



Fifth Generation Fixed Network (F5G); F5G Measurement Specification for Residential Services Quality Evaluation

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Reference

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Foreword

This Group Specification (GS) has been produced by ETSI Industry Specification Group (ISG) Fifth Generation Fixed Network (F5G).

Modal verbs terminology

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1 Scope

The present document specifies the measurement methodologies to evaluate the quality of residential network services and network characteristics/functionalities based on the service and network KQIs defined in document ETSI GS F5G 015 [1]. The measurement methodologies include measurement setup, measurement procedure, and measurement recording.

2 References

2.1 Normative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

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The following referenced documents are necessary for the application of the present document.

- [1] [ETSI GS F5G 015](#): "Fifth Generation Fixed Network (F5G); F5G Residential Services Quality Evaluation and Classification Release 2".
- [2] [BBF TR-126](#): "Triple-play Services Quality of Experience (QoE) Requirements".
- [3] [Recommendation ITU-T G.9976](#): "Supporting ultra-high-definition video service over G.hn".
- [4] [BBF TR-398 Issue: 2 Corrigendum 1](#): "Wi-Fi Residential & SOHO Performance Testing".
- [5] [Recommendation ITU-T X.509](#): "Information technology - Open Systems Interconnection - The Directory: Public-key and attribute certificate frameworks".
- [6] [IETF RFC 2544](#): "Benchmarking Methodology for Network Interconnect Devices".
- [7] [Recommendation ITU-T P.863](#): "Perceptual objective listening quality assessment".
- [8] [IETF RFC 791](#): "Internet protocol".
- [9] [Recommendation ITU-T G.107](#): "The E-model: a computational model for use in transmission planning".
- [10] [IETF RFC 793](#): "Transmission Control Protocol".
- [11] [IEEE 802.11kTM-2008](#): "IEEE Standard for Information technology -- Local and metropolitan area networks -- Specific requirements -- Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 1: Radio Resource Measurement of Wireless LANs".
- [12] [IEEE 802.11vTM-2011](#): "IEEE Standard for Information technology -- Local and metropolitan area networks -- Specific requirements -- Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications Amendment 8: IEEE 802.11 Wireless Network Management".
- [13] [IEEE 802.11acTM-2013](#): "IEEE Standard for Information technology -- Telecommunications and information exchange between systems-Local and metropolitan area networks -- Specific requirements -- Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications -- Amendment 4: Enhancements for Very High Throughput for Operation in Bands below 6 GHz".

- [14] [IEEE 802.11ax™-2021](#): "IEEE Standard for Information Technology -- Telecommunications and Information Exchange between Systems Local and Metropolitan Area Networks -- Specific Requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 1: Enhancements for High-Efficiency WLAN".

2.2 Informative references

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The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

- [i.1] Wikipedia: "[Cumulative distribution function](#)".
- [i.2] [BBF TR-309 \(Issue 2 Amendment 1\)](#): "XG-PON and XGS-PON TC Layer Interoperability Test Plan".
- [i.3] [ETSI TS 102 165-2](#): "Telecommunications and Internet converged Services and Protocols for Advanced Networking (TISPAN); Methods and protocols; Part 2: Protocol Framework Definition; Security Counter Measures".
- [i.4] [ETSI TR 103 733](#): "Speech and multimedia Transmission Quality (STQ); Best practices of testing the performance of web content delivery".
- [i.5] [ETSI TS 102 250-2](#): "Speech and multimedia Transmission Quality (STQ); QoS aspects for popular services in mobile networks; Part 2: Definition of Quality of Service parameters and their computation".
- [i.6] [ETSI TS 102 250-4](#): "Speech and multimedia Transmission Quality (STQ); QoS aspects for popular services in mobile networks; Part 4: Requirements for Quality of Service measurement equipment".
- [i.7] [ETSI TR 101 578](#): "Speech and multimedia Transmission Quality (STQ); QoS aspects of TCP-based video services like YouTube™".
- [i.8] [ETSI GS F5G 014](#): "Fifth Generation Fixed Network (F5G); F5G Network Architecture Release 2".

3 Definition of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the following terms apply:

CDF99: value indicating less than or equal to 99 percentage probability of all outcomes

firmware analysis tool: software tool for firmware analysis

NOTE: For firmware security analysis, the encryption status of the binary source code is examined.

render start: time when the browser starts rendering, which is an approximation of the user's perception when the user sees the first content on the screen

security scanning tool: software tool to perform network discovery and security auditing which scans the target host's port and service information

telework: practice of working from home, making use of residential internet, email, telephone, etc.

3.2 Symbols

Void.

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

AC	Alternating Current
ACK	Acknowledge
AES	Advanced Encryption Standard
AP	Access Point
APBEA	Average Percentage of the black Edge Area
APFF	Average Percentage of Frame Freezing
APP	Application
APTQIA	Average Percentage of The low-Quality Image Area
BNG	Broadband Network Gateway
BRAS	Broadband Remote Access Server
CDF99	99 % of Cumulated Distribution Function
CDN	Content Delivery Network
CP	Content Provider
CPU	Central Processing Unit
CSMA	Carrier Sense Multiple Access
dBm	dB relative to 1 milliwatt
DC	Direct Current
DDoS	Distributed Denial of Service
DHCP	Dynamic Host Configuration Protocol
DNS	Domain Name Server
DoS	Denial of Service
DRR	Download Rate Ratio
DTR	Desynchronization Time Ratio
E2E	End to End
E-ONU	Edge-ONU
FFT	Frame Freezing Times
FFTR	Frame Freezing Time Ratio
FLT	Full Load Time
FSDT	First Screen Display Time
FSPL	Free Space Path Loss
FTTR	Fibre-To-The-Room
GB	Gigabyte
GHz	Giga Hertz
HTML	Hypertext Markup Language
HTTP	Hypertext Transfer Protocol
IBD	Initial Buffering Duration
ICMP	Internet Control Message Protocol
ID	Identifier
IGMP	Internet Group Management Protocol
IP	Internet Protocol
IPTV	Internet Protocol Television
KQI	Key Quality Indicator
LAN	Local Area Network
MAC	Medium Access Control
MOS	Mean Opinion Score
MTU	Maximum Transmission Unit
NBI	North Bound Interface
NIC	Network Interface Card
NST	Network Start-up Time
O&M	Operation & Management

OLT	Optical Line Termination
ONU	Optical Network Unit
ORD	Operation Response Delay
OTT	Over The Top
PBED	Percentage of the Black Edge Duration
PC	Personal Computer
PID	Protocol Identifier
PING	Packet Internet Groper
PLQID	Percentage of Low-Quality Image Duration
POLQA	Perceptual Objective Listening Quality Analysis
PON	Passive Optical Network
P-ONU	Primary ONU
POTS	Plain Old Telephone Service
PRT	Page Response Time
QoE	Quality of Experience
RFC	Request for Comments
RSSI	Received Signal Strength Indication
RTP	Real-time Transport Protocol
RTT	Round Trip Time
SLA	Service Level Agreement
SP	Service Provider
SSID	Service Set Identifier
STB	Set-Top Box
SYN	Synchronization
TCP	Transmission Control Protocol
TV	Television
UDP	User Datagram Protocol
URR	Upload Rate Ratio
VLAN	Virtual Local Area Network
VOD	Video On Demand
VR	Virtual Reality
WAN	Wide Area Network
WPA2	Wi-Fi® Protected Access 2
xPON	(x = G, XG, XGS) PON

4 Introduction

4.1 Overview

ETSI GS F5G 015 [1] specifies the service KQIs, experience evaluation methodology with MOS value, and corresponding network KQIs. The overview of the service KQIs and network KQIs is shown in Figure 1.

The services specified in ETSI GS F5G 015 [1] include voice, web browsing, data upload/download, IPTV, terminal-based rendered game, cloud-based rendered game, internet video, on-line Education/Telework, cloud VR video, cloud VR game.

The network KQI contains six dimensions, which are: throughput, latency, connectivity, handover, green & security and smart O&M.

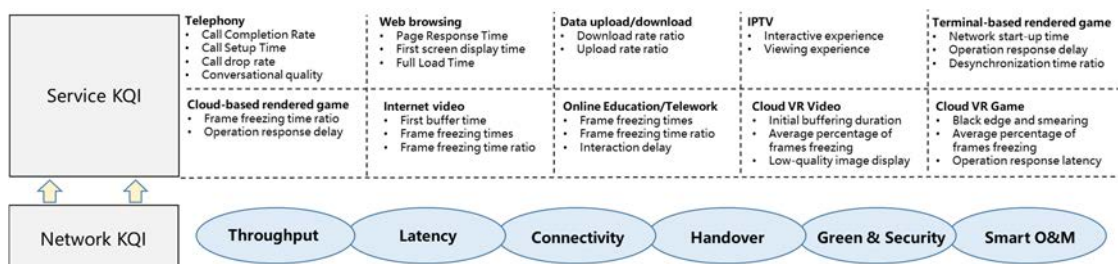


Figure 1: Overview of service KQIs and network KQIs

The detailed service KQIs are listed below each service, as shown in Figure 1. For example, the KQIs of Telephony service include: call completion rate, call setup time, call drop rate and conversational quality.

In general, the service KQIs quantify the user experience from different aspects while the network KQIs reflect the network capabilities (shown in Figure 1) and can significantly influence the service KQIs.

Figure 2 shows the general E2E measurement setup for service KQI.

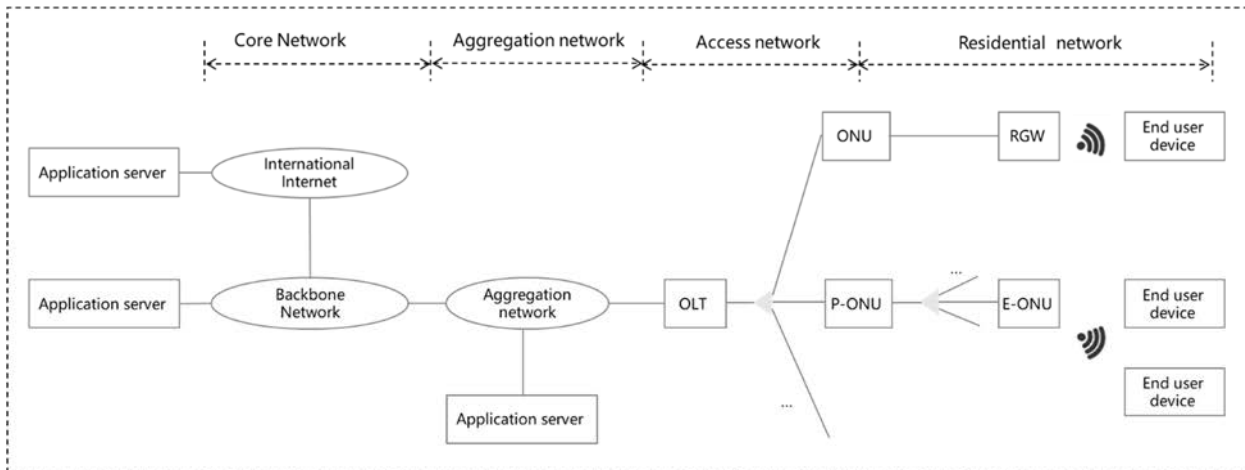


Figure 2: E2E measurement setup for service KQIs

The E2E network is composed of the following network segments:

- 1) Residential network: from the end user device to the access network terminal.

NOTE: The residential network is grouped under the general term Customer Premises Network in ETSI GS F5G 014 [i.8]. The type of access network terminal depends on the residential network. In a FTTR network, the P-ONU is the access network terminal. In another case, an ONU can be the termination of the access network.

- 2) Access network: from the access network terminal to the access network central office. In F5G, the access network is PON, and the central office equipment is an OLT.
- 3) Aggregation network: from central office of access network to the aggregation network egressing port (Aggregation edge node).
- 4) Core network: from the Aggregation Edge network node egress port to the server.

