; \mathrm{B}], \tag{14}$$

the number of TCP sessions should correspond to the result of the equation (rounded up to the nearest whole number):

$$\mathrm{n} = \left\lceil \frac{\mathrm{TCP\ RWNDmin}}{\mathrm{TCP\ RWND}} \right\rceil;\ [\text{-}; \mathrm{B}, \mathrm{B}], \tag{15}$$

where n is the number of TCP sessions and $\mathrm{TCP\ RWND}$ represents the actually set size of the window on the data receiver side. An example can be a situation where the subscriber can access an electronic communications network with the capacity of the network under test $\mathrm{BB} = 500\ \mathrm{Mb}/s$ and $\mathrm{Delay(baseline)} = 5\ \mathrm{ms}$. The BDP parameter can be determined according to the equation (11), or specifically $312{,}5\ \mathrm{kB}$. Within each sequence of tests, it is necessary to establish the respective number of TCP sessions such as to achieve maximum utilization of the capacity of the network under test. If we set $\mathrm{TCP\ RWND} = 64\ \mathrm{kB}$, which corresponds to the basic used maximum, the number of TCP sessions should be $\mathrm{n} = 5$.

General recommendation:

- It is better to perform measurements for multiple TCP sessions, even if apparently a measurement with multiple TCP sessions according to the equation (15) is not necessary. The reason is that a greater capacity of the network under test can be allocated with respect to the settings of the parameters of electronic communications networks. It is therefore recommended to use $\mathrm{n} \geq 2$.
- $\mathrm{TCP\ RWND}$ with size greater than $64\ \mathrm{kB}$ may not be always available because it can only be set in the case of using TCP extension (so-called "TCP window scale option"). Moreover, a situation can occur in actual implementations where the set size of the window can be ignored by the program or re-configured to the default value (e.g. $64\ \mathrm{kB}$).
- When using any application measuring equipment, it is necessary to have access to the configuration and reports of both measuring sides. The default setting values may not be sufficient and may lead to erroneous results.
- It is necessary to identify whether the measuring tool uses the fixed $\mathrm{TCP\ RWND}$, or whether it determines the value of $\mathrm{TCP\ RWND}$ itself based on the NUT status before starting the measurement and maintains it constant during the measurement, or whether it continuously changes this value during the measurement. This fact has significant impact on the measurement.

1.5.5. Calculation of the TCP throughput value

IETF recommendation RFC 6349 defines two different methods of calculation of the parameters determining the value of TCP throughput. The first calculation method is theoretical, based on the structure of the individual layers of the ISO/OSI model, and determines the ideal value of TCP throughput $\mathrm{TCP\ iTR}$. The second method is practical and is based on the current status of the NUT. The result of this method is the current value of TCP throughput $\mathrm{TCP\ aTR}$.

An example can be an interface corresponding to standard IEEE 802.3u, 100BASE-TX, where speed of $100\ \mathrm{Mb}/s$ (NBR; "net bit rate") is achieved on the first layer of the ISO/OSI model. The maximum achievable information rate IR of the link layer of the ISO/OSI model is limited by the maximum number of frames FPS (“frames per second”) according to the equation (Ethernet II frame):

$$\mathrm{FPS} = \frac{\mathrm{NBR}}{(\mathrm{IFG + Preamble + MAC\ DST + MAC\ SRC{+}Ethertype + 802.1Q\ (802.1ad) + MTU + FCS}) \cdot 8}; [1/\mathrm{s}; \mathrm{b/s}, \mathrm{B}], \quad (4)$$

In the above example, if we assume that the values $\mathrm{IFG} = 12\ \mathrm{B}$, $\mathrm{Preamble} = 8\ \mathrm{B}$, $\mathrm{MAC\ DST} = 6\ \mathrm{B}$, $\mathrm{MAC\ SCR} = 6\ \mathrm{B}$, $802.1\mathrm{Q}\ (802.1\mathrm{ad}) = 0\ \mathrm{B}$, $\mathrm{Ethertype} = 2\ \mathrm{B}$, $\mathrm{MTU} = 1500\ \mathrm{B}$ and $\mathrm{FCS} = 4\ \mathrm{B}$, the interface corresponding to IEEE 802.3u (100BASE-TX) according to the formula (4) amounts to $\mathrm{FPS} = 8127\ 1/\mathrm{s}$. The value of parameter $\mathrm{TCP\ iTR}$ on the transport layer of the ISO/OSI model, when using the IPv4 protocol as a network layer protocol without optional parts of the header (20 B) and TCP header without any extensions (20 B), is determined according to the following equation:

$$\mathrm{TCP\ iTR} = (\mathrm{MTU} - \mathrm{IP_{header}} - \mathrm{TCP_{header}}) \cdot 8 \cdot \mathrm{FPS}; [\mathrm{b/s}; \mathrm{B}, 1/\mathrm{s}]. \quad (16)$$

In the above-mentioned case, the value is $\mathrm{TCP\ iTR} = 94.92\ \mathrm{Mb/s}$. If an extended TCP/IP header (20 to 60 B) is used in the process of measurement of TCP throughput it is necessary to consider this extended header in the formula (16). The method of determination of the current value of TCP throughput $\mathrm{TCP\ aTR}$ is based on continuous measurement of Delay and the subsequent determination of the average value of this delay, $\mathrm{Delay(avg)}$, during the test in question. The average value of delay, $\mathrm{Delay(avg)}$, can therefore be defined as:

$$\mathrm{Delay(avg)} = \frac{1}{\mathrm{t}} \sum_{\mathrm{i}=0}^{\mathrm{N}-1} \mathrm{Delay_i}; [\mathrm{s}; \mathrm{s}, \mathrm{s}], \quad (3)$$

where $\mathrm{Delay_i}$ means individual values of Delay which are measured continuously with period $1\ \mathrm{s}$ and recorded during the test, and parameter t refers to the total duration of the test. The resulting current value of TCP throughput $\mathrm{TCP\ aTR}$ of the transport layer of the ISO/OSI model can be written as follows:

$$\mathrm{TCP\ aTR} = \frac{\mathrm{TCP\ RWND} \cdot 8}{\mathrm{Delay(avg)}}; [\mathrm{b/s}; \mathrm{B}, \mathrm{s}]. \quad (2)$$

1.5.6. Calculation of TCP metrics

IETF recommendation RFC 6349 defines three basic TCP metrics which may be used for better understanding and comparison of the individual results of the measurement. In addition, these metrics make it possible to compare the TCP throughput in different network conditions and settings of the measuring sides, and for these reasons they should be determined during each TCP test. The necessary condition is that all three basic TCP metrics must be determined separately for each direction.

TCP transfer time ratio

TCP transfer time ratio ($\mathrm{TCP\ TTR}$) is a ratio between the actual value of $\mathrm{TCP\ aTT}$ (current transfer rate value) and the ideal form thereof ($\mathrm{TCP\ iTT}$). This TCP metric, which defines how many times the actual TCP transfer time is greater than its ideal value, can be determined according to the following equation:

$$\mathrm{TCP\ TTR} = \frac{\mathrm{TCP\ aTT}}{\mathrm{TCP\ iTT}}; [\text{-}; \mathrm{s}, \mathrm{s}], \quad (17)$$

where $\mathrm{TCP\ aTT}$ is the actual time of transfer of a data set time through the TCP session, whereas the ideal value $\mathrm{TCP\ iTT}$ is the predicted time in which the data set should be transferred through the TCP session. The ideal time $\mathrm{TCP\ iTT}$ is derived from the ideally achievable TCP throughput ($\mathrm{TCP\ iTR}$) on the transport layer of the ISO/OSI model. Ideal time of data set transfer time $\mathrm{TCP\ iTT}$ can be determined according to the following equation:

$$\mathrm{TCP\ iTT} = \frac{\mathrm{SD}}{\mathrm{TCP\ iTR}}; [\mathrm{s}; \mathrm{b}, \mathrm{b/s}], \quad (18)$$

where SD refers to the size of the data set intended for transfer.

TCP efficiency

TCP efficiency ($\mathrm{TCP\ EFF}$) represents the percentage of successfully transferred bits without the need of retransmission. This metric provides a picture of the error rate of the entire TCP session. The calculation of the effectiveness of TCP transfer can be performed using the following equation:

$$\mathrm{TCP\ EFF} = \frac{\mathrm{TB} - \mathrm{rTB}}{\mathrm{TB}} \cdot 100;\ [\%; \mathrm{b}, \mathrm{b}], \quad (19)$$

where TB indicates the number of bits transferred and rTB indicates the number of bits which had to be retransmitted after a detected error.

Buffer delay

Buffer delay (BD) represents the relationship between the increase of the average value of delay, $\mathrm{Delay(avg)}$, during the measurement process (test) in question and the initial value of delay, $\mathrm{Delay(baseline)}$, determined prior to the start of the test. The resulting value of BD can be defined as follows:

$$\mathrm{BD} = \frac{\mathrm{Delay(avg)} - \mathrm{Delay(baseline)}}{\mathrm{Delay(baseline)}} \cdot 100;\ [\%; \mathrm{s}, \mathrm{s}]. \quad (20)$$

1.6. Sequence of measurements

Measurement in fixed or semi-fixed 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, i.e. at least one measurement at the peak hour and at least one measurement during an off-peak hour. With regard to the end user and due to the time-consuming process of measuring TCP throughput, it is permissible to perform all three main measurements at peak hour, or to perform measurements with respect to the definition of time availability (time dimension) of normally available speed.