4.2 Measurement methodologies

4.2.1 Measurement methodology for the service KQIs

The measurement of the service KQIs shall be performed in one of two ways using the following methodologies:

- Methodology 1: Embed measurement code in the end user device for broadband services. When the broadband services are subscribed to by the end user, the end user device automatically runs the dedicated measurement suit and report the measurement result to the server of the service provider. This methodology is suitable for the CP/SP (content/service provider) to collect measurement data.
- Methodology 2: The user proactively initiates the measurement for a dedicated service through the end user device (including mobile phone, PC, IPTV set-top box, helmets). The measurement procedure can be performed by measurement software installed on the end user device. This methodology is suitable for broadband users, which enables the service operator to evaluate the user experience.

NOTE: The measurement software could be a mobile App.

The chosen method shall be recorded in the report (see Annex A).

4.2.2 Measurement methodology for the network KQIs

4.2.2.1 Measurement methodology of the detailed network evaluation

Detailed network evaluation is a comprehensive approach to quantify the residential network capabilities for the different classification levels for the residential services. The measurement shall leverage professional test equipment or measurement software to perform the detailed network evaluation. These measurements are performed either by third-party testing institutions or the network providers.

NOTE: These measurements should be performed by professional network testing personnel.

4.2.2.2 Measurement methodology of the basic network evaluation

Basic network evaluation is an E2E measurement and shall be performed using one of the following methodologies:

- Methodology 1: The user initiates the measurement using an application installed on the end user device to collect the network KQIs.
- Methodology 2: The network monitoring platform collects the network KQIs. The result can be used for performance monitoring or diagnostics of the residential network.

The chosen method shall be recorded in the report (see Annex A).

5 Measurement methodology of service KQIs

5.1 Measurement requirements

5.1.1 Requirements of the end user device

The performance of the end user device may impact the measurement and evaluation of the user experience. The measurement shall be performed according to dedicated hardware requirements. If a laptop is used the hardware requirement shall comply with the requirement specified in reference [2]. If a mobile phone is used the hardware requirements shall be as follows:

- Number of CPU core: at least 8.
- CPU frequency: $\geq 1,7$ GHz.
- Mobile phone memory: ≥ 8 GB.
- The end user device supports at least Wi-Fi® 6.

NOTE: If the available Wi-Fi® generation does not match between the end user device and the access point, then the measurement can use a previous Wi-Fi® generation. This will be recorded in the report (see Annex A).

5.1.2 Additional Measurement requirements

Measurement time period requirement: the measurement shall be conducted during network peak time.

Measurement location requirement: the measurement should be conducted in the location where the end user frequently utilizes the network. This is a requirement for basic network evaluation when the end user performs the measurement.

5.1.3 Data record requirements

The evaluation of the user experience over a dedicated E2E network may be affected by the E2E network components, including the end user device, the network segments, and the servers involved. Specifically, differences in the device capability used shall be avoided in the measurement mentioned in the present document, to eliminate inconsistencies in the measurements. It is mandatory to record the measurement environment, equipment used and any conditions that influence the user experience as part of the test procedure. For the detailed format of the record, see Annex A.

Every time the end user device initiates a service request, the end user device or server shall record the following information:

- 1) User account/MAC address. It is required that the end user's personal information is protected.
- 2) Network connection interface (Wi-Fi®, Ethernet).
- 3) Wi-Fi® generation (Wi-Fi®5, Wi-Fi®6, Wi-Fi®7), frequency band in uses (2,4 GHz/5 GHz/6 GHz), negotiated transmission rate, received signal power, number and strength of interference sources, number of spatial streams, frequency channel in use.
- 4) F5G broadband network provider.
- 5) User location (accurate to the city/region). It is required that the end user's personal information is protected guaranteeing end-user privacy.
- 6) Record time (accurate to ms).
- 7) Status of the subscribed broadband network service (success or failure).

The record may include other service relevant information:

- 1) Type of end user device.
- 2) Model number of end user device.
- 3) Operating system and version.
- 4) NIC driver information (including version number) of end user device if a laptop is used.
- 5) The server information of data source.

5.2 Measurement of service KQIs

5.2.1 Telephony

5.2.1.1 Measurement environment

The measurement defined in the present clause focuses on the widely used telephony services based on IP networks. The measurement set up is shown in Figure 3:

- 1) A telephone simulator connects to the access network terminal of the access network through an Ethernet or POTS interface. The digitized voice signals are transmitted from one telephone simulator to another telephone simulator. The telephone simulator is the test equipment used to complete the measurements autonomously (see for example the telephone simulator in ETSI TS 102 250-4 [i.6]).

NOTE 1: When the telephone simulator is connected to the access network terminal via a POTS interface, the analogue signals are digitalized in the access network terminal and encapsulated as packets. The access network terminal is an independent gateway or voice modem.

- 2) The access network terminals connect to the public internet through a Wide Areas Network (WAN) interface.
- 3) The measurement provides the ability to determine the voice quality in an E2E network.

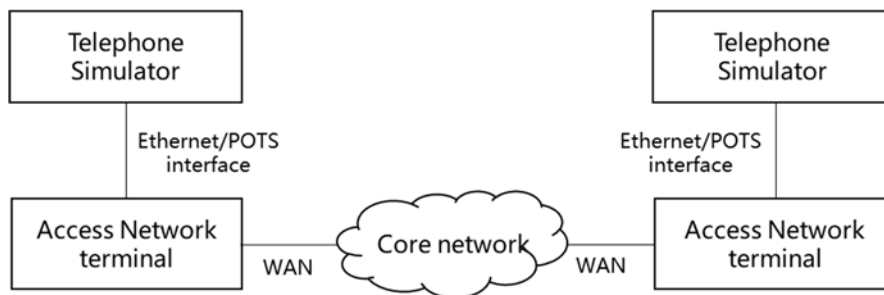


Figure 3: The measurement setup for the Telephony service

NOTE 2: The core network in Figure 3 is simplified containing F5G end-to-end network segments in addition to voice gateways and servers.

5.2.1.2 Measurement suite

5.2.1.2.1 Call completion ratio

For individual call completion measurements, the calling subscriber initiates the call. If the call is received and answered by the called subscriber, then the voice communication link is successfully established. This dedicated call is marked as a complete call establishment.

To obtain an accurate measurement, the measurement shall be performed greater than 30 and less than 60 times in an hour time period. Record the number of call initialization X_1 and number of successfully completed call establishment Y_1 in the report (see Annex A).

5.2.1.2.2 Call setup time

Record time that the calling subscriber dials the last digit of the telephone number as T_1 and record the time that the calling subscriber receives a network response as T_2 . The network response can be a ring tone, busy tone, terminal prompt tone, and recorded message. Other call setup indication can be used. All call setup indications shall be recorded in the report (see Annex A). Determine and record the mean and the maximum value of call setup time.

5.2.1.2.3 Call drop rate

For individual measurement, establish the voice call between the calling subscriber and called subscriber. Maintain the connection for 20 minutes and determine if the call is dropped within this interval. If the call is dropped during this interval, the call is marked as a dropped call. The total measurement is performed by Y_2 times. The number of dropped calls is recorded as X_2 . All call drop measurements shall be recorded in the report (see Annex A).

5.2.1.2.4 Conversational quality

The measurement of conversational quality shall follow the specifications of either the E-model [9] or the POLQA model [7]. The measurement methodology shall be recoded in Annex A.

To obtain an accurate measurement, the measurement shall be conducted greater than 30 and less than 60 times in an hour time period. Then, the mean MOS value shall be calculated.

5.2.1.3 Data processing

The summary of the voice service measurements are listed below:

- Call completion rate = Y_1/X_1 .
- Call setup time = $T_2 - T_1$.
- Call drop rate = X_2/Y_2 .
- Conversational quality: measures the parameters based of the E model or the POLQA model and calculate the MOS value.

Each measurement shall record the measurement result of the KQI and corresponding MOS value of call completion rate, call setup time, call drop rate, and conversational quality. The comprehensive MOS value shall also be calculated.

For the calculation methodology of MOS value, refer to ETSI GS F5G 015 [1].

5.2.2 Web browsing

5.2.2.1 Measurement environment

The following environment shall be setup prior to starting the web browsing measurements and repeating the measurements. The measurement set up is shown in Figure 4:

- Clear the browser cache, cookie, and DNS cache of the end user device to prevent reloading the web content from the cache during the repeated measurement.
- Three of the most popular web services shall be selected to perform the measurements. This ensures that measurements performed by different content providers or in different locations (cities, towns, and countries) are comparable and consistent. The selected data source, network operator, and location shall be recorded in the report (see Annex A).

NOTE: The ranking in terms of popularity of the web services could be obtained through a third party. The web services are not necessarily the same in different locations.

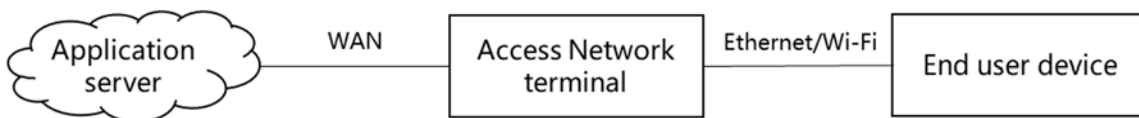


Figure 4: The measurement setup for Web browsing

5.2.2.2 Measurement suite

5.2.2.2.1 Page response time

The measurements of the page response time shall be performed by one of the following methods [i.4]:

- Method 1: The measurement tool records the time when the first DNS request packet is sent as T_1 . Record the time when the browser event Render Start is completed as T_2 . Thus, the page response time is calculated as $T_2 - T_1$. This method is applicable to both desktop and mobile browsers.
- Method 2: The measurement tool records the time when the first DNS request packet is sent as T_1 . Record the time when the browser completes the decapsulation of the HTML file header as T_2 . Thus, the page response time is calculated as $T_2 - T_1$. This method is applicable to both desktop and mobile browsers.
- Method 3: The measurement tool records the time when the first DNS request packet is sent as T_1 . Record the time when the tab of the requested website is displayed in the browser as T_2 . Thus, the page response time is calculated as $T_2 - T_1$. This method is only applicable to desktop browsers.

The chosen method shall be recorded in the report (see Annex A).

If the measurement tool cannot obtain T_2 within 15 seconds, the measurement tool shall terminate the measurement. In this case, record the page response time as 15 seconds, which leads to $MOS_{PRT} = 0$. Record the selected timeout period in the report (see Annex A).

5.2.2.2.2 First screen display time

The measurement tool records the time when the first DNS request packet is sent as T_1 . Record the time when the completed page is shown in the visible window of the browser as T_3 . Thus, first screen display time is calculated as $T_3 - T_1$.

If the measurement tool cannot obtain T_3 within a timeout period of 30 seconds, the measurement tool shall terminate the measurement. In this case, record the first screen display time as 30 seconds, which leads to $MOS_{FSDT} = 0$. Also record the selected timeout period in the report (see Annex A).

5.2.2.2.3 Full load time

The measurement tool records the time when the first DNS request packet is sent as T_1 . If within 1s from the last received HTTP response packet, the browser does not initiate a new HTTP GET request, record the arrival time T_4 of the last received HTTP response packet in the present document (see Annex A). Thus, the full load time is calculated as $T_4 - T_1$. If HTTP response packet has not been received, the measurement is considered a failure, which leads to a $MOS_{FLT} = 0$.

5.2.2.3 Data processing

The summary of the single web page measurements from a specific end user are listed below:

- Page response time = $T_2 - T_1$.
- First screen display time = $T_3 - T_1$.
- Full load time = $T_4 - T_1$.

Each measurement of a dedicated web page shall include the calculated service KQI and MOS value of the page response time, first screen display time, and full load time. The comprehensive service MOS value shall also be calculated. For multiple measurement over several web pages on an end user device, the average value of service KQI and MOS should be used. In addition, the maximum, minimum and average of the comprehensive MOS value measured from multiple measurement reflects the web browsing user experience during the measurement time period.