One measurement should not exceed the timeframe of 30 minutes during which a sequence of three tests will be performed. Because the resulting data parameters of the measuring process can be included in the set of basic data parameters, i.e. TCP throughput (upload) $\mathrm{TCP\ aTR_{up}}$, TCP throughput (download) $\mathrm{TCP\ aTR_{down}}$ and Delay, or, more precisely, $\mathrm{Delay(avg)}$, the term *basic test* (hereinafter referred to as “testB”) is introduced. One test of the testB category must guarantee the length of measurement of TCP throughput meeting the following condition:

$$\mathrm{T_{TCP}} \geq 210\ \mathrm{s}. \quad (21)$$

The reason for determining this value is detection of a regularly recurring discrepancy of the actual performance of internet access services from the normally available speed. With respect to the processing of the values measured ($\mathrm{T_{proc}}$) by the measuring tools used, the total duration of one test should not exceed $\mathrm{T_{testB}}$ (see Figure 1):

$$\mathrm{T_{testB}} = \mathrm{T_{TCP}} + \mathrm{T_{proc}} \leq 300\ \mathrm{s}. \quad (22)$$

The resulting measurement process should consist of the following steps (see Figure 1):

- Step 1 – one-way test of TCP throughput (upload) $\mathrm{TCP\ aTR_{up}}$ including the value of $\mathrm{Delay(avg)}$ with total duration of the test $\mathrm{T_{testB}} \leq 300\ \mathrm{s}$,
- Step 2 – a break (saving the previous test results) with duration $\mathrm{T_{break}} \leq 90$ seconds,
- Step 3 – one-way test of TCP throughput (download) $\mathrm{TCP\ aTR_{down}}$ including the value of $\mathrm{Delay(avg)}$ with total duration of the test $\mathrm{T_{testB}} \leq 300\ \mathrm{s}$,
- Step 4 – a break (saving the previous test results) with duration $\mathrm{T_{break}} \leq 90$ seconds,

- Step 5 – a bidirectional test of TCP throughput (upload + download) $\mathrm{TCP\ aTR_{up}}$ and $\mathrm{TCP\ aTR_{down}}$ including the value of $\mathrm{Delay(avg)}$ with total duration of the test $\mathrm{T_{testB}} \leq 600\ \mathrm{s}$,
- Step 6 – a break until the start of the next sequence of measurements corresponding to the lapse of time (saving the previous test results, preparation for the next test) with duration $\mathrm{T_{break}} \leq 90$ seconds.

If the measuring tool does not make it possible to set the order of the sequence of tests as recommended, it is possible to change the order without breaching the integrity of the measurement. In the same way, it is possible to omit the bidirectional test of TCP throughput (step 5) or the sequence of breaks between individual tests (steps 2, 4 and 6). The minimum admissible form of the process of measurement of TCP throughput must consist of a one-way upload test (step 1) and one-way download test (step 3) of TCP throughput.

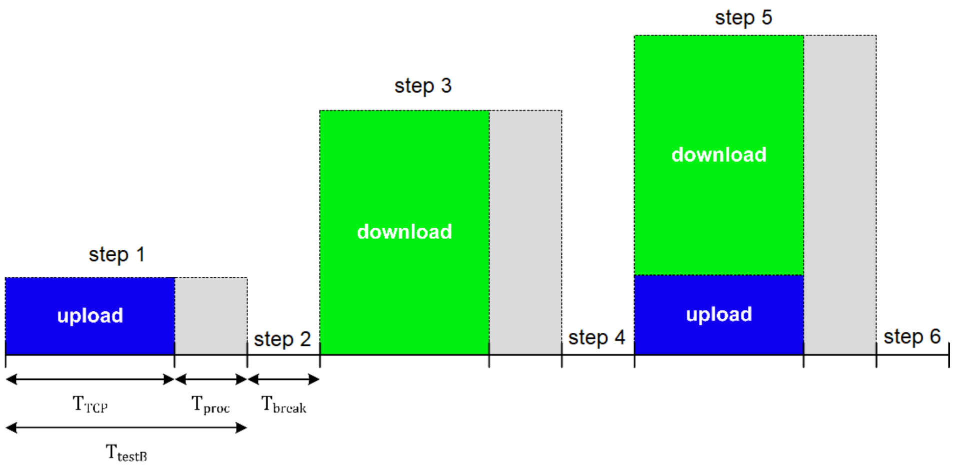

Fig. 1: Recommended form of the process of measurement of TCP throughput

The possible combinations of the implementation of the minimum admissible form of the process of measurement depend mainly on the measuring tools applied. The theoretically possible combinations are provided on Fig. 2, and they only differ by the processing of the values measured.

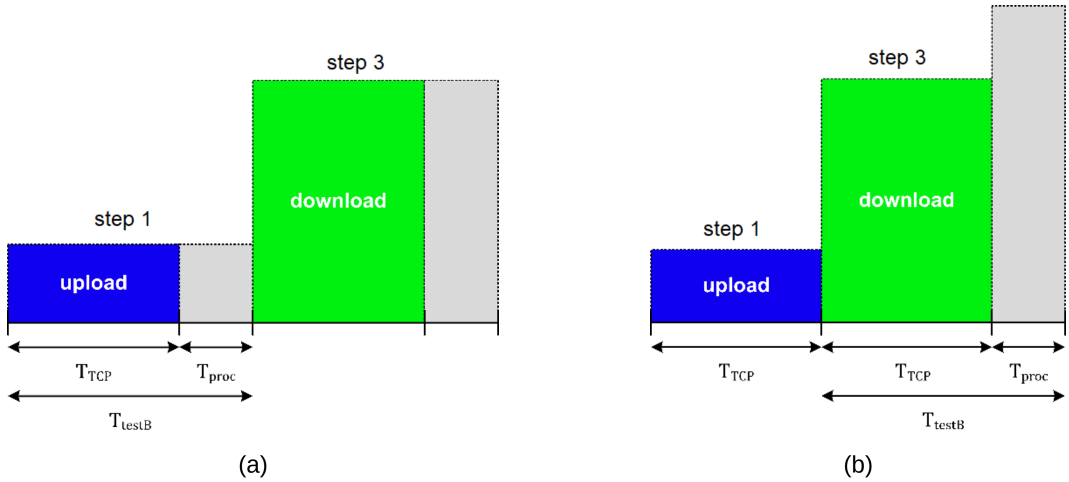

Fig. 2: Versions of the minimum permissible form of the process of measurement of TCP throughput: (a) processing each one-way test separately, (b) processing all one-way tests at the conclusion of the measurement process

1.6.1. Input parameters of the measurement sequence

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 Czech Telecommunication Office on selected issues relating to open internet access and European net neutrality rules and General Authorisation 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 the 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 four definitions of speeds related to the provision of internet access service in fixed or semi-fixed networks in the range from the point of handover of the service to the end user (DeP 7 or DeP 6, respectively) up to the MSEK access point via internet exchange NIX.CZ (DeP 1), including the possibility of using transit connectivity in the case of filtering the exchange of routing information in the internet exchange NIX.CZ, or the exchange of routing information in a foreign internet exchange. In the case of download and upload speeds according to Article 4(1)(d) of the Regulation, the definitions are provided within General Authorisation No. VO-S/1/08.2020-9.

The measurement process based on IETF recommendation RFC 6349 defines BB, $\mathrm{Delay(baseline)}$, $\mathrm{TCP\ RWND}$ and MTU as input parameters. Most of the available measuring tools makes it possible to set the input parameters BB and MTU; the other parameters can be set by these measuring tools according to the criteria provided in IETF recommendation RFC 6349. Some manufacturers of measuring tools incorrectly state the reference CIR in connection with parameter BB. This identification is misleading because it is prone to incorrect setting of the value of BB with the value corresponding to the link layer of the ISO/OSI model ("*committed information rate*"), but it is actually a physical layer. It is therefore recommended to ask the manufacturer of the measuring tool on which layer of the ISO/OSI model the input parameter BB is to be set. If the basic set of data parameters is measured, the input parameter BB will be equal to the contractually defined value of the maximum speed converted to the value of the physical layer (L 1) of data download and upload:

$$\mathrm{BB}\ (\mathrm{L}\ 1) = \mathrm{CIR}\ (\mathrm{L}\ 1) = \mathrm{R_{max}}\ (\mathrm{L}\ 1);\ [\mathrm{b}/s; \mathrm{b}/s]. \tag{23}$$

The value of MTU of the NUT measured, if not known (for example, for the VDSL2 technology conforming to standard ITU-T G.993.2 with the use of PPP and PPPoE, it is $\mathrm{MTU} = 1492\ \mathrm{B}$), is recommended to identify using the available test tools, for example Wireshark, a packet capturing program, or a tool functioning according to IETF recommendation RFC 4821: *Packetization Layer Path MTU Discovery*.

2. Measurement of a set of advanced data parameters

The procedure for measuring a set of advanced data parameters is based on the procedure for measuring basic data parameters, with the addition of qualitative data parameters, namely information rate (uplink; $\mathrm{IR_{up}}$) and information rate (downlink; $\mathrm{IR_{down}}$), which characterize the available bandwidth at a given measuring point for both directions of data communication, frame delay (FTD), inter-frame delay variation (IFDV) and frame loss ratio (FLR).

2.1. Sequence of measurements

As in the case of the procedure for measuring the set of basic data parameters, 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, i.e. at least one measurement at the peak hour and at least one measurement during an off-peak hour. With regard to the end user and due to the time-consuming process of measuring TCP throughput, which is, in addition, extended by the process of measuring qualitative data parameters, it is permissible to perform all three main measurements at peak hour, or to perform measurements with respect to the definition of time availability (time dimension) of normally available speed.

One measurement should not exceed a timeframe of 30 minutes during which a sequence of three basic tests (*basic test*; “testB”) based on IETF recommendation RFC 6349 and one complementary test (hereinafter referred to as “testC”) based on ITU-T Y.1564 will take place. One test of the testB category must guarantee the total length of the TCP throughput measurement, including the time intensity of the processing the measurement results that meet the condition:

$$\mathrm{T_{testB}} \leq 300\ \mathrm{s}. \quad (22)$$

Standard ITU-T Y.1564 recommends performing a basic performance test of a fixed or semi-fixed electronic communications network with a total duration of at least 15 minutes. Because it is recommended to perform 3 main independent measurements within the measuring process, one testC or, more precisely, its basic service performance test part, must guarantee the duration of measurement of the qualitative data parameters:

$$\mathrm{T_{perf}} \geq 300\ \mathrm{s}. \quad (24)$$

It is appropriate to use the basic service performance test according to ITU-T Y.1564 to verify the qualitative data parameters such as frame delay (FTD), inter-frame delay variation (IFDV) and frame loss ratio (FLR), and according to CEPT recommendation ECC (15)03, in the case of frame delay (FTD) and inter-frame delay variation (IFDV) 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/classes according to the technical specification MEF 23.2.