For the calculation of MOS value, see ETSI GS F5G 015 [1].

5.2.3 Data upload/download

5.2.3.1 Measurement environment

Prior to starting the data upload / download measurements, the background applications on the end user device shall be closed to avoid any background traffic, including downloading tools, OTT video playback applications, social network software for file transfer, and the update or on-line upgrade of the operating system and any other applications.

In the measurement, choose the data server that is operated by the same service operator as the residential broadband network provider. Alternatively, choose the server that is in close proximity to the measurement environment.

Select the speed measurement software that complies with [YD/T 2400-2018] [2] and perform the measurement for upload/download data rate. Record in the present document the speed measurement software and the chosen server (see Annex A). If download or upload fails, the measurement is considered a failure, this leads to a $MOS_{DRR} = 0$ or the $MOS_{URR} = 0$, respectfully.

5.2.3.2 Measurement suite

5.2.3.2.1 Download rate ratio

Once the end user device initiates the measurement request, it shall establish N ($N \geq 8$) TCP connections with the speed measurement server, and shall initiate a download request through the HTTP protocol on each TCP connection. From the receipt of the first download request, the transmitted data between the server and client is measured. The data transmission rate is then calculated. The measurement lasts for 15 seconds and then the server stops sending data. The average download rate R_1 is derived and recorded based on the rate between the 5th and 15th second, a time interval of 10 seconds. The subscribed download rate is recorded as R_2 . Record the number N TCP connections in the report (see Annex A).

5.2.3.2.2 Upload rate ratio

Once the end user device initiates the measurement request, it shall establish N ($N \geq 8$) TCP connections with the speed measurement server, and shall initiate an upload request through the HTTP protocol on each TCP connection. From the receipt of the first upload request, the transmitted data volume between the client and the server is measured. The real-time data transmission rate is then calculated. The measurement lasts for 15 seconds and then the client stops sending data after that. The average upload rate R_3 is derived based on the rate between the 5th and 15th seconds, a time interval of 10 seconds. The subscribed upload rate is recorded as R_4 . Record the number N TCP connections in the report (see Annex A).

5.2.3.3 Data processing

The summary for each upload/download service measurement is listed below:

- Download rate ratio = R_1/R_2 .
- Upload rate ratio = R_3/R_4 .

Each measurement for data upload/download shall include the calculated the service KQI and the MOS value of download rate R_1 subscribed download rate R_2 subscribed upload rate R_4 , and the upload rate R_3 . The comprehensive service MOS value shall also be calculated.

For the calculation of MOS value, see ETSI GS F5G 015 [1].

5.2.4 IPTV

5.2.4.1 Measurement environment

Three of the most popular live TV programs and three of the most popular VOD programs shall be selected as the data source to perform the measurements and the video resolution shall be recorded. This ensures that the measurements performed by different content providers or in different locations (cities, towns, and countries) are comparable and consistent. The measurement shall be performed over a fixed time period. The choice of video programs (i.e. live TV or VOD) and resolution shall be recorded in the report (see Annex A).

NOTE: The ranking in terms of popularity of the video programs could be obtained through a third party. The video programs are not necessarily the same in different locations.

5.2.4.2 Measurement suite

5.2.4.2.1 Interactive experience

- Live TV channel switching delay: after triggering the channel switching, record the time T_1 when the Set-top box (STB) or the end user IPTV viewing device initiates leaving the current IGMP group. Record the time T_2 when the first full video frame of the target TV channel is received. Thus, the switching delay is calculated as $T_2 - T_1$.
- VOD initial loading duration: record the time T_3 when the video displaying device initiates the VOD service request. Record the time T_4 when the first complete video frame is decoded. Thus, the loading duration is calculated as $T_4 - T_3$.

NOTE: Depending on the video encoding, the loading time and the time of the first complete decoded video frame might be different. E.g. the first complete decoded video frame is when the first I-frame in MPEG-2 is received and decoded.

5.2.4.2.2 Viewing experience

The viewing indicators of live TV include blurred screen duration ratio and blurred screen area ratio [1]. The blurred screen duration ratio is reflected by the ratio of the damaged video frames. The blurred screen area ratio is reflected by the average damage degree of damaged video frames. The detailed descriptions are as follows:

- The ratio of the damaged video frames: the number of damaged frames (including packet loss and frames with errors) in the measurement time period over total number of video frames that are received.
- The average damage degree of damaged video frames: average damage proportion of damaged frames. The calculation methodology refers to [YD/T 3779-2020] [3], in which a damaging estimation model is provided for video streaming over IP.

The viewing indicator of the VOD service include freezing duration ratio. The freezing duration is calculated as the time interval between the start and end of the freezing event. In the measurement time period, the ratio is the percentage of the sum of video freezing duration caused by buffer underload to the total video playback duration.

5.2.4.3 Data processing

For live TV, the KQI calculation method is described in clauses 5.2.4.2.1 and 5.2.4.2.2.

A single measurement of live TV shall include the KQI of channel switching delay, blurred screen duration ratio and blurred screen area ratio. The corresponding MOS value of interactive and viewing experience and comprehensive MOS value shall be calculated based on ETSI GS F5G 015 [1]. For multiple measurement of a specific residential user, the average MOS value (average MOS value of channel switching delay, blurred screen duration ratio and blurred screen area ratio, maximum/minimum/average comprehensive MOS value) shall be calculated to reflect experience estimation of live TV.

For the VOD service, the KQI calculation method is described in clauses 5.2.4.2.1 and 5.2.4.2.2.

A single measurement of VOD service shall include the KQI of initial loading duration and freezing duration ratio. The corresponding MOS value for interactive and viewing experience and comprehensive MOS value should be calculated based on ETSI GS F5G 015 [1]. For multiple measurement of a specific residential user, the average MOS value (average MOS value of initial loading duration and freezing duration ratio, maximum/minimum/average comprehensive MOS value) shall be calculated to reflect experience estimation of VOD service.

5.2.5 On-line game

5.2.5.1 Terminal-based rendered game

5.2.5.1.1 Measurement environment

PING test, similar to ETSI TS 102 250-2 [i.5], is used and the result shall be recorded. The measurement software shall be installed in the end user device for the measurement. The present document of the measurement software for this test is out of scope of the present document.

The measurement software shall be able to execute on the various mobile operating systems. The used operating system shall be recorded in the measurement report (see Annex A).

Prior to starting the measurement, all open applications or software packages running shall be closed to avoid any potential impact on the measurement.

Five of the most popular terminal-based rendered games shall be selected for this measurement. The chosen terminal-based rendered game shall be recorded in the report (see Annex A).

5.2.5.1.2 Measurement suite

5.2.5.1.2.1 Network Start-up Time (NST)

The Network Start-up Time (NST) is equal to $20 \times$ Round Trip Time (RTT) as specified in ETSI GS F5G 015 [1]. The measurement software is used to measure the RTT in terms of E2E network latency from the end user device to the game server. The measurements of the RTT shall be performed by one of the following methods:

- Method 1: Perform the PING test from the end user device to the game server every 200 ms. The measurement shall be performed greater than 100 times and the number of times the measurement was performed shall be recorded in the report (see Annex A). Record the average RTT from each PING test. The IP address of the game server can be obtained by capturing UDP/TCP information.
- Method 2: The round-trip time can be obtained by analysing the time of the three-way TCP handshake [10]. The interval between the time sending SYN and receiving SYN ACK in the end user device is an estimation of round-trip delay. At least 10 measurements of the three-way handshake shall be performed, and the number of times the measurement was performed shall be recorded in the report (see Annex A). The average value shall be calculated and recorded in the report (see Annex A). Such measurements are only suitable for a TCP based service [10].

NOTE: Both methods achieve the same result and the chosen method can be specified in the text of the report (see Annex A).

5.2.5.1.2.2 Operation response delay

The operation response delay is the time difference between the operation command trigger and the corresponding action displayed on the end user device screen as a response.

NOTE 1: The operation command trigger could be that the player clicks on the mobile phone screen or performs another game action.

The measurement methodology is as follows: The measurement tool monitors the start of the operation event which will be recorded in the report (see Annex A) as time T_1 . The time T_2 is recorded when the image of action is first displayed in the screen. Then the operation response delay is calculated as $T_2 - T_1$ and recorded in the report (see Annex A).

NOTE 2: An example for start of the operation event is a press on the display screen.

5.2.5.1.2.3 Desynchronization time ratio

Desynchronization of frames leads to the image freezing or image display discontinuity. The measurement software shall record the accumulated desynchronization duration of the images in the game process. The desynchronization time ratio = Total freezing duration/Total game duration. The measurements of desynchronization time ratio shall be performed using one of the following methods:

- Method 1: The measurement software shall dynamically monitor the image status after the user starts the game. If more than two consecutive frames are equivalent or the time interval of consecutive frame is greater than two frame time intervals (as an example, a 24 fps frame rate leads to a duration of $(1\ 000\ \text{ms}/24) \times 2 = 83\ \text{ms}$), then desynchronization has occurred. The measurement software shall record the desynchronization time duration as well the frames per second (fps). Record the previous frame start time T_3 when desynchronization takes place and frame end time T_4 when desynchronization ceases. Then, the desynchronization time for a single time period is $T_4 - T_3$. The total desynchronization duration can be calculated by the sum of all the single frame freezing durations in the measurement. In practice, the terminal-based rendered game generally utilizes the synchronization mechanism in which the server periodically sends out synchronization frames to the end user device.
- Method 2: Perform the PING test by using the end user device to request an ACK from the game server every 200 ms. If the RTT is larger than a threshold of 100 ms, then record the RTT as the freeze time (if another threshold is used, the threshold shall be recorded in the report (see Annex A)). The RTT is estimating the freeze time. The freeze time is the time from the last shown gaming frame to when a delayed frame appears. The total desynchronization duration is equal to the sum of all the RTTs which exceeded the threshold.

NOTE: Both methods achieve the same result and the chosen method will be specified in the text of the report (see Annex A).

5.2.5.1.3 Data processing

The summary of terminal-based rendered game measurements is listed below:

- Network Start-up Time (NST) = $20 \times \text{RTT}$.
- Operation Response Delay (ORD) = $T_2 - T_1$.
- Desynchronization Time Ratio (DTR) = Total desynchronization duration/Total game duration.

A single measurement of terminal-based rendered games shall include the KQI for network start-up time, operation response delay, and desynchronization time. The MOS value for each indicator and the comprehensive MOS value shall be calculated based on clause 7.6 of ETSI GS F5G 015 [1].

5.2.5.2 Cloud-based rendered game

5.2.5.2.1 Measurement environment

Five of the most popular cloud-based rendered game from at least three different game service providers shall be selected for the measurement. The choice of cloud-based rendered game and the service provider shall be recorded in the report (see Annex A). Prior to starting the measurement, the frame rate and image resolution shall be recorded. A single measurement should be performed during a specified time period to cover a complete game program and the time period shall be recorded in the report (see Annex A).

The measurement shall be performed on a high-end end user device. Prior to starting the measurement, the other applications or software running on the end user device shall be closed to avoid any potential impact on the measurement.

EXAMPLE: The potential impact can be high CPU usage.

5.2.5.2.2 Measurement suite

5.2.5.2.2.1 Frame freezing time ratio

To determine the start of frame freezing, the criteria for the frame duration shall simultaneously meet the following two condition:

- The frame duration shall be greater than the average duration of the previous three frames received.
- The frame duration shall be greater than twice the absolute time value of a nominal frame duration

EXAMPLE: A 24 fps frame rate leads to a duration of $1\ 000\ \text{ms}/24 \times 2 = 83\ \text{ms}$.

To determine the end of frame freezing, the criteria of the frame duration shall be less than twice the time of the absolute value of a nominal frame duration.