Standard ITU-T Y.1564 also recommends that it also includes the so-called configuration test. This test represents measurement of qualitative data parameters in dependence on the change of the input CIR value in six steps, namely with 50% CIR, with 75% CIR, with 90% CIR, and with 100% CIR, and also with $\mathrm{CIR} + \mathrm{EIR}$ and $\max \mathrm{NBR}$. Each step should correspond to the test duration in the range from 1 to 60 seconds. With regard to the parameters of the speed of Internet access services at a fixed and semi-fixed location, the Office decided to use only the first five steps with the duration of one step being 5 seconds ($\mathrm{T_{conf}} = 25$ seconds). The resulting value of the information rate in the case of the configuration test under the input condition $\mathrm{CIR} + \mathrm{EIR}$ can be used to verify the actual bandwidth. With respect to the processing of the values measured ($\mathrm{T_{proc}}$) by the measuring tools used, the total duration of one test should not exceed $\mathrm{T_{testC}}$:

$$\mathrm{T_{testC}} = \mathrm{T_{conf}} + \mathrm{T_{perf}} + \mathrm{T_{proc}} \leq 420\ \mathrm{s}. \quad (25)$$

The resulting measurement process should consist of the following steps (see Fig. 3):

- Step 1 – one-way test of TCP throughput (upload) $\mathrm{TCP\ aTR_{up}}$ including the value of $\mathrm{Delay(avg)}$ with total duration of the test $\mathrm{T_{testB}} \leq 300\ \mathrm{s}$,
- Step 2 – a break (saving the previous test results) with duration $\mathrm{T_{break}} \leq 90$ seconds,
- Step 3 – one-way test of TCP throughput (download) $\mathrm{TCP\ aTR_{down}}$ including the value of $\mathrm{Delay(avg)}$ with total duration of the test $\mathrm{T_{testB}} \leq 300\ \mathrm{s}$,
- Step 4 – a break (saving the previous test results) with duration $\mathrm{T_{break}} \leq 90$ seconds,
- Step 5 – a bidirectional test of TCP throughput (upload + download) $\mathrm{TCP\ aTR_{up}}$ and $\mathrm{TCP\ aTR_{down}}$ including the value of $\mathrm{Delay(avg)}$ with total duration of the test $\mathrm{T_{testB}} \leq 600\ \mathrm{s}$,
- Step 6 – a break until the start of the next sequence of measurements corresponding to the lapse of time (saving the previous test results, preparation for the next test) with duration pf $\mathrm{T_{break}} \leq 90$ seconds,
- Step 7 – bidirectional test of qualitative data parameters according to standard ITU-T Y.1564 with total duration of the test $\mathrm{T_{testC}} \leq 420\ \mathrm{s}$,

- Step 8 – a break until the start of the next sequence of measurements corresponding to the lapse of time (saving the previous test results, preparation for the next sequence of tests/measurements) with duration $T_{break} \leq 90\ s$.

If the measuring tool does not make it possible to set the order of the sequence of tests as recommended, it is possible to change the order without breaching the integrity of the measurement. In the same way, it is possible to omit the bidirectional test of TCP throughput (step 5) or the sequence of breaks between individual tests (steps 2, 4, 6 and 8). The minimum admissible form of the process of measurement of the extended set of data parameters must consist of a one-way upload test (step 1), one-way download test (step 3) of TCP throughput, and a bidirectional test of qualitative data parameters according to standard ITU-T Y.1564 (uplink + downlink; step 7). The possible combinations of the implementation of the minimum admissible form of the process of measurement depend mainly on the measuring tools applied.

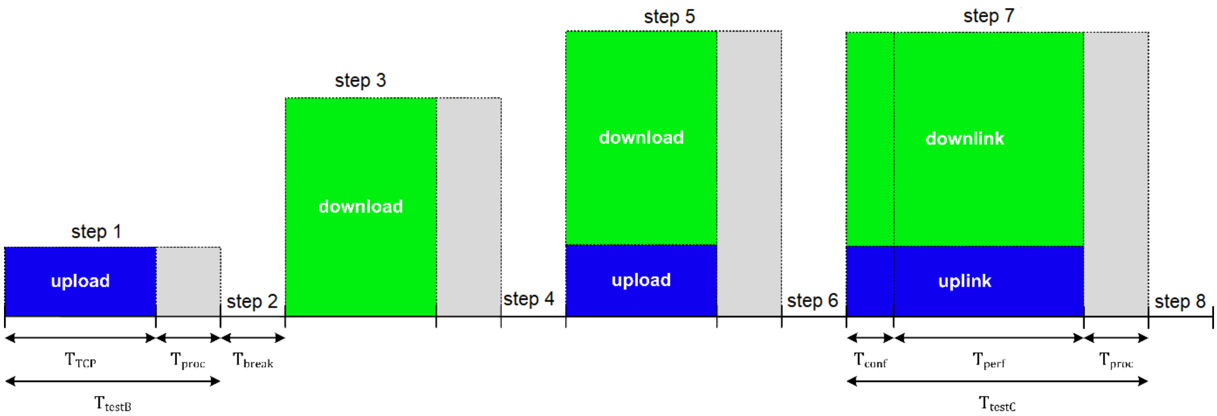

Fig. 3: Recommended form of the process of measurement of the extended set of data parameters of fixed or semi-fixed electronic communications networks

2.1.1. Input parameters of the measurement sequence

When measuring the qualitative data parameters within the extended set of data parameters, it is necessary to rely on standard ITU-T Y.1564 which defines, among other things, CIR, $\mathrm{CIR} + \mathrm{EIR}$ and the size of the Ethernet frame FS (from $64\ \mathrm{B}$ to $1526\ \mathrm{B}$) as input parameters. As implied by the identification of CIR and EIR, they are parameters corresponding to the link layer of the ISO/OSI model. Some manufacturers of measuring tools incorrectly label the values corresponding to the physical layer of the ISO/OSI model in connection with parameters CIR and EIR. It is therefore recommended to ask the manufacturer of the measuring tool on which layer of the ISO/OSI model the input parameters CIR and $\mathrm{CIR} + \mathrm{EIR}$ is to be set.

In the case of measurement of qualitative data parameters, the input parameter CIR should equal the contractually defined value of the normally available speed (BDR) for download or upload of data of the internet access service at a fixed or semi-fixed location:

$$\mathrm{CIR\ (L\ 1) = BDR\ (L\ 1);\ [b/s; b/s]}, \tag{26}$$

due to the elimination of the possibility of prioritization and distortion of the achieved values of qualitative data parameters in the form of frame delays (FTD), inter-frame delay variation (IFDV) and frame loss ratio (FLR) of the NUT in question, if the information rate during the measurement process approached the defined value of the maximum speed ($\mathrm{R_{max}}$), which is also in accordance with the measurement conditions according to ITU-T Y.1564. For the purposes of the configuration test, it is advisable to set parameter $\mathrm{CIR} + \mathrm{EIR}$ in the form of a contractually defined value of maximum speed ($\mathrm{R_{max}}$) for download or upload of data of the internet access service at a fixed or semi-fixed location converted to a value corresponding to the physical layer of the ISO/OSI model:

$$\mathrm{CIR + EIR\ (L\ 1) = R_{max}\ (L\ 1);\ [b/s; b/s]}. \tag{27}$$

The settings defined in this way provide the possibility of verifying the ability of the NUT in question to provide contractually set values of the maximum download and upload speed in terms of verifying the actual value of bandwidth. The result is the information rate IR corresponding to the link layer of the ISO / OSI model for both directions or, as appropriate, the actual bandwidth in the uplink direction and in the downlink direction.

When determining the value of the frame size FS, it is advisable to rely on the determined value of MTU used in the measurement of basic data parameters or, specifically:

$$\mathrm{FS} = \mathrm{MTU} + \mathrm{MAC\ DST} + \mathrm{MAC\ SRC} + 802.1\mathrm{Q}\ (802.1\mathrm{ad}) + \mathrm{Ethertyp} + \mathrm{FCS}; [\mathrm{B}; \mathrm{B}], \qquad (28)$$

if the value set for the NUT in question is $\mathrm{MTU} = 1500\ \mathrm{B}$ then in the case of $\mathrm{MAC\ SRC} = 6\ \mathrm{B}$, $\mathrm{MAC\ DST} = 6\ \mathrm{B}$, $802.1\mathrm{Q}\ (802.1\mathrm{ad}) = 0\ \mathrm{B}$, $\mathrm{Ethertyp} = 2\ \mathrm{B}$ and $\mathrm{FCS} = 4\ \mathrm{B}$ the result will be $\mathrm{FS} = 1518\ \mathrm{B}$.

3. Alternative measurement of a set of basic data parameters

An alternative method of measuring a set of basic parameters must be used in cases where a fixed or semi-fixed electronic communications network shows a high packet (frame) loss ratio and high packet (frame) delay variation. According to IETF recommendation RFC 6349, the threshold of 5 % packet loss and packet delay variation of 150 ms can be used as a reference value. These or even higher values suggest a failure or emergency status of the network (for example, overloading, insufficient network capacity), or application of traffic management measures. In such cases, it is necessary to choose an alternative method of measuring the basic data parameters. As an alternative method of measurement, it is possible to choose the measurement of qualitative data parameters according to the ITU-T Y.1564 standard, which uses a connectionless UDP protocol during the measurement process on the transport layer. The result is uplink information rate values ($\mathrm{IR_{up}}$) and downlink information rate values ($\mathrm{IR_{down}}$) which characterize the actual bandwidth at the measurement location for both directions of the data communication, as well as frame delay (FTD), inter-frame delay variation (IFDV) and frame loss ratio (FLR). In cases where the NUT shows a very high frame (packet) loss ratio, which makes it impossible to complete the measurement according to the ITU-T Y.1564 standard, this loss ratio can be identified using the ITU-T Y.150 tool.

Based on the obtained values of qualitative data parameters, preferably supplemented by the results of the *tracert (traceroute)* command, it is possible to deduce the state of the whole NUT and the reason for the impossibility of measuring a set of basic data parameters according to IETF recommendation RFC 6349, or, more precisely, whether the state shows signs of significant discrepancies, or service outages, or the application of traffic management measures, e.g. due to insufficient network capacity.

3.1. Sequence of measurements

As in the case of the procedure for measuring a set of basic data parameters, 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, i.e. at least one measurement at the peak hour and at least one measurement during an off-peak hour. It is permissible to perform all three main measurements at peak hour, or to perform measurements with respect to the definition of time availability (time dimension) of normally available speed.

One measurement should not exceed a timeframe of 30 minutes, during which one alternative test (*alternative test*; hereinafter referred to as “testA”) based on ITU-T Y.1564 standard, will take place. Standard ITU-T Y.1564 recommends performing the basic test of performance with total duration of 15 minutes. Since it is recommended to perform 3 main independent measurements within the measuring process, one testA or, more precisely, its basic service performance test part, must guarantee the duration of measurement of the qualitative data parameters:

$$\mathrm{T_{perf}} \geq 300\ \mathrm{s.} \tag{24}$$

It is appropriate to use the basic service performance test according to ITU-T Y.1564 to verify the qualitative data parameters such as frame delay (FTD), inter-frame delay variation (IFDV) and frame loss ratio (FLR), and according to CEPT recommendation ECC (15)03, in the case of frame delay (FTD) and inter-frame delay variation (IFDV), it is their resulting average values.

Standard ITU-T Y.1564 also recommends that it also include the so-called configuration test. This test represents measurement of qualitative data parameters depending on the change of the input CIR value in six steps, namely with 50% CIR, with 75% CIR, with 90% CIR, and with 100% CIR, and also with $\mathrm{CIR} + \mathrm{EIR}$ and $\max \mathrm{NBR}$. Each step should correspond to the test duration in the range from 1 to 60 seconds. With regard to the parameter definitions of internet access services, the Office decided to use only the first five steps with the duration of one step being 5 seconds ($\mathrm{T_{conf}} = 25$ sec.). The resulting value of the information rate in the case of the configuration test under the input condition $\mathrm{CIR} + \mathrm{EIR} = \mathrm{R_{max}}$ can be used to verify the actual bandwidth. With respect to the processing of the values measured ($\mathrm{T_{proc}}$), the total duration of one test should not exceed $\mathrm{T_{testA}}$:

$$\mathrm{T_{testA}} = \mathrm{T_{conf}} + \mathrm{T_{perf}} + \mathrm{T_{proc}} \leq 420\ \mathrm{s.} \tag{25}$$

The resulting measurement process should consist of the following steps (see Figure 4):

- Step 1 – bidirectional test of qualitative data parameters according to the ITU-T Y.1564 standard with total duration of the test $\mathrm{T_{testA}} \leq 420\ \mathrm{s}$,
- Step 2 – a break until the start of the next sequence of measurements corresponding to the lapse of time (saving the previous test results, preparation for the next sequence of tests/measurements) with duration $\mathrm{T_{break}} \leq 1380\ \mathrm{s}$.

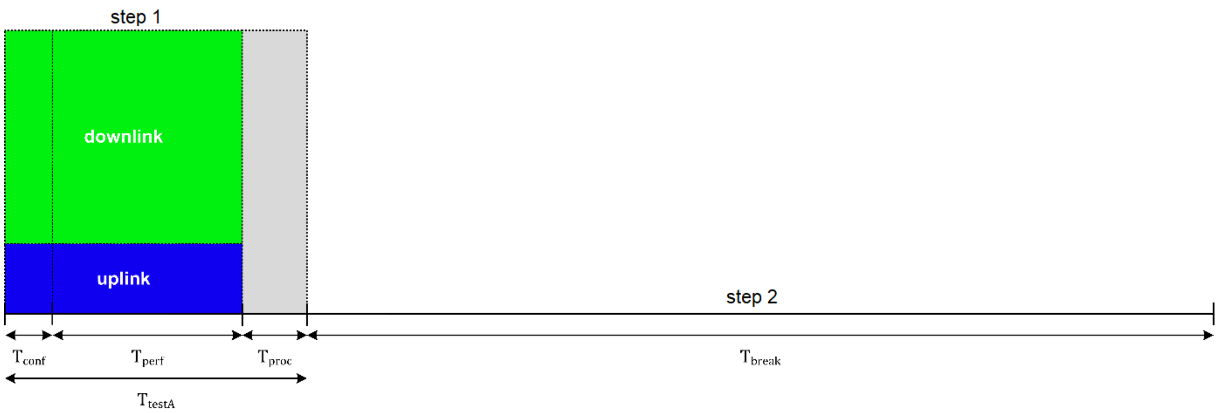

Fig. 4: Recommended form of the process of measurement of the basic set of data parameters of fixed or semi-fixed electronic communications networks

4. Demarcation points of measurement

The demarcation points of measurement are such points (nodes) within the network, between which the set of data parameters of the fixed or semi-fixed electronic communications network will be measured. In general, a demarcation point can be imagined as a network node interface (a specific interface/port of an active element). The Office will perform the measurements according to the methodology directly at a specific demarcation point or, as the case may be, at a near location in the range which does not exceed the distance of the respective adjacent demarcation point according to the contract terms. The Office defines the following demarcation points, whereas it is always assumed that the measurement is performed at the ethernet interface (in particular when carrying out measurements in order to exercise the Office's powers):

- The first demarcation point is defined in the form of access of MSEK (measuring server) to the internet through the internet exchange NIX.CZ, see DeP 1 on Figure 5. The first demarcation point can also be used to define another location within the network, but only in cases where the situation cannot be resolved by means of demarcation point DeP 1. A typical situation can be, for example, the measurement of a dedicated line, or the use of transit connectivity when detecting the filtering of routing information exchange in the internet exchange NIX.CZ, or routing information exchange in a foreign internet exchange.
- The second demarcation point can be imagined in the form of a network node interface (a specific interface/port of an active element) or, as the case may be, at a near location in the range which does not exceed the distance of the respective adjacent demarcation point according to the contract terms, where a measurement according to the guideline will take place by means of the measuring device (terminal). This document defines the positions of demarcation points DeP 2 to DeP 7, see Figure 5, according to the general structure of the access network and its access to the internet or, more precisely, to MSEK (DeP 1). It is evident that within the actual structure of the access network of a particular provider of the Internet access service, some demarcation points can be merged or, as the case may be, added in the case of an extensive network (e.g. DeP 5a, DeP 5b and DeP 5c). The nature and properties of the demarcation point (node) are always important.

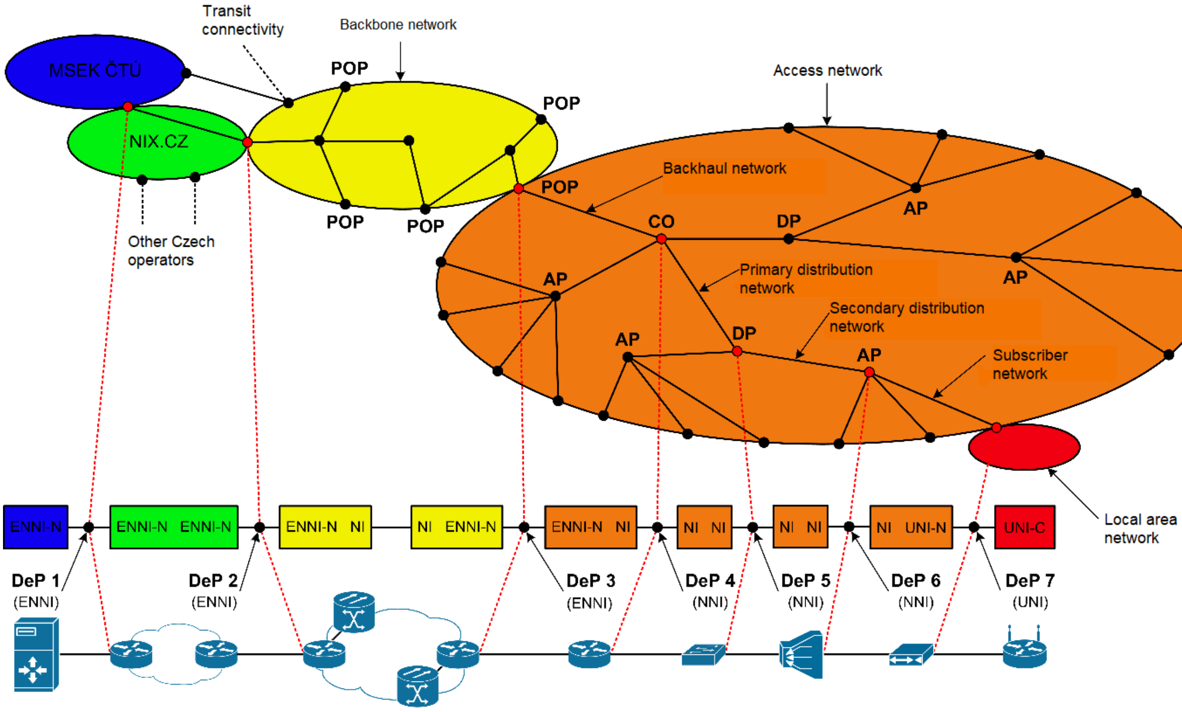

Fig. 5: Defined positions of the demarcation points (DeP) within the general diagram of the access network structure and its connection to the Internet

Such defined demarcation points can be used also when it is necessary to monitor data traffic with the use of the SNMP protocol which, among other things, enables continuous collection of data traffic at the relevant physical interface/port of the active elements associated with the respective demarcation point. The monitored values of data traffic correspond in most cases to the link layer of the ISO/OSI model (L 2). Pursuant to Article 5(2) of the Regulation, the Office may, in case of doubt about the sufficient capacity of the respective section of the provider's access network, require submission of information in the form of data traffic monitoring results at particular demarcation points, at least in the form of incoming (*Bits* *received; incoming*) and outgoing *(Bits sent; outgoing)* data traffic of the relevant physical interfaces/ports of the active elements associated with the demarcation point (node) in a minimum period of time of the last 30 calendar days, see Figure 6.