The measurement software shall record the freezing time duration. Record the frame start time T_1 and the frame end time T_2 . The freezing time for a single frame is $T_2 - T_1$. The total freezing duration shall be calculated by the sum of all the single frame freezing duration in the measurement. The frame freezing time ratio is the ratio of the sum of all the single frame freezing to the total game duration. The result shall be recorded according to Annex A.

5.2.5.2.2.2 Operation response delay

For operation response delay Cloud-based rendered game measurement refer to the measurement for terminal-based rendered game in clause 5.2.5.1.2.2.

5.2.5.2.3 Data processing

The summary of the Cloud-based rendered game measurements is listed below:

- Frame Freezing Time Tatio (FFTR) = Total freezing duration/Total game duration.
- Operation Response Delay (ORD), refer to ORD defined for terminal-based rendered game in clause 5.2.5.1.3.

A single measurement of cloud-based rendered games shall include the KQI of frame freezing time ratio, and operation response delay. The MOS value of each indicator and comprehensive MOS value shall be calculated based on clause 7.7 of ETSI GS F5G 015 [1].

5.2.6 On-line education/telework

5.2.6.1 Measurement environment

Prior to starting the measurement, all open applications, software packages running or updates of the operation system shall be closed to avoid any potential impact on the measurement.

Prior to each measurement, clear the browser cache, cookies, and the DNS cache of the end user device. The end user devices shall be selected from one of the following smart phone, tablet, and laptop. The chosen end user device shall be recorded in the report (see Annex A).

The measurement shall be performed during both the peak time and idle times of the day. Multiple measurement should be performed in the different time period. These times shall be identified and recorded in the report (see Annex A).

The services for on-line education/telework shall include real-time audio conversations and video sharing. The services shall be recorded in the report (see Annex A).

5.2.6.2 Measurement suite

5.2.6.2.1 Frame freezing time

To determine the frame freezing time parameter, the criteria used for the frame freezing time shall follow two conditions:

NOTE: The frame freezing time is described in ETSI TR 101 578 [i.7].

- The number of times the end user device cannot synchronize the video and audio due to poor network conditions or due to interface loading stuttering, screen flickering and jumping.
- The frame duration shall be greater than twice the absolute value of a nominal frame duration (for example, a 24 fps frame rate leads to a duration of $1\ 000\ \text{ms}/24 \times 2 = 83\ \text{ms}$). The frames per second (fps) shall be recorded in the report (see Annex A).

To determine the end of frame freezing, the frame duration shall be less than twice the absolute value of a nominal frame duration.

The frame freezing time shall be recorded.

5.2.6.2.2 Frame freezing time ratio

The measurement of frame freezing time ratio is the same as cloud-based rendered game, refer to clause 5.2.5.2.2.1.

5.2.6.2.3 Interaction delay

The interaction delay is measured between two end user devices for video interaction, desktop control, and screen sharing. The choice of interaction between two end user devices shall be recorded in the report (see Annex A).

As an example for screen sharing both client A and client B successfully join the remote conference, record the time when client A clicks to start screen sharing as T_1 . When the screen of client A displayed on client B's screen, is recorded as time T_2 .

The time interval is then calculated as interaction delay using $T_2 - T_1$.

5.2.6.3 Data processing

A summary of the on-line education/telework measurements, are listed below:

- Frame Freezing Time (FFT) = S.
- Frame Freezing Time Ratio (FFTR), is the same as for the FRTR in cloud-based rendered game refer to clause 5.2.5.2.2.
- Interaction Delay (ID) = $T_2 - T_1$.

A single measurement for on-line education/telework shall include the KQI of frame freezing time, frame freezing time ratio, and interaction delay. The MOS value for each indicator and comprehensive MOS value shall be calculated based on clause 7.8 of ETSI GS F5G 015 [1].

5.2.7 Cloud VR

5.2.7.1 Cloud VR video

5.2.7.1.1 Measurement environment

The measurement shall be conducted based on the five most popular cloud VR video service platforms. The most popular cloud VR video shall be selected as the data source and shall be recorded in the report (see Annex A). The measurement report shall indicate the cloud VR video characteristics. The measurement shall be performed over a time period to obtain repeatable measurements. The time period shall be recorded in the report (see Annex A).

For cloud VR devices (i.e. a cloud VR helmet), if battery powered, the battery shall be charged to greater than 50 % of its total charge to avoid any performance degradation due to low power issues. The chosen device shall be recorded.

The measurement method uses the E2E setup shown in Figure 2, using the application service as a Cloud VR server and having the Cloud VR clients connected to the ONUs, P-ONUs, or E-ONUs. An accurate time measurement tool should be used to accurately record the timing of the events. The chosen event types shall be recorded in the report (see Annex A) along with the measurement tool used. The present document of the measurement tool is out of scope of the present document.

5.2.7.1.2 Measurement suite

5.2.7.1.2.1 Initial buffering duration

The measurements of the initial buffering duration shall be performed using one of the following methods:

- Method 1: A measurement from the start of the cloud VR video, the measurement tool records the time T_1 when the first video program DNS request packet is sent. Record the time T_2 when the video is first displayed on the end user device. Thus, the initial buffering duration is calculated as $T_2 - T_1$.
- Method 2: A measurement is triggered by fast forwarding or rewinding during video streaming, the measurement tool records the time T_1 when the target video segment request packet is sent to the server. Record the time T_2 when the target video is first displayed on the end user device. Thus, the initial buffering duration is calculated as $T_2 - T_1$.

The method, which is used, shall be recorded in the report (see Annex A).

5.2.7.1.2.2 Average percentage of frames freezing

During the measurement time period, record each time interval t_n , in which the frame freezing takes place. The total measurement time is recorded as T_{total} . The frame freezing time interval does not include the case that the user pauses the video or a pause occurs due to a CPU overload in the end user device.

5.2.7.1.2.3 Low-quality image display

The low-quality image display includes two indicators:

- Average percentage of the low-quality image area.
- Percentage of low-quality image duration.

When a user wearing a helmet makes a head movement, leading to a posture change, this action will trigger the end user device to recalculate the target video streaming segment that matches the video content of the new view angle. Then the download request of the target video streaming segment is sent to the server. If the calculation has an error or the downloading segment does not arrive in time, this leads to insufficient data to derive the high-quality image before the video is shown. In this case, the media player in the end user device will use the low-quality or even wrong image to fill the video segment until the target data is received.

The measurement tool records every time interval t'_n , in which the low-quality image occurs, and the low-quality image area l'_n , within each low-quality image. Depending on the actual network status, the low-quality image varies from the entire image to a small part of the image. The entire image area is recorded as l_{total} . The total measurement time is recorded as T_{total} . Average Percentage of The low-Quality Image Area (APTQIA) is calculated as the average of l'_n divided by l_{total} . The percentage of low-quality image duration (PLQID) is calculated as the summation of t'_n divided by T_{total} .

5.2.7.1.3 Data processing

The summary of the Cloud VR video measurements is listed below:

- Initial Buffering Duration (IBD) = $T_2 - T_1$.
- Average Percentage of Frames Freezing (APFF) = $\sum(t_n)/T_{total} \times 100 \%$.
- Average Percentage of The low-Quality Image Area (APTQIA) = $\text{average}(l'_n)/l_{total}$.
- Percentage of Low-Quality Image Duration (PLQID) = $\sum(t'_n)/T_{total} \times 100 \%$.

NOTE: APTQIA is equivalent to R_{LA} and PLQID is equivalent to R_{LD} in ETSI GS F5G 015 [1]. The corresponding quantization parameter for calculating the MOS [1] is obtained from the client and recorded (see Annex A).

A single cloud VR video measurement shall include the KQI of the initial buffering duration, the average percentage of frames freezing, the average percentage of the low-quality image and the percentage of low-quality image duration. The MOS value for each indicator and comprehensive MOS value shall be calculated based on clause 7.9 of ETSI GS F5G 015 [1]. For multiple measurement of a specific residential user, the average value of MOS (which includes the average MOS value of initial buffering duration, average percentage of frames freezing, average percentage of the low-quality image, the percentage of low-quality image duration, and the maximum/minimum/average comprehensive MOS value) shall be calculated to reflect the experience estimation of the cloud VR video.

5.2.7.2 Cloud VR game

5.2.7.2.1 Measurement environment

The measurement shall be performed on the three most popular cloud VR game service platforms. The most popular cloud VR game per platform shall be selected and recorded. The measurement should indicate the video game characteristics. The measurement shall be performed in a time period during the game duration. The time period in the game shall be recorded.

The VR device (i.e. a cloud VR helmet), if battery powered, shall be charged to greater than 50 % of its total battery capacity to avoid any performance degradation due to low power issue. The chosen device shall be recorded.

5.2.7.2.2 Measurement suite

5.2.7.2.2.1 Black edge and smearing

When the user's head moves, the image adapts with an offset adjustment in cloud rendering. Black edge and smearing occur if the rendering is not accurately done. In this case, the content in the new view angle, outside the original rendering image, will be displayed as black edge or smearing (i.e. interpolation of the surrounding image pixels). Two parameters shall be measured:

- Average Percentage of the black Edge Area (APBEA).
- Percentage of the Black Edge Duration (PBED).

The measurement methodology shall be as follows: once the cloud VR game starts, the user head moves according to the actions of the cloud VR game, record each time period t_n and the black edge area I_n when black edge occurs in the view angle of the user.

5.2.7.2.2.2 Average percentage of frames freezing

When the end user device (i.e. the VR helmet), where the type of the device is recorded in the report (see Annex A), does not receive a new gaming frame within a certain time recorded, the device will keep displaying the last frame it received. The freezing will remain until the new frame is correctly received.

NOTE: Most cloud VR game platforms utilize TCP to transmit data packets, ensuring data integrity and order preservation in the application layer.

If the frames are reaching the end user devices simultaneously due to network congestion, the end user device will update the image shown in the display by using the newest frame and discard the old frames which are late. This is to guarantee the real-time performance and synchronicity in the game but leads to discontinuity of the video image. If multiple frames are not displayed in time and discarded, the freezing will be more obvious. The average percentage of frame freezing is calculated by the total freezing duration to the total measurement time in cloud VR games.

During the measurement time period, record each time interval t'_n , in which the frame freezing takes place. The total measurement time is recorded as T'_{total} .

5.2.7.2.2.3 Operation response delay

The operation response delay is the time difference between the operation command trigger and the corresponding action displayed on the screen as the response.

NOTE: The operation command trigger could be a system event to request a new view because players moved, pulled a trigger, waved a hand or performed another motion.

The measurement methodology shall be as follows: the measurement tool monitors the start of the operation event (the key press of the joystick which shall be recorded in the report (see Annex A)) and record the time as T_1 . Record the time T_2 when the action is first displayed on the screen. Then the operation response delay is calculated as $T_2 - T_1$.

5.2.7.2.3 Data processing

The summary of the Cloud VR game measurements is listed below:

- Average Percentage of the Black Edge Area (APBEA) = $\text{average}(I_n)/I_{total}$.
- Percentage of the Black Edge Duration (PBED) = $\sum(t_n)/T_{total} * 100 \%$.
- Average Percentage of Frames Freezing (APFF) = $\sum(t'_n)/T'_{total} * 100 \%$.
- Operation Response Delay (ORD) = $T_2 - T_1$.

NOTE: APBEA is equivalent to R_{BA} and PBED is equivalent to R_{BD} in ETSI GS F5G 015 [1].

A single cloud VR game measurement shall include the KQI of the average percentage of the black edge area, the percentage of the black edge duration, the average percentage of frames freezing and the operation response delay. The corresponding MOS value and the comprehensive MOS value shall be calculated based on clause 7.9 of ETSI GS F5G 015 [1]. For multiple measurement for a specific residential user, the average MOS value (which includes the MOS value of average percentage of the black edge area, the percentage of the black edge duration, the average percentage of frames freezing, the operation response delay, and the maximum/minimum/average comprehensive MOS value) shall be calculated to reflect the experience estimation of the Cloud VR game.