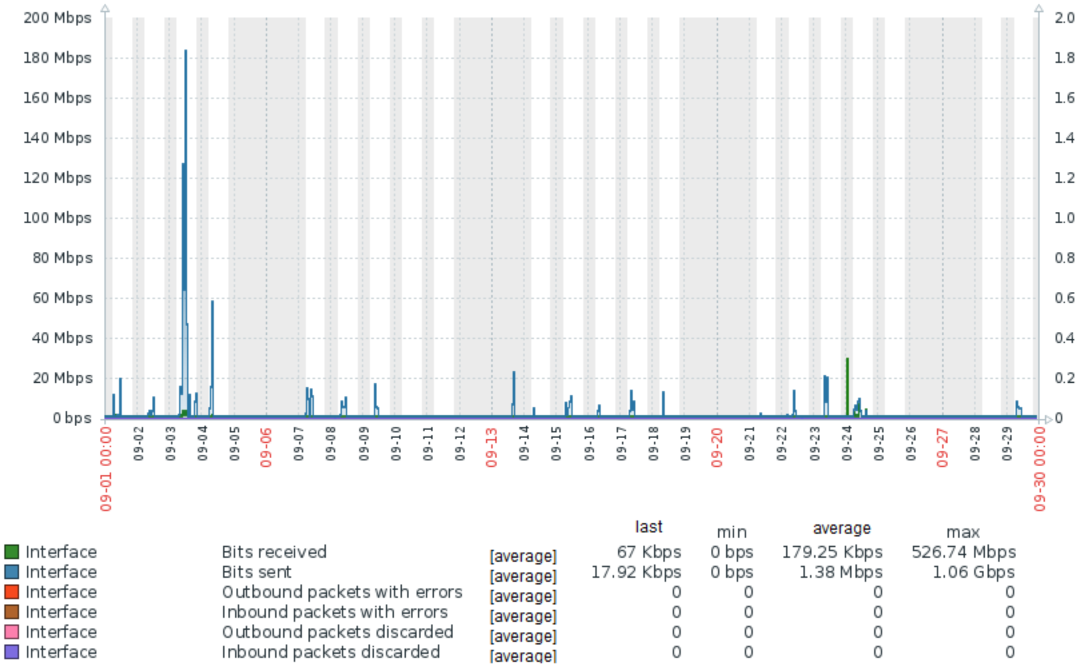

Fig. 6: An example of the speeds of incoming (*Bits received*) and outgoing (*Bits sent*) network traffic to the internet exchange NIX.CZ of the relevant interface of the border router of MSEK, DeP 1

Utilization of the relevant demarcation point by data traffic U (*link utilization*) can be determined as a share of average monthly incoming (*Bits received; incoming*) and outgoing *(Bits sent; outgoing)* data traffic, generally referred to as F (*link flow*) of the relevant physical interfaces/ports of the active elements associated with the demarcation point in the time period of the last 30 calendar days and the value of the total capacity C (*link capacity*) of the relevant demarcation point in the uplink and downlink directions:

$$\mathrm{U} = \frac{\mathrm{F}}{\mathrm{C}} \cdot 100\ \%. \tag{26}$$

In a situation where Ethernet interface is not available at the demarcation point in question, it is necessary to use a certified converter of the network operator for the measurement. If no such converter is available, it is necessary to use a converter which is supplied to the customer upon activation of the service, but if required by the situation, it is possible to use another converter which is suitable for this service and technology. After connecting and switching on such converter, it is necessary to wait the necessary time to achieve synchronization and stabilized state in the network (for example, 5 minutes) or proceed based on consultation with the network operator.

5. Security considerations

Because the measurement of the extended set of data parameters uses the UDP protocol on the transport layer of the ISO/OSI model, the behaviour of the measurement process can be perceived by network operators (providers) as an attempt for DoS or a DDoS attack. Therefore, the measurement of an advanced set of data parameters may require coordination with the Internet service provider.

5.1. Measurements in the networks with IPv6 and NAT

With respect to the possibility to encapsulate the TCP and UDP protocol 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.

5.2. 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 from server (“remote”) → client (“local”) is impossible, it is necessary to use such a measuring tool that enables reverse initiation of network session when measuring download direction. This situation may occur for example 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.

5.3. 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 problem, eliminate it if possible and, if applicable, subsequently perform a repeated measurement.

V. Terms, definitions and abbreviations

AP – access point on the side of access network

BB (*bottleneck bandwidth*) – the lowest bandwidth value (capacity) of the measured network under test corresponding to the first layer of ISO/OSI model

BDR – normally available speed which the end user can estimate and actually reach when downloading and uploading data in a time period corresponding to 95 % of the time of 1 calendar day

CIR (*committed information rate*) – guaranteed minimal information speed corresponding to the second layer of ISO/OSI model

CO (*central office*) – provider's central office through which the internet access (access to the core network) is provided

C (*link capacity*) – the total capacity of the given data link in the given direction (uplink or downlink). The capacity is usually related to the physical possibilities of the given data link or with set limit values (the real bandwidth in the given direction)

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

$\mathrm{Delay(avg)}$ – the average Delay value during a TCP data flow throughput test

DeP x (*demarcation point x*) – a specific demarcation point as a transfer interface between two different network entities (core network, access network, local area network, etc.)

DP (*distribution point*) – distribution point (node) of the distribution network belonging to a set of the access network

EIR (*excess information rate*) – information speed overlap, or non-guaranteed information speed corresponding to the second layer of ISO/OSI model and covering the band from upper CIR limit to maximal NBR value

ENNI (*external network to network interface*) – an interface between two providers of the Internet access service

ENNI-N (*external network to network interface-network side*) – a port on an active network element physically connected to the interface between two providers of the Internet access service

F (*link flow*) – marks the workload of a given data link in a given direction in time (uplink/downlink), usually states as an average value in a given monitored time period

FS (*frame size*) – Ethernet frame size

FD (*frame delay*) – frame delay constituting the NUT time delay between sending and receiving of the Ethernet frame

$\mathrm{FD}\ (RTT)$ – corresponds to the time passed between sending of the first frame bit from end user in direction to the Internet access service and receiving the last bit of the return frame from service provider in direction to end user

FLR (*frame loss ratio*) – packet loss as a ratio of all non-delivered (lost) Ethernet frames to the total number of all sent Ethernet frames

FWA (*fixed wireless access*) – wireless electronic communications network on a fixed location

IFDV (*inter-frame delay variation*) – delay fluctuation or jitter, a difference between the reference time of delivery of the Ethernet frame ($\mathrm{c_k}$) and the actual time of delivery thereof ($\mathrm{d_k}$)

IR – (*information rate*) – data transmission speed in the direction from the end user to the provider of the Internet access service corresponding to the link layer of the ISO/OSI model

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

Delay(baseline) – corresponds to the smallest measured value of the delay during the established initial testing NUT session connection not burdened by the TCP metric

MS – measuring server

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

MT – measuring terminal

MTU (*maximum transmission unit*) – maximal IP datagram size (TCP segment) which can be sent through a given network interface

NBR (*net bit rate*) – transfer speed corresponding to physical layer of ISO/OSI model of a given interface with assumption of Ethernet frame utilization

NNI (*network to network interface*) – interface between active network elements of Internet access service provider

NI (*network interface*) – port on an active network element

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

POP (*point of presence*) – demarcation point between two different types of data networks (core and access network). POP is primarily an infrastructure which allows distant users to connect to the Internet network

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 guaranteed speed for download or upload

R_{min} – minimal speed, i.e. the lowest guaranteed speed for download or upload

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

Network node – a group of one or more network elements

t – a time duration of test in general

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

TCP RWND (TCP *receive window*) –TCP window size on the receiving side

U (*link utilization*) – utilisation of a given data link as a percentual workload of the total capacity of a given data link

UNI *(user network interface*) – interface between Internet access service provider and end user

UNI-C (*user network interface-customer side*) - port on an active network element on the end user's side physically connected to the interface between Internet access service provider and end user

UNI-N (*user network interface-network side*) - port on an active network element on the Internet access service provider's side physically connected to the interface provider and end user

VI. Annexes

1. Measurement of the fixed and semi-fixed electronic communications network for the purpose of inspection the data parameters belonging to the set of basic data parameters

Annex 1, version 2.1, valid from 1 March 2021, is intended for measurement of data parameters in normal network traffic which belong to the set of basic data parameters. The measurement according to annex 1 is intended for exercise of the Office's powers in terms of checking data parameters of the Internet access service.

1.1. Description of the measurement scenario

The measurement scenario corresponds to the measurement process that is specified in the measurement procedure. The specified measurement scenario is defined by the Office for measuring data parameters of fixed or semi-fixed electronic communications networks belonging to the set of basic data parameters for the purpose of inspection them. The measurement scenario and selected set of basic data parameters are related in particular to the following documents: Determination of the basic parameters and measurement of the quality of the internet access service and Statement of the Czech Telecommunication Office on selected issues of access to open internet and European net neutrality rules, and is also related to General Authorisation No. VO-S/1/08.2020-9 laying down conditions for the provision of electronic communications services. The measurement scenario is also in accordance with the BEREC Guidelines BoR (20) 112: *Implementation of the Open Internet Regulation*.

1.2. Selection of the measurement method

For the purpose of performing measurements according to the specified measurement scenario, a measurement method is chosen as defined in the measurement guideline based on IETF recommendation RFC 6349. In defining the basic set of data parameters, the Office relied primarily on the requirement for comprehensibility of individual parameters from the point of view of a regular user of the internet access service and also took into account the text of the Regulation and the related Statement of the Czech Telecommunication Office on selected issues of access to open internet and European net neutrality rules and General Authorisation 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 the internet access service According to Article 4(1)(d) of the Regulation, in the range from the point of handover of the service to the end user (DeP 7 or DeP 6, as the case may be) up to the point of access of MSEK to Internet exchange NIX.CZ (DeP 1). In the case of data download and upload, the definitions of speeds apply to each direction separately. The selected measurement method will be applied by the Office in the case of verification measurements of compliance with the defined speeds, namely in terms of verification of a service outage and significant discrepancies of the performance of the service from normally available speed. The measurement method selected by the Office defines the measurement of the performance of the internet access service on the transport layer of the ISO/OSI model by means of the TCP protocol (testB).

In exceptional cases, for example, for the measurement of data parameters of dedicated lines, MPLS, or when it is necessary to measure at demarcation points DeP < 6, or also in a situation where the state of the NUT does not allow the use of the measurement method according to IETF recommendation RFC 6349 (high packet loss ratio and high packet delay variation), it is possible to use a measurement method defined by the ITU-T Y.1564 standard, i.e. to perform measurement of qualitative data parameters belonging to the set of advanced data parameters defined in this document. The alternative method chosen in this way defines the performance of the measurement on the link layer of the ISO/OSI model (L 2) using the connectionless UDP protocol of the transport layer (testA) and, in combination with the results of the *tracert* (*traceroute*) command or with the results of the tool according to ITU-T O.150, it will allow the Office to deduce the reason for the impossibility of measurement according to IETF recommendation RFC 6349, or whether the NUT state shows signs of significant discrepancies, or service outages, or the application of traffic management measures, e.g. due to insufficient network capacity.

1.3. Measurement sequence

Measurement in fixed or semi-fixed 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, i.e. at least one measurement at the peak hour and at least one measurement during an off-peak hour. With regard to the end user and due to the time-consuming process of measuring TCP throughput, it is permissible to perform all three main measurements at peak hour, or to perform measurements with respect to the definition of time availability (time dimension) of normally available speed. One measurement should not exceed a timeframe of 30 minutes during which there will be a sequence of 3 tests of the testB category according to section 1.6 of the measurement procedure, or alternatively a sequence of 3 tests of the testA category according to section 3.1 of the measurement procedure.

If the measuring tool does not make it possible to set the order of the sequence of tests as recommended, it is possible to change the order without breaching the integrity of the measurement. In the same way, it is possible to omit the bidirectional test of TCP throughput (step 5) or the sequence of breaks between individual tests (steps 2, 4 and 6). The minimum admissible form of the process of measurement of TCP throughput must consist of a one-way upload test (step 1) and one-way download test (step 3) of TCP throughput. The possible combinations of the implementation of the minimum admissible form of the process of measurement depend mainly on the measuring tools applied. Using the so-called “loopback” test during the measurement is not recommended, not even in the case of symmetrical NUTs. An exception is the situation when the NUT state requires the use of a tool according to the ITU-T O.150 standard.

1.4. Demarcation points

The first demarcation point will be the access of the MSEK system to the internet via Internet exchange NIX.CZ in accordance with section 4 specifying the demarcation points of the measurement, see DeP 1 on Figure 5 (alternatively, access by means of transit connectivity). The second demarcation point can be imagined in the form of an interface/port of the network node (a specific port of an active element) or, as the case may be, at a near location in the range which does not exceed the distance of the respective adjacent demarcation point according to the contract terms where a measurement by means of the measuring device (terminal) will take place. Within the measurement according to annex 1, DeP 7 is assumed as the second demarcation point, see Fig. 5, i.e. the demarcation point in the form of an interface/port between the Internet access service provider and the end user or, more precisely, at the network termination point (device). With respect to the diversity of technologies of the access networks and their structure, the second demarcation point can occasionally be also DeP 6, for example in a situation where the concentration point AP is implemented in the form of a router or network switch.

1.5. Setup of the measuring terminal and start of the measurement process

After determining the measuring method, measuring sequence and the demarcation point, the measuring device (terminal) is physically connected to the terminal equipment device at the termination point of the network (DeP 7), or to the handover interface/port. (DeP 6). In the case of a terminal equipment device, actions are taken to prevent parallel (cross) data communication, i.e. deactivation of IEEE 802.11 standard interfaces and physical prevention of the use of other IEEE 802.3 compliant terminal interfaces (physical ports). Correct connection will subsequently be verified by means of the measuring device (terminal) where it is subsequently necessary to select and set the parameters of the measuring interface. In addition, it is necessary to set other parameters of the higher network layers, if necessary, e.g. $\mathrm{MAC\,SRC}$, $802.1\mathrm{Q}\,(802.1\mathrm{ad})$, IP address of the measuring device (terminal), if it does not receive it through the DHCP server, and the number of the TCP port of the measuring tool on the measuring device (terminal) and the measuring server, unless it is pre-set. Subsequently, the recommended steps are performed before starting the measurement process, specified in the measurement procedure.

In the next stage, it is necessary to set the input parameters of the measuring tool on the side of the measuring device (terminal). The input parameters of the measuring tool or, more precisely, the measurement sequence, must be based on the defined parameters presented by the electronic communications service providers in their offers of the internet access service with regard to the Article 4(1)(d) of the Regulation and the related Statement of the Czech Telecommunication Office on selected issues relating to open internet access and European net neutrality rules and General Authorisation 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 the internet access service. The input parameters need to be set according to the measuring tool applied in accordance with section 1.6.1. defining the input parameters of the sequence of measurement, where, however, it is necessary to pay attention on which layer of the ISO/OSI model and under which name the input BB parameter is set in the measuring tool. In this case, the formula (23) must apply.

Another key parameter is MTU. It is recommended to identify the value of MTU of the NUT measured, if not known, using the available test tools, for example Wireshark, a packet capturing program, or a tool functioning according to IETF recommendation RFC 4821: *Packetization Layer Path MTU Discovery*.

Based on the settings of the input parameters of the measuring tool, including the intervals of the measurement sequence, it is possible to perform the test according to the selected steps, preferably in the recommended order, the result of which is the measured values of the set of basic data parameters. The results of the individual tests of the testB category will be subsequently saved in the form of reports allowing for subsequent machine processing (HTML, CSV, etc.) in the final form of the Measurement Protocol.

1.6. Evaluation of the measurement process result

When evaluating the results of the testB category measurement process according to annex 1, the Office will monitor compliance with the defined speeds, in terms of service outages and significant discrepancies of service performance from the normally available speed. In the case of minimum speed ($\mathrm{R_{min}}$), it is the lowest guaranteed speed for data download and upload which the relevant provider of the internet access service has undertaken to provide to the end user under the contract. If the actually achieved speed (TCP throughput) falls below this value, even in one case (test), such a condition shall be considered a service outage. The following should therefore apply to the data download or upload speeds:

$$\mathrm{TCP\ aTR} \geq \mathrm{R_{min}};\ [\mathrm{b/s};\mathrm{b/s}], \tag{27}$$

otherwise an outage of the internet access service has occurred. In its document entitled Statement of the Czech Telecommunication Office on selected issues of access to open internet and European net neutrality rules and also in General Authorisation No. VO-S/1/08.2020-9, the Office defines a significant and continuous or regularly recurring discrepancy of the actual performance of internet access service. Both defined discrepancies are derived from the value of the normally available speed (BDR) which is two-dimensional; the first dimension is defined in the form of the level of TCP throughput in the download and upload direction and the second dimension is defined in the form of the time availability of this level for the period of one calendar day.

Significant continuous discrepancy from the normally available speed (BDR) for download or upload shall be a deviation that causes a continuous decrease in the performance of the internet access service, i.e. a decrease in the actual achieved speed by measuring the specified TCP throughput below a defined value of normally available speed, in an interval longer than 70 minutes, during the measurement process performed by the Office in the time period of 90 minutes. It is therefore possible to state that the following applies to the significant continuous discrepancy:

$$\mathrm{T_{BDR}} > 70\ \mathrm{min}, \tag{28}$$

where $\mathrm{T_{BDR}}$ refers to the length of the interval of exceeding the value of the normally available speed corresponding to the start time of the measuring process, when the resulting value of the actual transmission speed is lower than the defined value of the normally available speed. With respect to the measurement process itself and its individual steps, the Office will consider the situation where the condition will hold for all results of the tests of testB category for download or upload to be an occurrence of a significant continuous discrepancy $\mathrm{TCP\ aTR} < \mathrm{BDR}$.

Regularly recurring discrepancy from the normally available speed for download or upload shall be a discrepancy at which there are at least three decreases of the actually achieved speed corresponding to the measurement of the determined TCP throughput below the defined value of the normally available speed in an interval longer than or equal to 3.5 minutes in a time period of 90 minutes during the measuring process performed by the Office. If we mark the time of launching the test during which the BDR limit was exceeded as $\mathrm{t_x}$, where $\mathrm{x} \in \mathbb{N}^+$, and we also use the determined length of the interval of the test $\mathrm{T_{testB}}$, it will be possible to state that the following applies to the significant regularly recurring discrepancy:

$$\exists\ \mathrm{t_1, t_2, t_3}: \mathrm{T_{BDR}} > 3{,}5\ \mathrm{min} \wedge (\mathrm{t_3} - \mathrm{t_1}) \leq (90\ \mathrm{min} - \mathrm{T_{testB}}). \tag{29}$$

A statement as to whether a service outage or significant discrepancies occurred during the measurement process as indicators of the fact that the performance of the internet access service does not achieve the agreed value of the normally available speed will be an integral part of the Measurement Protocol, including the indication of the resulting values of TCP metrics for individual results of TCP throughput measurements, for the sake of a better understanding of what has led to the decrease, if any, in the performance of the internet access service. In order to determine the resulting value of the internet access service, Delay, or its average value $\mathrm{Delay(avg)}$, which is part of a set of basic data parameters, it is necessary to specify for each result of the TCP throughput measurement the value of parameter $\mathrm{Delay(baseline)}$, which corresponds to the smallest measured value of the delay not burdened by the established TCP session and the value of the TCP metric, Buffer delay (BD), which represents the relationship between the increase in the average value of the delay, $\mathrm{Delay(avg)}$, during the measurement process and the default value of $\mathrm{Delay(baseline)}$. Another key TCP metric that should be part of the result of any TCP throughput measurement is TCP efficiency ($\mathrm{TCP\ EFF}$) representing the percentage of successfully transmitted bits without the need for retransmission. This metric provides a picture of the error rate of the entire TCP session.

In the final evaluation, it is recommended to take into account the measurement results from the operations before the start of the measurement process itself, i.e. the basic verification of the state, for example using available test tools (complying with the methodology of BEREC BoR (17) 178 within an installed server within MSEK), which may indicate the expected values, and the results of the *tracert* (*traceroute*) command with entering the IP address of the MS in the form of path diagnostics via individual demarcation points to the MSEK. This information may be used in other procedures, if appropriate, in the exercise of the Office's powers and responsibilities in the sense of checking the data parameters of the internet access service, for example with regard to the disclosure of information on the capacity of parts of the network.

In a situation where in exceptional cases, e.g. for measuring data parameters of dedicated lines, MPLS, or if necessary to measure at demarcation points DeP <6, or also in case of situation when the NUT state does not allow using measurement method according to IETF recommendation RFC 6349 (high frame loss ratio and high inter-frame (packet) delay variation), it is necessary to use alternatively a measurement method (testA) defined by ITU-T Y.1564, i.e. to perform measurements of qualitative data parameters belonging to the set of advanced data parameters defined in this document, the evaluation in the case of internet access service is performed on the basis of the results of the actual bandwidth or, more precisely, information rate IR corresponding to the link layer of the ISO/OSI model in the uplink and downlink direction. If the result of the configuration test with the input parameter $\mathrm{CIR} + \mathrm{EIR}$ in the form of a contractually defined maximum speed value ($\mathrm{R}_{\mathrm{max}}$) converted to the value corresponding to the physical layer of data download or upload of the internet access service at a fixed or semi-fixed location is less than the contractually defined value of a normally available speed, it is evident that its value cannot be achievable due to the principle of physical behaviour of the TCP protocol and the state of NUT causes the occurrence of significant discrepancies of service performance, or service outage. It is also necessary to take into account the impact of the value of frame (packet) loss ratio measured with the input parameter CIR corresponding to normally available speed. If its value is higher than 3%, it is evident that the internet access service manifests significant discrepancies of performance, which are caused either by insufficient NUT capacity or the application of traffic management measures.