6 Measurement of network KQI

6.1 Detailed network evaluation

6.1.1 Background

Detailed network evaluation is a comprehensive approach to quantify the residential network capability for the different classification levels for the residential services as defined in ETSI GS F5G 015 [1]. The measurement shall leverage professional testing equipment or measurement software in a controlled laboratory environment. Therefore, the measurement results guarantee repeatability and can be used for comparison from different testing labs.

6.1.2 Throughput

6.1.2.1 Measurement purpose

The throughput measurement measures the maximum throughput to the end user device when connected to an access network terminal or Access Point (AP) through Wi-Fi®.

NOTE 1: An Access Network Terminal can be a P-ONU. An Access Point can be an E-ONU.

NOTE 2: For the purpose of this measurement only Wi-Fi® connections are considered, other interfaces are possible, but for further study.

6.1.2.2 Measurement environment

TCP throughput is measured with wireless capable end user devices such as professional equipment or an end user device, such as mobile phone or laptop, or testing instrument that simulates practical wireless access of users. The professional equipment or end user device used will be recorded in the report (see Annex A):

- The measurement should be performed in a shielded environment [4]. The shielded environment should support an ambient noise floor of less than -105 dBm and is verified by a spectrometer, which shall not scan any other Wi-Fi® devices on the same channel or adjacent channels.
- When the measurement is performed with an actual end user device, the end user device shall be placed one meter away from the access network terminal or access points and at the same height. The end user device Wi-Fi® used in the measurement should have at least the same generation as the access network terminal or access points.
- When the measurement is performed using a professional equipment for emulating the end user devices, the Wi-Fi® connection should be established over the air. The end user device emulator is placed one meter away from the access network terminal or access point.
- The network performance testing server is connected to the central office by a 10GE wired interface. The server executes TCP performance measurement by establishing TCP service flow with the end user device or professional equipment of the residential network. At least 10 service flows shall be established between each end user device emulator and the performance testing server. TCP window size for the testing server and end user device is set to 64 Kbyte [4].
- The CPU capability of the network performance testing server and end user device shall not impact the measurement.

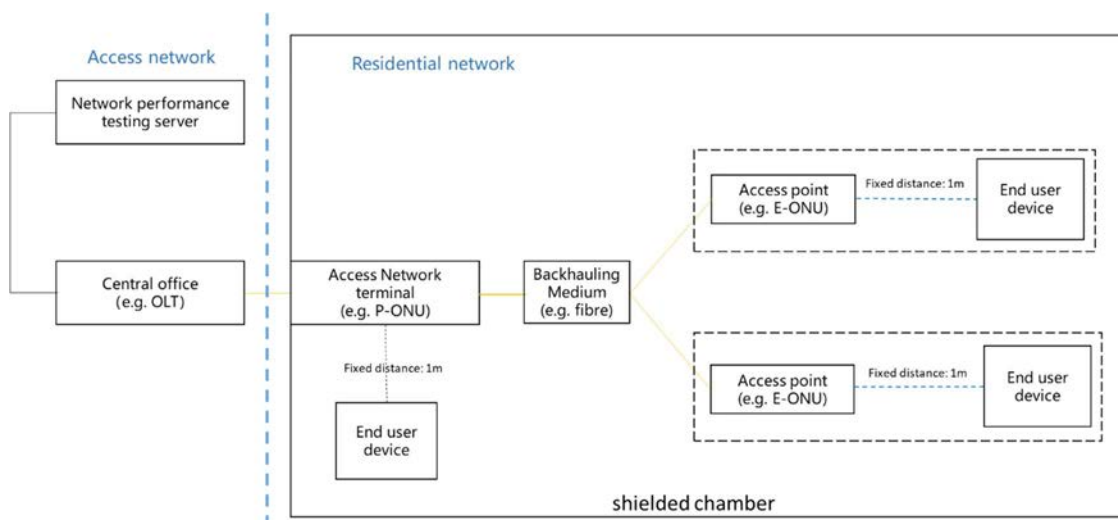


Figure 5: The measurement setup of Throughput

6.1.2.3 Measurement configuration

The measurement shall be configured as follows:

- a) As shown in Figure 5, the residential network consists of access network terminal and access point(s), and end user devices. The access network terminal, access point, and end user devices used should be recorded in the report (see Annex A). The backhauling medium could be fibre, copper (including phone line, Ethernet cable, and coax) or air interface. The backhauling medium used shall be recorded in the report (Annex A).
- b) The access network terminal connects to the access network (i.e. through an xPON link). The PON interface, which is used, should be recorded in the report (see Annex A). Each access network terminal or access point has one end user device connected.
- c) Power up all the devices in the measurement setup.
- d) Wi-Fi® configuration (including mode, bandwidth, channel, authentication encryption mode) of access network terminals and AP shall be consistent. The Wi-Fi® configuration should be recorded in the report (see Annex A).
- e) Adjust the channel condition to make sure that the signal level between access network terminal and AP or between APs are around -60 dBm. The signal level should be recorded in the report (see Annex A).

NOTE: The detected signals -60 dBm mimics the interference between different network devices (access network terminal and access points).

6.1.2.4 Measurement procedure

The measurement procedure for throughput measurement is as follows:

Test 1:

- a) Complete Wi-Fi® association between end user device and access network terminal. The distance shall be 1 m.
- b) Establish 10 TCP session(s) between the end user device and network performance testing server, and perform TCP download services continuously for 60 seconds.
- c) Record the throughput as Throughput_nt.

Test 2:

- d) Disassociate the end user device from the access network terminal and complete Wi-Fi® association between end user device and AP. The distance shall be 1 m.

- e) Establish 10 TCP session(s) between the end user device and network performance testing server, and perform TCP download services continuously for 60 seconds.
- f) Record the throughput as Throughput_ap.

Test 3:

- g) Disassociate the end user device from the access point and complete Wi-Fi® association between multiple end user devices and APs or an access network terminal. The distance between each end user device and either the APs or the access network terminal shall be 1 m.
- h) Establish 10 TCP session(s) between all the end user devices and network performance testing server, and conduct TCP download services continuously for 60 seconds.
- i) Record the throughput as Throughput_concurrency.

Record the type of backhauling medium between access network terminal and APs, including copper cable, optical fibre, power line or air.

6.1.2.5 Measurement result

Record the results in step c, f, i of tests 1 to 3. Compare all these results against the throughput requirements in ETSI GS F5G 015 [1] for residential service classification. If all of the three throughputs measured above exceed the throughput requirement of a dedicated classification level, the network can be considered to have the capability of this classification in terms of throughput. The network classification is determined in clause 6.1.8.

6.1.3 Latency

6.1.3.1 Overview of latency measurement

The E2E latency is defined in clause 6.3 of ETSI GS F5G 015 [1] for multiple segments, which are core network, aggregation network, access network and residential network, shown in Figure 2. The latency in the residential network is considered between access network terminal and end user device. It consists of transmission latency on the optical connection and Wi-Fi®, plus the buffering time and processing time of data packets in the network nodes. In general, the packet processing time is relatively small compared to the Wi-Fi® transmission latency, which is the main factor for residential network latency.

The latency is dependent on the network link utilization. If data transmission is less than the network link capacity, the end-to-end connection has sufficient capacity, thus leading to relatively low transmission latency. According to IETF RFC 2544 [6], to measure transmission latency of a communication system, the data rate is set to 90 % of the network capacity. For Wi-Fi® connection, working over a shared air interface, the latency also depends on the channel quality, interference level, and number of connected end user devices.

The measurement defined in the present clause includes:

- Measure the latency under single user scenario.
- Measure the latency under multiple user scenario.

6.1.3.2 Single user scenario

6.1.3.2.1 Measurement purpose

The single user scenario is designed to measure the latency in a residential network when a single user is connected.

6.1.3.2.2 Measurement condition

The measurement setup is shown in Figure 6, and is similar to the one shown in Figure 5. Instead of measuring using a real air interface, the channel condition between end user device and the measured device (ONU, P-ONU, E-ONU) is implemented through either a channel simulator, or using the real environmental conditions or using artificial attenuation based on free space path loss. Although the total signal loss could be set to be same level, the practical channel response may be slightly different since multi-path fading exists in the real environment. The free space path loss of omnidirectional antenna is as following:

$$FSPL(dB) = 20 \times \log_{10}(d_m) + 20 \times \log_{10}(f_{GHz}) + 32,45$$

In which, f is the centre frequency (in GHz), and d is the distance (in meters) between the end user device and the access point or access network terminal. Table 1 shows typical value of FSPL for 2 meters:

Table 1: Typical value of FSPL for 2 meters

Frequency	2,4 GHz	5,2 GHz	5,8 GHz
FSPL	46 dB	52,8 dB	53,7 dB

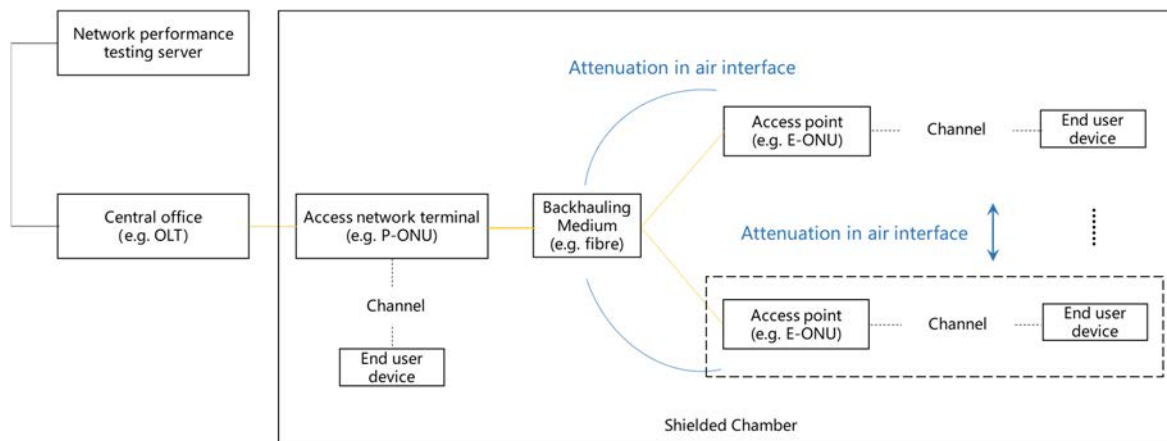


Figure 6: Measurement setup for latency measurement of single end user scenario

6.1.3.2.3 Measurement configuration

The measurement setup shall follow the configuration below for the single user scenario:

- The measurement shall be performed in a shielded environment [4]. The shielded environment requires an ambient noise floor of less than -105 dBm at the working frequency of the Wi-Fi® connection.
- As shown in Figure 6, the residential network consists of an access network terminal and access point(s). Record the backhauling medium used in the measurement (including fibre, copper or air interface).
- The network performance testing server is used to inject the service data for the residential network through the access network. In the single user scenario, only one end user device shall be activated in the access network through the central office.
- Power up all the devices used in the measurement setup.
- Use the default configuration (including channel, channel bandwidth and authentication) for Wi-Fi® of the access network terminal and the access point(s). The configuration should be recorded in the report (see Annex A).

NOTE: The configuration of the P-ONU and E-ONU generally could be achieved through LAN connection by a webpage portal.

- Configure the end user device to work in the 5GHz band by using the default channel bandwidth.

- Adjust the channel condition to make sure that the signal level between access network terminal and access point (also between access points) is set to -60 dBm.

6.1.3.2.4 Measurement procedure

The measurement procedure shall follow the steps below for the single user scenario:

Test 1:

- Complete Wi-Fi® association between the end user device and the access network terminal (P-ONU, E-ONU). The distance to FSPL shall be 1 m.
- Establish TCP session(s) (for data transmission, configuration, report collection and so on) between the end user device and the network performance testing server.
- Transmit downstream/upstream TCP flow with a data rate of 90 Mbps (90 % of the network KQI in ETSI GS F5G 015 [1]) for 60 seconds with an Ethernet packet length of 1 500 bytes. The measurement shall be run once for downstream, and again for upstream. For each direction, the measurement data shall be collected and averaged over a 60 seconds period.
- Record the downstream/upstream latency as Latency_up_nt/Latency_down_nt.

Test 2:

- Disassociate the end user device with the access network terminal and complete Wi-Fi® association between the end user device and the access point. The distance shall be 1 m.
- Establish TCP session(s) (for data transmission, configuration or report collection) between end user device and network performance testing server.
- Repeat step c).
- Record the downstream/upstream latency as Latency_up_ap/Latency_down_ap.

Test 3:

- Disassociate the end user device with the access network terminal and complete Wi-Fi® association of each end user device with the access points or the access network terminal. The distance to FSPL shall be 1 m.

NOTE 1: Each access network terminal or the access point has one end user device connected.

- Establish TCP sessions (for data transmission, configuration, report collection and so on) between all the end user devices and the network performance testing server.
- For each end user device, transmit downstream/upstream TCP flow with a data rate of 90 Mbps/(N+1) (90 % of the network KQI in ETSI GS F5G 015 [1]) for 60 seconds with Ethernet packet of 1 500 bytes.

NOTE 2: N indicates the number of access points. Number N should be recorded in the report (Annex A).

- Record the downstream/upstream average latency as Latency_up /Latency_down.

Test 4:

- Disassociate the end user devices with the access network terminal and the access points. Reconfigure the data rate according to the requirement of L1 (900 Mbps) and L2 (1 800 Mbps).

NOTE 3: L0 has a lower requirement and is not tested in test 4.

- Repeat step c to l.

6.1.3.2.5 Measurement result

Record the results in step d, h, i, and n and compare the results against the latency requirements in ETSI GS F5G 015 [1] for residential service classification and determine the level L0, L1 or L2.

If all of the latencies measured above exceed the latency requirement of a dedicated classification level, the network can be considered to have the capability of this classification in terms of latency. The network classification is determined in clause 6.1.8.

6.1.3.3 Multiple user scenario

6.1.3.3.1 Measurement purpose

The multiple user scenario is designed to measure the latency (average latency and latency distribution) in the residential network when multiple users connect to the residential network with certain interference from the neighbour network.

6.1.3.3.2 Measurement condition

The latency is the primary network KQI to guarantee the user experience, especially for latency sensitive network services (including on-line game, and cloud VR). Large latency leads to uncomfortable experience including frame freezing, delayed operation response, etc. In the residential network, the latency of communication over Wi-Fi® network is the core bottleneck. In the single user scenario mentioned above (see clause 6.1.3.2) with a small number of connected devices and no assuming interference, a relatively low latency is expected. In multiple user scenario, due to a number of connections to a single device with neighbouring interference, the Wi-Fi® connection based on the CSMA mechanism will significantly impact to the communication latency.

This measurement setup leverages lab instruments to generate the Wi-Fi® interference. The average latency and proportion latency in the multiple user scenario are measured and analysed. To estimate the latency distribution, 99% of Cumulated Distribution Function (CDF99) is used [i.1].

6.1.3.3.3 Measurement configuration

The measurement setup shall follow the configuration below for the multiple user scenario:

- The measurement shall be performed in a shielded environment [4]. The shielded environment requires an ambient noise floor of less than -105 dBm at the working frequency of Wi-Fi® connection.

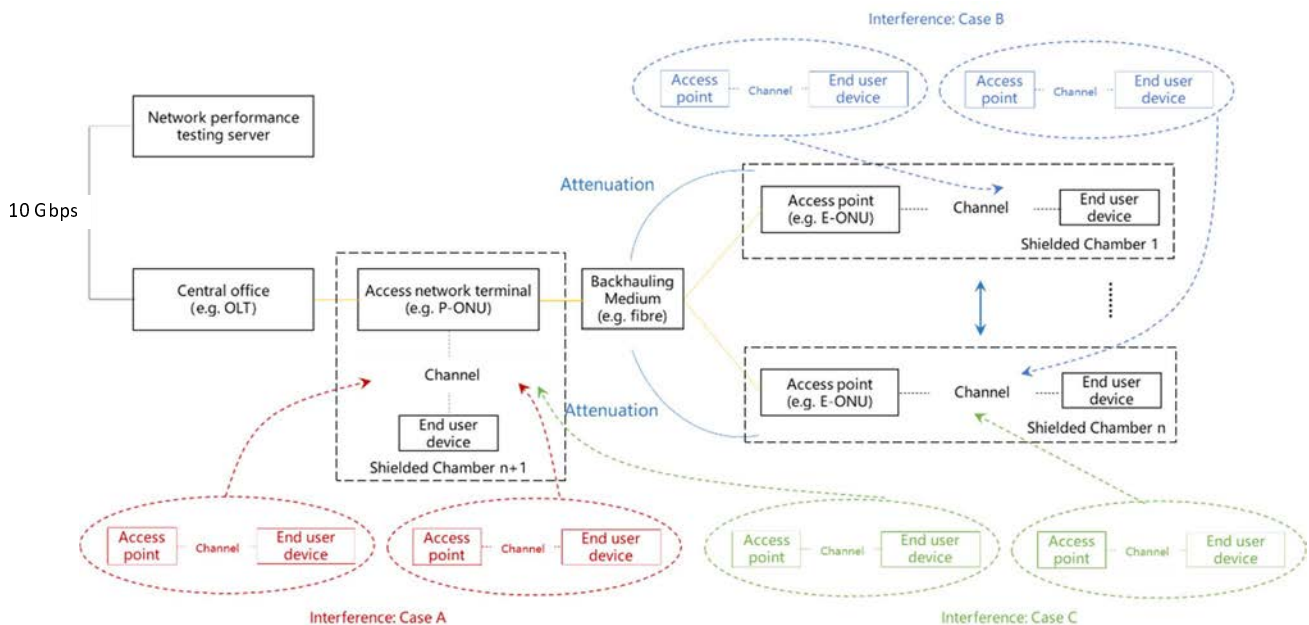


Figure 7: Measurement setup for latency measurement of multiple user scenario

- Figure 7 shows, the residential network which consists of an access network terminal and access point(s). The backhauling medium used in the measurement (including fibre, copper or air interface) shall be recorded.

- The network performance testing server is used to inject the service/data for the residential network through the access network. In this measurement, each access network terminal and access points are connected by one end user device.
- Once the configuration is setup, power up all the devices used in the measurement.
- Use the default configuration (including channel, channel bandwidth, and authentication) for Wi-Fi® of the access network terminal and the access point(s).
- Configure the end user device to work in the 5 GHz band by using the default channel bandwidth.
- Adjust the channel condition to make sure that the signal level between access network terminal and access point (also between access points) is set to -60 dBm.

NOTE: The number of devices under measurement (access network terminal and access points) should be less than 4, to reflect the typical residential scenario case. In F5G FTTR, the access network terminal is a P-ONU while access points are E-ONUs. The number of devices under measurement should be recorded in the report (Annex A).

- The measurement procedure contains three sub measurements (shown in Figure 7):
 - a) Measurement is performed with the interference generator collocated with the access network terminal. In this case, two access points that generate the interference are put in the shielded chamber n+1, where the access network terminal is located.
 - b) Measurement is performed with the interference generator collocated with the access points. In this case, two access points that generate the interference are put in the shielded chamber, where the access point under measurement is located.
 - c) Measurement is performed with the interference generator collocated with the access network terminal and access points. In this case, additional access points that generate the interference are put in each of the shielded chamber, where the access network terminal and access points are located. The number of additional access points should be recorded in the report (Annex A).

The configuration of the access points that generate the interference is shown in Table 2. Each AP generating interference is connected to an individual end user device. The characteristics of packet flow of the generated interference is also indicated in Table 2.

Table 2: Configuration of interference

AP as interference	Protocol Version	Channel number	Bandwidth	Number of connected Users	RSSI	Packet Type	Packet Size (Bytes)	Rate (Mbps)	Priority
AP1	IEEE 802.11ac [13] IEEE 802.11ax [14]	Same as the access network terminal or access points		1	-70±2	TCP	1 460	20/1	BE
AP2	IEEE 802.11ac [13] IEEE 802.11ax [14]	Same as the access network terminal or access points		1	-70±2	TCP	1 460	20/1	BE
...
AP (n+1)	IEEE 802.11ac [13] IEEE 802.11ax [14]	Same as the access network terminal or access points		1	-70±2	TCP	1 460	20/1	BE

6.1.3.3.4 Measurement procedure

The measurement procedure shall follow the steps below for the multiple user scenario. The measurement is repeated three times for different service classification L0, L1, L2:

Test 1:

- a) Complete the Wi-Fi® association between the end user device and the access network terminal (P-ONU) or access points (E-ONU). The equivalent distance to FSPL is 1 m.
- b) Set up the interference generation according to Table 2.
- c) Establish TCP session(s) (for data transmission, configuration, or report collection) between the end user device and the network performance testing server.
- d) Transmit downstream TCP flow for each end user device (i.e. end user device) with a data rate of 5 Mbps, 70 Mbps, 80 Mbps for L0, L1 and L2, respectively. Each measurement is continuously conducted over a 60 seconds period.

NOTE: The data flow service corresponds to web browsing in L0, 4K video in L1 and weak interaction cloud VR in L2 [1]. Other set of service type may be used based and recorded in the report (see Annex A).

- e) Calculate the average latency and CDF99 of the test stream set up for the end user device(s).

Test 2:

- f) Disassociate the end user device from the access network terminal and complete the Wi-Fi® association between the end user device and the access point. The distance shall be 1 m.
- g) Repeat step b) to e).

Test 3:

- h) Disassociate the end user device from the access point and complete the Wi-Fi® association between the end user device and the access network terminal/access point simultaneously. The distance shall be 1 m.
- i) Repeat step b) to e).

6.1.3.3.5 Measurement result

Record the results from step e), g), i) and compare them to the latency requirements in ETSI GS F5G 015 [1] for residential service classification and determine the level as shown in Table 3.

Table 3: Latency requirements in the multiple user scenario

Multiple user scenario	Access Network terminal	Access point	Access Network terminal + access points
	CDF99		
L0 (refer to the requirements for web browsing)	≤ 100 ms	≤ 100 ms	≤ 100 ms
L1 (refer to the requirements of 4K video)	≤ 50 ms	≤ 50 ms	≤ 50 ms
L2 (refer to the requirements of cloud VR)	≤ 30 ms	≤ 30 ms	≤ 30 ms
NOTE 1: The measurement can be performed through the higher level. If the high level passes, the pass of lower level is derived.			
NOTE 2: In the F5G FTTR network, the Access network terminal is P-ONU while access points are E-ONUs.			

The network classification is determined in clause 6.1.8.

6.1.4 Connectivity

6.1.4.1 Number of connected devices

6.1.4.1.1 Measurement purpose

The measurement for the number of connected devices is intended to verify the capability of the access network terminal, to determine, if it can support 32 end user devices simultaneously with minimal packet loss and no disassociations.

6.1.4.1.2 Measurement condition

The measurement shall be performed in a shielded environment [4]. The Wi-Fi® network analyser is used to emulate multiple end user devices supporting 2,4 GHz and 5 GHz band. The maximum number of associated end user devices is measured.

6.1.4.1.3 Measurement configuration

The setup consists of an access network terminal and N access points (usually 3 reflecting the typical residential scenario). There are various backhauling options, including fibre or copper (i.e. phone line, Ethernet cable and coax) or air interface, the access network terminal is connected to the access network. The end user devices can be emulated by a Wi-Fi® network analyser. The value of N and the backhaul option should be recorded in the report (Annex A).