2. Measurement of the fixed or semi-fixed electronic communication network for the purpose of inspection the data parameters belonging to the set advanced data parameters

Annex 2, version 2.1, valid from 1. March 2021, is intended for measurement of data parameters in normal network traffic which belong to the set of advanced data parameters. The measurement according to annex 2 is intended for the exercise of the Office's powers and responsibilities in the sense of checking the data parameters of the internet access service, it is applicable for the purpose of checking the data parameters of newly deployed and existing NGA networks, or, as the case may be, to meet the Office's need to assess the condition of existing fixed or semi-fixed networks in terms of the achieved qualitative data parameters, or their comprehensive condition with respect to the end user.

2.1. Description of the measurement scenario

The measurement scenario corresponds to the measurement process that is specified in the measurement procedure. The specified measurement scenario is defined by the Office for measuring data parameters of fixed or semi-fixed electronic communications networks belonging to the set of advanced data parameters for the purpose of inspection them. The measurement scenario and selected set of advanced data parameters are related in particular to the following documents: Determination of the basic parameters and measurement of the quality of the internet access service and Statement of the Czech Telecommunication Office on selected issues of access to open internet and European net neutrality rules, and is also related to General Authorisation No. VO-S/1/08.2020-9 laying down conditions for the provision of electronic communications services. The measurement scenario is also in accordance with the BEREC Guidelines BoR (20) 112: *Implementation of the Open Internet Regulation* including the technical specification MEF 23.2: *Carrier Ethernet Class of Service*.

2.2. Selection of the measurement method

For the purpose of performing measurements according to the specified measurement scenario, the measurement method chosen is based on the measurement guideline based on IETF recommendation RFC 6349 and the ITU-T Y.1564 standard. In defining the advanced set of data parameters, the Office relied primarily on the basic set of data parameters with regard to the text of the Regulation and the related Statement of the Czech Telecommunication Office on selected issues of access to open internet and European net neutrality rules and General Authorisation 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 the internet access service according to Article 4(1)(d) of the Regulation, in the range from the point of handover of the service to the end user (DeP 7 or DeP 6, as the case may be) up to the point of access of MSEK to Internet exchange NIX.CZ (DeP 1). The basic set of data parameters is thus expanded by the addition of qualitative data parameters, namely information rate (uplink; $\mathrm{IR}_{\mathrm{up}}$) and information rate (downlink; $\mathrm{IR}_{\mathrm{down}}$), which characterize the available bandwidth at the measuring point for both directions of data communication, frame delay (FTD), inter-frame delay variation (IFDV) and frame loss ratio (FLR), whereas the determination of the values of qualitative data parameters is based on the ITU-T Y.1564 standard.

The chosen measuring method will be applied not only in the case of verification measurements of compliance with the defined speeds, in terms of verifying the occurrence of service outages and significant discrepancies as indicators of the fact that the performance of the internet access service does not achieve the agreed parameters, but also in terms of verifying the real achievability of the defined maximum speed or, more precisely, whether the bandwidth at the termination point (device) corresponds to a defined maximum speed, which can be applied in the case of checking the achievement of qualitative data parameters in comparison with the technical specification MEF 23.2 of the Performance Tier 2 (Regional) category for the purpose of inspection the parameters of newly deployed and existing NGA networks, or, as the case may be, to meet the Office’s need to assess the condition of existing fixed or semi-fixed networks in terms of the achieved qualitative data parameters, or their comprehensive condition with respect to the end user. The measurement method defines performance of measurement on the transport layer of the ISO/OSI model (L 4) by means of the TCP protocol for the set of basic data parameters and measurement on the link layer of the ISO/OSI model (L 2), while simultaneously using the UDP protocol on the transport layer for the measurement of the complementary qualitative data parameters within the set of advanced data parameters (testC). An integral part of the measuring method used are the recommended steps before starting the measuring process.

2.3. Measurement sequence

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, i.e. at least one measurement at the peak hour and at least one measurement during an off-peak hour. With regard to the end user and due to the time-consuming process of measuring TCP throughput which is, in addition, extended by the process of measuring qualitative data parameters, it is permissible to perform all three main measurements at peak hour, or to perform measurements with respect to the definition of time availability (time dimension) of normally available speed (network under load). In the case of newly deployed fixed or semi-fixed electronic communications networks (fixed networks without load), it is possible to perform all three main measurements also during off-peak hour. One measurement should not exceed a timeframe of 30 minutes during which a sequence of three basic tests (“testB”) based on IETF recommendation RFC 6349 and one complementary test (“testC”) based on ITU-T Y.1564 will take place.

If the measuring tool does not make it possible to set the order of the sequence of tests as recommended, it is possible to change the order without breaching the integrity of the measurement. In the same way, it is possible to omit the bidirectional test of TCP throughput (step 5) or the sequence of breaks between individual tests (steps 2, 4, 6 and 8). The minimum admissible form of the process of measurement of the advanced set of data parameters must consist of a one-way upload test (step 1), one-way download test (step 3) of TCP throughput, and a bidirectional test of qualitative data parameters according to standard ITU-T Y.1564 (uplink + downlink; step 7). The possible combinations of the implementation of the minimum admissible form of the process of measurement depend mainly on the measuring tools applied. Using the so-called “loopback” test during the measurement is not recommended, not even in the case of symmetrical NUTs.

2.4. Demarcation points

The first demarcation point will be the access of the MSEK to the internet via internet exchange NIX.CZ in accordance with section 4 of the methodology specifying the demarcation points of the measurement, see DeP 1 on Figure 5 (alternatively, access by means of transit connectivity). The second demarcation point can be imagined in the form of an interface/port of the network node (a specific port of an active element) or, as the case may be, at a near location in the range which does not exceed the distance of the respective adjacent demarcation point according to the contract terms where a measurement by means of the measuring device (terminal) will take place. Within the measurement according to annex 2, DeP 7 is assumed as the second demarcation point, see Fig. 5, i.e. the demarcation point in the form of an interface/port between the Internet access service provider and the end user or, more precisely, at the network termination point (device). With respect to the diversity of technologies of the access networks and their structure, the second demarcation point can occasionally be also DeP 6, for example in a situation where the concentration point AP is implemented in the form of a router or network switch.

2.5. Setup of the measuring terminal and start of the measurement process

After determining the measuring method, measuring sequence and the demarcation point, the measuring device (terminal) is physically connected to the terminal equipment device at the termination point of the network (DeP 7), or to the handover interface/port (DeP 6). In the case of a terminal equipment device, actions are taken to prevent parallel (cross) data communication, i.e. deactivation of IEEE 802.11 standard interfaces and physical prevention of the use of other IEEE 802.3 compliant terminal interfaces (physical ports). Correct connection will subsequently be verified by means of the measuring device (terminal) where it is subsequently necessary to select and set the parameters of the measuring interface. In addition, it is necessary to set other parameters of the higher network layers, if necessary, e.g. $\mathrm{MAC\,SRC}$, $802.1\mathrm{Q}\,(802.1\mathrm{ad})$, IP address of the measuring device (terminal), if it does not receive it through the DHCP server, and the number of the TCP port of the measuring tool on the measuring device (terminal) and the measuring server, unless it is pre-set. Subsequently, the recommended steps are performed before starting the measurement process, specified in the measurement procedure.

In the next stage, it is necessary to set the input parameters of the measuring tool on the side of the measuring device (terminal). The input parameters of the measuring tool or, more precisely, the measurement sequence, must be based on the defined parameters presented by the electronic communications service providers in their offers of the internet access service with regard to the Article 4(1)(d) of the Regulation and the related Statement of the Czech Telecommunication Office on selected issues relating to open internet access and European net neutrality rules and General Authorisation 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 the internet access service. The input parameters must be set according to the measuring tool applied, in the case of IETF recommendation RFC 6349 in accordance with section 1.6.1. defining the input parameters of the sequence of measurement, where, however, it is necessary to pay attention on which layer of the ISO/OSI model and under which name the input parameter BB is set in the measuring tool. In this case, the formula (23) must apply. In the case of a measuring tool conforming to the ITU.T Y.1564 standard, the input parameters are to be set in accordance with section 2.1.1. In this case, the formulas (26) and (27) must apply. Another key parameter is MTU. It is recommended to identify the value of MTU of the NUT measured, if not known, using the available test tools, for example Wireshark, a packet capturing program, or a tool functioning according to IETF recommendation RFC 4821: *Packetization Layer Path MTU Discovery*. The result of the process of determining the value MTU is a part of another input parameter of the measuring tool (ITU.T Y.1564 standard) or, more precisely, Ethernet frame size FS according to the formula (28).

Based on the settings of the input parameters of the measuring tools, including the interval of the measurement sequence, it is possible to perform the test according to the chosen steps, preferably in the recommended order, the result of which is the measured values of the set of extended data parameters. The results of the individual tests of the testC category will be subsequently saved in the form of reports allowing for subsequent machine processing (HTML, CSV, etc.) into the final form of the Measurement Protocol.

2.6. Evaluation of the measurement process result

When evaluating the results of the testB category measurement process according to annex 2, the Office will monitor compliance with the defined speeds, in terms of service outages and significant discrepancies of performance of internet access service from the normally available speed (BDR). In the case of minimum speed ($\mathrm{R_{min}}$), it is the lowest guaranteed speed for download and upload which the relevant provider of the internet access service has undertaken in the contract to provide to the end user. If the actually achieved speed (TCP throughput) falls below this value, even in one single case (test), such a condition shall be considered a service outage. The following should therefore apply to the download or upload speeds:

$$\mathrm{TCP\ aTR} \geq \mathrm{R_{min}};\ [\mathrm{b/s;b/s}], \tag{27}$$

otherwise an outage of the internet access service has occurred. In its document entitled Statement of the Czech Telecommunication Office on selected issues of access to open internet and European net neutrality rules and also in General Authorisation No. VO-S/1/08.2020-9, the Office defines a significant and continuous or regularly recurring discrepancy of the actual performance of Internet access service. Both defined discrepancies are derived from the value of the normally available speed which is two-dimensional; the first dimension is defined in the form of the level of TCP throughput in the download and upload direction and the second dimension is defined in the form of the time availability of this level for the period of one calendar day.