6.1.4.1.4 Measurement procedure

The measurement procedure for the number of connected end user devices is as follows:

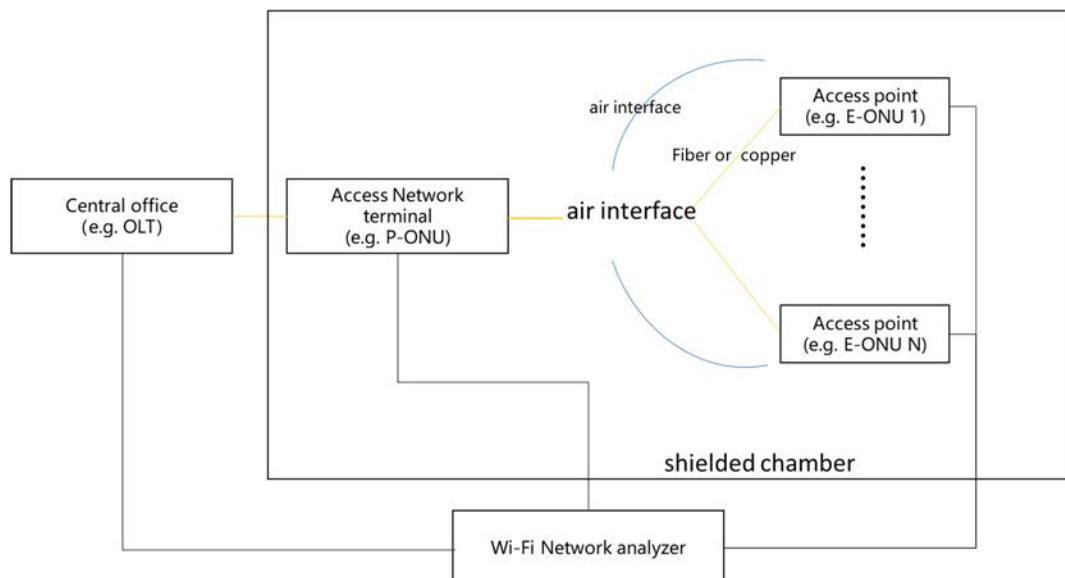


Figure 8: FTTR measurement setup of number of connected devices

- Use a Wi-Fi® network analyser to emulate 64 end user devices connecting to the access network terminal and N access points through 2,4 GHz and 5 GHz SSID randomly, and investigate the number of end user devices that are successfully associated with the network.
- The network analyser sends UDP traffic to an end user device through the OLT in the central office, with a rate of 1 Mbps and a packet length of 1 518 bytes. Continuously transmit the data packets for 30 seconds, and investigate whether the packet loss ratio is less than 0,1 %
- If the packet loss ratio is less than 0,1 %, add an additional end user device with 2,4 GHz band and an additional end user device with 5 GHz band to the access network terminal. Check whether the association is successful.

- d) Repeat step b to c until the association is not successful, or the packet loss ratio is larger than 0,1 %. Record the number of successful associated end user devices to the access network terminal or access points. If the condition still maintains (packet loss ratio is less than 0,1 %), add an additional end user device with 2,4 GHz band and an additional end user device with 5 GHz band is added to the first AP.

NOTE: Each implementation of step e will lead to two (one in 2,4 GHz and one in 5 GHz) end user devices connected to a new network device. The connection of the end user devices to network devices follows the order of the access network terminal, first AP, second AP, etc. in a round robin fashion.

6.1.4.1.5 Measurement result

Record the results in step b), d), e), compare the connectivity results with that specified in ETSI GS F5G 015 [1] for different service classification and summarize the results. The network classification is determined in clause 6.1.8.

6.1.4.2 Performance of concurrently connected devices

6.1.4.2.1 Measurement purpose

According to ETSI GS F5G 015 [1], Table 24, there is no performance requirements for L0, the L1 residential network shall support 16 simultaneously connected devices with 50 Mbps throughput per device, The L2 residential network shall support 16 simultaneously connected devices with 100 Mbps throughput per device. This measurement is intended to verify whether the residential network is compliant to those requirements.

When multiple devices are connected to the Wi-Fi® network concurrently, due to the impact of potential interference, the total performance of the entire network will deteriorate with the increased number of concurrently active devices and throughput per device.

6.1.4.2.2 Measurement configuration

The measurement configuration shall be as follows (measurement diagram is shown in Figure 9):

- a) The residential network consists of an access network terminal and multiple access points through optical fibre, copper cable, or air interface. Both the access network terminal and the access point support the Wi-Fi® interface.
- b) The Northbound Interface (NBI) of the access network terminal connects to the access network. In order to measure the performance of the residential network, it shall be guaranteed that there is no performance limitation of the access network compared to residential network.
- c) Configure the Wi-Fi® simulator or the end user device to work over 5 GHz band with a default channel and WPA2/AES encryption authentication.
- d) Let the simulated/real end user device connect to the residential network. If end user devices are utilized for measurement, then the end user devices need to install software to support a traffic generation and evaluation. The implementation software is out of scope.
- e) The distance between the end user device and the access network terminal (or the access point) shall be set to one meter (corresponding to a free space loss on the air interface of 46 dB [4]).

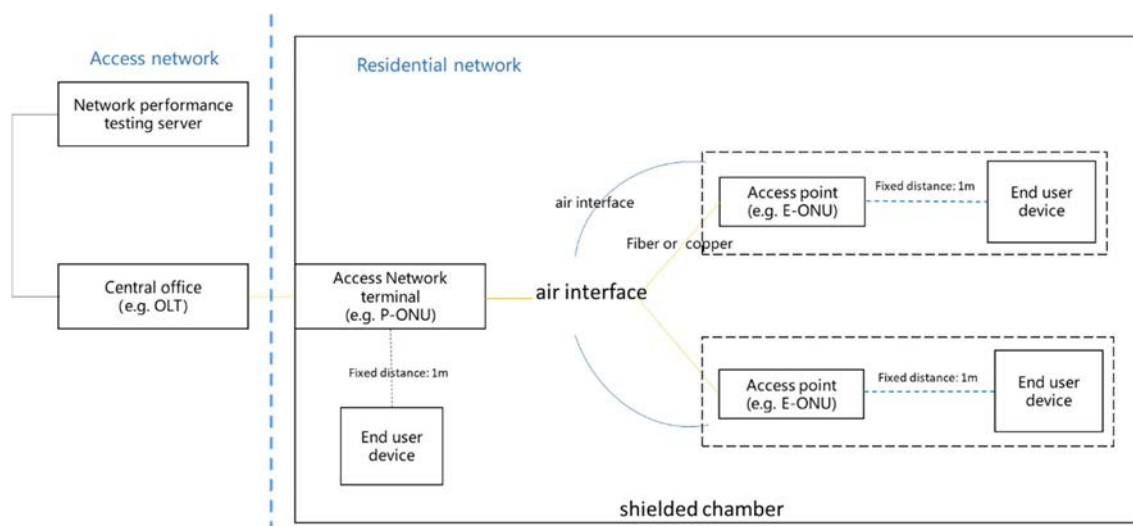


Figure 9: Measurement setup of number of concurrently active devices

6.1.4.2.3 Measurement procedure

According to the requirements for the number of concurrently connected devices in a residential network [1]:

- a) For L0 classification: no measurement is needed, since there are no performance requirements.
- b) For L1 classification: utilize an emulator or end user devices to construct 16 end user devices to simultaneously connect to the 5 GHz SSID of the access network terminal or APs. For each end user device, generate 50 Mbps UDP data stream with a packet length of 1 500 Byte. The measurement is run continuously for a time period of 120 seconds. Record the packet loss ratio of each end user device.
- c) For L2 classification: utilize a simulator or the end user device to construct 16 end user devices and simultaneously connect to 5 GHz SSID of the access network terminal or APs. For each end user device, generate 100 Mbps UDP data stream with a packet length of 1 500 Byte. The measurement is run continuously for a time period of 120 seconds. Record the packet loss ratio of each terminal.

6.1.4.2.4 Measurement result

For the procedure in step a), if the packet loss ratio of each end user device is lower than 0,1 % and the throughput per device reaches 50 Mbps, the performance of the residential network fulfils the requirement of L1 classification [1].

For the procedure in step b), if the packet loss ratio of each end user device is lower than 0,1 % and the throughput per terminal reaches 100 Mbps, the performance of residential network fulfils the requirement of L2 classification [1].

The network classification is determined in clause 6.1.8.

6.1.5 Handover

6.1.5.1 Measurement purpose

The handover measurement is designed to determine the switching time between different network devices (the access network terminal or the access points) under the mobility of the connected end user device.

6.1.5.2 Measurement condition

The switching time period in the handover procedure is the time required to maintain the service continuity while an end user device switches the connection from one network device to the other. The measurement needs to analyse the interruption of the service flow. BBF TR-309 [i.2] defines the measurement methodology of network interruption in network backup and protective switchover, by investigating the status change through packet loss and packet latency, etc. In this measurement, a similar way of calculating the packet loss rate and the packet latency is used to judge the start and the completion of the handover procedure by sending continuous background packets at a certain rate.

6.1.5.3 Measurement configuration

The measurement setup shall follow the configuration below for determining handover time period:

- 1) The measurement shall be performed in a shielded environment (BBF TR-398 [4]). The shielded environment requires an ambient noise floor of less than -105 dBm at the Wi-Fi® connection working frequency.

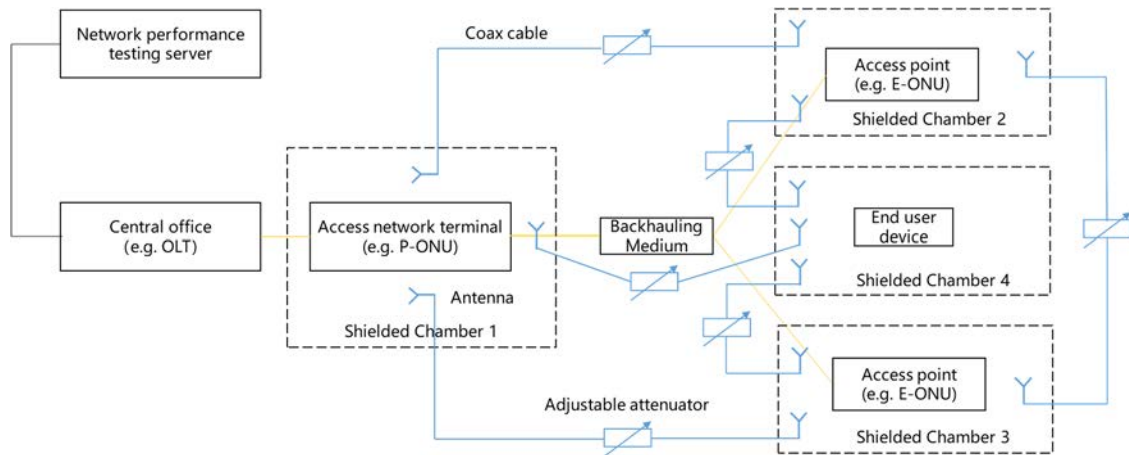


Figure 10: Measurement setup for handover

- 2) Figure 10 shows the measurement setup for handover, in which two access points are used as the two devices for the end user device to connect to before and after handover. The backhaul medium used in the measurement (including fibre, copper or air interface) shall be recorded (see Annex A).
- 3) The network performance testing server is used to inject the measurement data for the residential network through the access network.
- 4) The initial attenuation between each shielded box/chamber of network devices (the access network terminal and access points) is set up to ensure that the detected Received Signal Strength Indicator (RSSI) is -60 dBm. The RSSI value will be recorded.
- 5) Set the attenuation between the shielded chamber #4 and shielded chamber #1 to ensure that the end user device detects the RSSI of -50 dBm from the access network terminal. Set RSSI between end user devices with the access points is around -90 dBm. The RSSI value will be recorded (see Annex A). Therefore, the end user device will connect to the access network terminal over Wi-Fi® when all the devices are powered on.

NOTE 1: To avoid an initial large attenuation in the adjustable attenuator, the antenna in each of the shielded chamber has a high antenna gain.