Significant continuous discrepancy from the normally available speed for download or upload shall be a discrepancy that causes a continuous decrease in the performance of the internet access service, i.e. a decrease in the actual achieved speed by measuring the specified TCP throughput below a defined value of normally available speed, in an interval longer than 70 minutes, during the measurement process performed by the Office in the time period of 90 minutes. It is therefore possible to write that the following applies to the significant continuous discrepancy:

$$\mathrm{T_{BDR}} > 70\ \mathrm{min}, \tag{28}$$

where $\mathrm{T_{BDR}}$ refers to the length of the interval of exceeding the value of the normally available speed corresponding to the start time of the measuring process, when the resulting value of the actual transmission speed is lower than the defined value of the normally available speed. With respect to the measurement process itself and its individual steps, the Office will consider the situation where the condition will hold for all results of the tests of testB category for download or upload to be an occurrence of a significant continuous discrepancy $\mathrm{TCP\ aTR} < \mathrm{BDR}$.

Regularly recurring discrepancy from the normally available speed for download or upload shall be a discrepancy at which there are at least three decreases of the actually achieved speed corresponding to the measurement of the determined TCP throughput below the defined value of the normally available speed in an interval longer than or equal to 3.5 minutes in a time period of 90 minutes during the measuring process performed by the Office. If, therefore we mark the time of launching the test during which the limit of normally available speed was exceeded as $\mathrm{t_x}$, where $\mathrm{x} \in \mathbb{N}^{+}$, and we also use the determined length of the interval of the test $\mathrm{T_{testB}}$, it will be possible to state that the following applies to the significant regularly recurring discrepancy:

$$\exists\ t_1, t_2, t_3 \colon T_{BDR} > 3{,}5\ min \land (t_3 - t_1) \leq (90\ min - T_{testB}). \quad (29)$$

A statement as to whether a service outage or significant discrepancies occurred during the measurement process as indicators of the fact that the performance of the internet access service does not achieve the agreed value of the normally available speed will be an integral part of the Measurement Protocol, including the indication of the resulting values of TCP metrics for individual results of TCP throughput measurements, for the sake of a better understanding of what has led to the decrease, if any, in the performance of the internet access service. In order to determine the resulting value of the internet access service Delay, or its average value $\mathrm{Delay(avg)}$, which is part of a set of basic data parameters, it is necessary to specify for each result of the TCP throughput measurement the value of parameter $\mathrm{Delay(baseline)}$, which corresponds to the smallest measured value of the delay not burdened by the established TCP session and the value of the TCP metric, Buffer delay (BD), which represents the relationship between the increase in the average value of the delay, $\mathrm{Delay(avg)}$, during the measurement process and the default value of $\mathrm{Delay(baseline)}$. Another key TCP metric that should be part of the result of any TCP throughput measurement is TCP efficiency ($\mathrm{TCP\ EFF}$) representing the percentage of successfully transmitted bits without the need for retransmission. This metric provides a picture of the error rate of the entire TCP session.

When evaluating the results of the measurement process according to annex 2, part of the testC category, it is also necessary to assess the measured qualitative data parameters belonging to the set of advanced data parameters of fixed electronic communications networks, in the case of verifying the real achievability of the defined maximum speed or, more precisely, whether the bandwidth at the termination point (device) corresponds to a defined maximum speed, which can be applied in the case of checking the achievement of qualitative data parameters in comparison with the technical specification MEF 2 of the Performance Tier 23.2 (Regional) category for the purpose of checking the parameters of newly deployed and existing NGA networks, or, as the case may be, to meet the Office’s need to assess the condition of existing fixed or semi-fixed networks in terms of the achieved qualitative data parameters, or their comprehensive condition with respect to the end user.

Maximum speed is defined in General Authorisation No. VO-S/1/08.2020-9 laying down conditions for the provision of electronic communications services, as the speed corresponding to download and upload, which must be determined realistically with regard to the technology used and its transmission capabilities and with regard to the specific conditions of deployment, which are limiting for the download and upload direction. The maximum speed must be realistically achievable at the connection line or at the connection point in question with a possible variation caused demonstrably only by the physical properties of the network termination point. Information on possible variation and its physical causes must be stated in the subscriber contract. Verification of the realistic achievability of a defined maximum speed shall be performed by measuring the actual bandwidth, whereas, with regard to the characteristics of the interface of terminal equipment devices compliant with IEEE 802.3u (NBR = 100 Mbit/s), or IEEE 802.3ab (NBR = 1000 Mbit/s), a tolerance in the form of 95% of the defined value of the maximum speed (L 2) is introduced due to the elimination of overhead costs of each layer of the ISO/OSI model:

$$R_{max}(L\ 4) \rightarrow\ R_{max}(L\ 2) \geq 95\ \%\ IR_{CIR+EIR}, \quad (30)$$

where $IR_{CIR+EIR}$ is the resulting value of the information rate in the case of a configuration test under an input condition $\mathrm{CIR} + \mathrm{EIR} = R_{max}$, wherein the result in the data upload direction is referred to as the uplink and in the data download direction as the downlink. In the case of termination points that demonstrably show bandwidth variation $\mathrm{D(X)}$ due to physical phenomena, the tolerated level of actual bandwidth derived as a percentage from the defined maximum speed can be determined based on statistical theory. Since the result of all acting physical properties at the termination point with an impact on the final value of the maximum speed can theoretically take any value from a certain interval, it is possible to refer to the maximum speed generally as a random variable with a continuous distribution. Such a random variable is subsequently described by a probability function which assigns to each possible real value x the probability that a random variable X, i.e. maximum speed, will take the value $p(x) = P(X = x)$, whereas this probability function is characterized by a probability density $f(x)$. An important factor for determining the tolerance is the inversely proportional dependence of the maximum values of the probability density of the normal distribution f(x) on the value of the maximum speed (L 2), or on the mean value E(x) = μ, where the inverse proportionality constant corresponds to k = 2.5563, with an accuracy corresponding to the method of least squares R^2 = 100%. This finding can be used to simplify the calculation of the value of variation D (x), or standard deviation σ:

$$f(x=\mu) = \frac{1}{\sqrt{2\pi}\sigma} = \frac{2{,}5563}{R_{max}(L\,2)} \Rightarrow \frac{R_{max}(L\,2)}{\sqrt{2\pi}\sigma} = 2{,}5563 \Rightarrow \frac{R_{max}(L\,2)}{2{,}5563} = \sqrt{2\pi}\sigma \Rightarrow$$

$$\sigma = \frac{R_{max}(L\,2)}{2{,}5563\sqrt{2\pi}} \doteq \frac{R_{max}(L\,2)}{6{,}408}. \tag{31}$$

The resulting percentage of the value of the ratio of the tolerated value of the measured information rate $IR_{CIR+EIR}$ (actual bandwidth) and maximum speed (L 2) corresponding to the tolerated level μ–σ can be derived from a simplified expression of the standard deviation σ:

$$\frac{IR_{CIR+EIR}}{R_{max}(L\,2)} = \frac{\mu-\sigma}{\mu} \Rightarrow \frac{R_{max}(L\,2) - \frac{R_{max}(L\,2)}{6{,}408}}{R_{max}(L\,2)} = \frac{R_{max}(L\,2)}{R_{max}(L\,2)} - \frac{R_{max}(L\,2)}{6{,}408 \cdot R_{max}(L\,2)} =$$

$$= 1 - \frac{1}{6{,}408} = 84{,}39\ \% \doteq 84\ \%. \tag{32}$$

When verifying the realistic achievability of a defined maximum speed which shows a variance caused demonstrably only by the physical properties of the termination point in question, while the information on possible variance and its physical causes must be specified in the subscriber contract, it is possible to use the tolerated value of actual bandwidth equal to 84% of the contractually defined maximum speed.

The process of measurement according to annex 2 is applicable also for the purpose of verification of the data parameters of NGA networks, or, as the case may be, fulfilment of the Office's need to assess the existing fixed networks in terms of the qualitative data parameters achieved. Due to the location of the measuring server as a part of MSEK with internet access through the Internet exchange NIX.CZ or by means of transit connectivity (see DeP 1 on Figure 5), and due to the area of the Czech Republic, the Office has decided to recommend using for the evaluation of the results of the process of measurement of qualitative data parameters the values provided in the technical specification MEF 23.2, Performance Tier 2 (Regional), corresponding to distances of less than 1200 km, whereas the values of the specific CoS in the form of usable quality classes are provided in table No. 1, table No. 2 and table No. 3.

Table No. 1: Category of Performance Tier 2 (Regional), class CoS High according to MEF 23.2

Qualitative data parameter	Required value
FD – frame delay[1]	≤ 25 ms
IFDV – inter-frame delay variation	≤ 8 ms
FLR – frame loss ratio	≤ 0,01 %

[1] Frame delay FD is defined in the technical specification MEF 23.2 as a resulting value of a measurement of the "end-to-end" type. In the case of the measuring process of the Office according to annex 2, the double value thereof, or the FD (RTT) will be monitored.

Table No. 2: Category of Performance Tier 2 (Regional) class CoS Medium according to MEF 23.2

Qualitative data parameter	Required value
FD – frame delay	≤ 75 ms
IFDV – inter-frame delay variation	≤ 40 ms
FLR – frame loss ratio	$\leq 0{,}01$ %

Table No. 3: Category of Performance Tier 2 (Regional) class CoS Low according to MEF 23.2

Qualitative data parameter	Required value
FD – frame delay	≤ 125 ms
IFDV – inter-frame delay variation	N/S
FLR – frame loss ratio	$\leq 0{,}1$ %

Tables No. 1, No. 2 and No. 3 will be used by the Office for its internal purposes of classification of networks according to the reported values of their qualitative data parameters. The statement, whether the set criteria of the category of Performance Tier 2 (Regional) of selected classes CoS according to MEF 23.2 were fulfilled during the measuring process will be an integral part of the Measurement Protocol.

In the final evaluation, it is recommended to take into account also the measurement results from the operations before the start of the measurement process itself, i.e. the basic verification of the state, for example using available test tools (complying with the methodology of BEREC BoR (17) 178 with an installed server within MSEK), which may indicate the expected values, and the results of the *tracert* (*traceroute*) command with entering the IP address of the MS in the form of diagnostics of the path via individual demarcation points to the MSEK, if allowed by the active elements of the NUT. This information may be used in other procedures, if appropriate, in the exercise of the Office's powers and responsibilities in the sense of inspection the data parameters of the internet access service, for example with regard to the disclosure of information on the capacity of parts of the network.