- 6) Once the configuration is set up, power up all the devices used in the measurement.
- 7) Use the default configuration (including channel, channel bandwidth, and authentication) for Wi-Fi® of the access network terminal and the access point(s). The default configuration is recorded.

NOTE 2: The configuration of the P-ONU and E-ONU can be achieved through a LAN connection via the webpage portal.

- 8) Configure the end user device to operate in the 5 GHz band by using the default channel bandwidth.
- 9) The measurement should be performed using different types of end user devices to support typical handover protocol (support/not support of IEEE 802.11k [11], IEEE 802.11v [12]). The support/not support of IEEE 802.11k [11]/IEEE 802.11v [12] should be recorded in the report (see Annex A).

6.1.5.4 Measurement procedure

The measurement procedure shall follow the steps below to determine the handover time period:

Test 1:

- a) Complete the Wi-Fi® association between the end user device in shielded chamber #4 and the access network terminal in shielded chamber #1.
- b) Transmit downstream UDP flow to each end user device with a uniform 1 000 packets per second and with a packet size of 1 500 byte (Ethernet payload) over a 30 seconds period.
- c) At the same time, decrease the attenuation between shielded chamber #4 and shielded chamber #2, by 2 dB per second, while increasing the attenuation between shielded chamber #4 and shielded chamber #1 by 2 dB per second.

NOTE: This step triggers the handover procedure.

- d) Record the packet loss status and latency for each packet. Calculate the continuous packet loss number N_{PL} (one packet per 1 ms). Determine the maximum latency T_m from the successfully received packet (assuming the packet is successfully transmitted after a number of retransmission on the Wi-Fi® air interface). The handover time period is calculated as the maximum of $N_{PL} * 1$ ms and T_m .

Test 2:

- e) Wait for 10 seconds. Increase the attenuation between shielded chamber #4 and shielded chamber #2 by 2 dB per second, while decrease the attenuation between shielded chamber #4 and shielded chamber #1 by 2 dB per second. Repeat step d) to measure the handover time period for each end user device with the connection from access point to access network terminal.

Test 3:

- f) Repeat steps b) to e) with shielded chamber #3 instead of shielded chamber #2.

6.1.5.5 Measurement result

Record the handover time period in the present document and compare the measurement results of the handover time period to the handover requirements in ETSI GS F5G 015 [1]. The network classification is determined in clause 6.1.8.

6.1.6 Green & security

6.1.6.1 Green (power consumption)

6.1.6.1.1 Measurement purpose

This measurement intends to estimate the power consumption of the network devices (the access network terminal and access points), in three scenarios (full loading, light loading and standby) [1].

6.1.6.1.2 Measurement condition

The power consumption as one of the network KQIs is defined in clause 6.2.2 of ETSI GS F5G 015 [1]. To objectively evaluate the power consumption of a network device, the power per Mbit (mW/Mbit) is used. Figure 11 shows the full loading scenario, as an illustration, in which high traffic flow rate is configured for LAN, Wi-Fi® and backhauling.

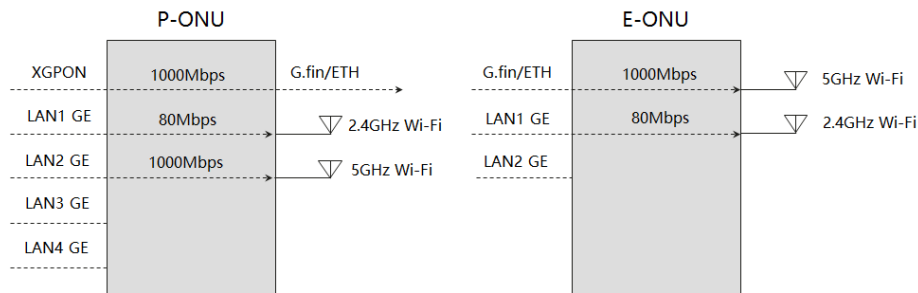


Figure 11: Full loading scenario

6.1.6.1.3 Measurement configuration

The configuration of the measurement shall be as follows:

- As shown in Figure 12, guarantee that there is no alien signal (no unwanted signal) in the Wi-Fi® operating channel of the devices under measurement.
- Make sure that network interfaces of both the access network terminal and the access point function correctly. A power meter is connected between the AC power and AC-DC adapter.
- The access network terminal and the access point are connected to each other through fibre, cable or wireless connection, and the medium shall be recorded.
- The access network terminal is connected to the central office's OLT. To correctly measure the power consumption of the residential network, the performance of the access network shall not be a bottleneck that impacts the measurements.
- The Wi-Fi® configuration (mode, bandwidth, channel, authentication encryption mode) of the access network terminal and access points shall be the same and recorded.

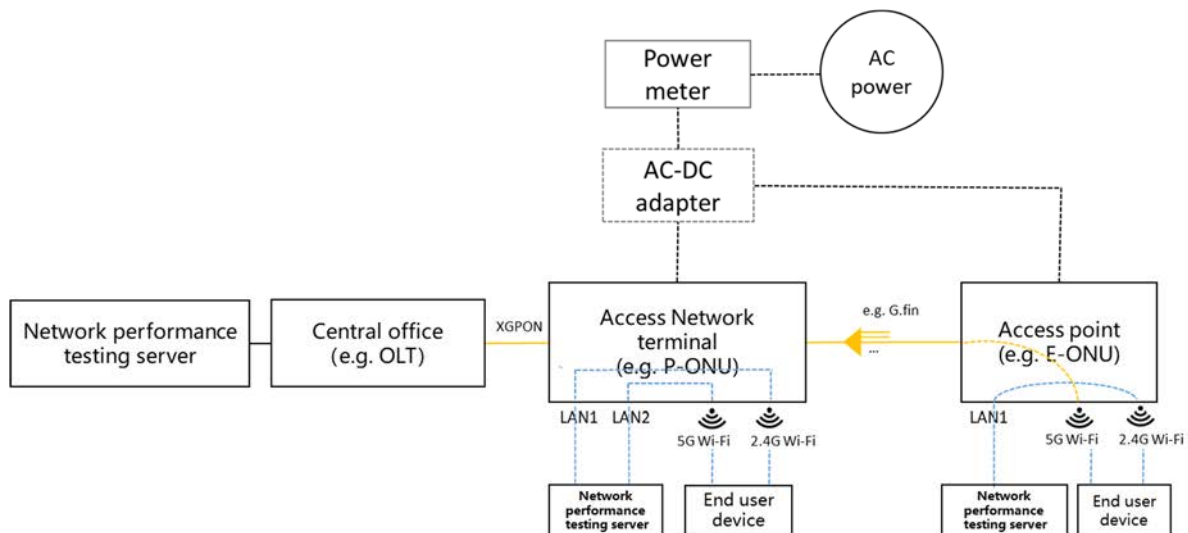


Figure 12: Measurement setup for power consumption

6.1.6.1.4 Measurement procedure

The measurement procedure shall follow the steps below for power consumption measurement:

- Turn on the devices according to the measurement setup in Figure 12 and make sure that the access network terminal and the access points (if there are any) register with the access network and the residential network, respectively.

- b) Configure the Wi-Fi® transmission power level to the transmission limit according to the regional requirements. The channel bandwidth is set as default. The Wi-Fi® transmission power level shall be recorded in the report (see Annex A).
- c) Configure two WAN connections for the access network terminal with two different VLANs and enable the DHCP function.

Test 1: Full loading scenario:

- d) The full loading scenario requirements of the power consumption measurement, for the access network terminal, use two LAN ports, connect the Network performance testing server and inject data flows while for the access point, use one LAN port to inject data flow. Stream direction is from the WAN port of the P-ONU to the E-ONU.
- e) For multiple E-ONUs, the measurement procedures and connection methods shall be consistent with the E-ONU in Figure 12.
- f) Configure the flow parameters for the full loading scenario [1].
- g) Perform the power consumption measurement after the data flows is running normally for at least 5 minutes. Record the power consumption as P_{max} .

Test 2: Light loading scenario:

- h) Repeat step d to e for Light loading scenarios, using lightly loading traffic rates. For the traffic loading of the P-ONU and E-ONUs refer to the ETSI GS F5G 015 [1].
- i) Record the power consumption as P_{sm} .

Test 3: Standby scenario:

- j) Repeat step d to e for Standby scenarios, using Standby traffic rates. For the traffic loading of the P-ONU and E-ONUs refer to the ETSI GS F5G 015 [1].
- k) Record the power consumption as P_{idle} .

Referring to the formulas in the ETSI GS F5G 015 [1], calculate the average power consumption for each device.

6.1.6.1.5 Measurement result

Compare the power consumption results with that of the green & security requirements in ETSI GS F5G 015 [1]. The network classification is determined in clause 6.1.8.

6.1.6.2 Security of hardware and system

6.1.6.2.1 Overview

The security of residential network devices (the access network terminal and access points) ensures availability, confidentiality and integrity (not tampered) of service data.

The security functionality of residential network devices (the access network terminal and access points) is multi-dimensional and consists of: hardware security, system security, network security, application security, data security, software security. Specifically, hardware security is the most basic security function, which includes a chip security, a secure boot, and a secure root key.

In addition, the access network terminal and access points shall ensure that network services are not affected, and the user is notified when a security attack occurs. For F5G broadband service with a high data rate and a low latency, the system security shall ensure the normal operation of network services and protect the system against network attacks. The service QoE shall not be affected due to a network security attack.

The present clause defines the measurement methodology for the hardware security and the system security, including a secure boot, a firmware encryption, and a security setting of key documents.

6.1.6.2.2 Measurement purpose

The measurement evaluates the functionality of the hardware and the system security for the access network terminal and the access point in a residential network, including the secure boot, the firmware encryption, the system backup, the vulnerability remediation of the network system, the vulnerability management of the ports, and the minimization of authorization.

6.1.6.2.3 Measurement condition

For the security measurement, a series of dedicated security testing tool are used for the access network terminal and access points.

For the secure boot: the devices shall provide visibility of their status during the secure boot. It should be allowed to download the signature file for the secure boot through the web interface. The signature file shall meet the Recommendation ITU-T X.509 [5] standard requirements.

For the firmware encryption: use the firmware analysis tool to extract the binary programs to verify whether the firmware is encrypted.

For the vulnerability management of the ports: use the security scanning tool to scan the ports of the system.

For the vulnerability remediation of network system: use security scanning tools to scan system vulnerabilities and check whether open source vulnerabilities have been fixed.

For the minimization of privilege: use a Linux[®] command to confirm that the processes for an external system service are running over non-root users accounts and have no high-risk privileges.

NOTE: Linux[®] is the registered trademark of Linus Torvalds in the U.S. and other countries.

The measurement report shall record the tool used in the measurement (see Annex A).

6.1.6.2.4 Measurement configuration

The measurement setup shall follow the configuration below for the security measurement:

- 1) Restore the factory settings for the access network terminal and access points. Make sure that the service provisioning from the service provider can deliver the public network service for the residential network.
- 2) Enable the Shell permission for the access network terminal.
- 3) Set up the security tool for port scanning, vulnerability scanning, and firmware analysis.
- 4) Set up the software upgrade package V2 (a new software version compared to the default installed version V1). V2 is used for security testing.

6.1.6.2.5 Measurement procedure

The measurement procedure shall follow the steps below for the hardware and the system security measurement:

Test 1:

- a) Log into the WEB interface of the access network terminal, download the digital signature file of the secure boot. Use the signature verification tool or the signature verification website to verify the signature file and software (Marked as V1 version).
- b) Upgrade the software version to V2 (a different version of V1), download the digital signature file of the secure boot. Use the signature verification tool or signature verification website to verify the signature file and software (Marked as V2 version).
- c) Use the signature verification tool or the signature verification website to verify the signature file and software (Marked as V1 version).

Test 2:

- d) Use the firmware analysis tool to analyse the encrypted software version (V2) and extract the binary program. Check whether the extraction is successful.

Test 3:

- e) Use a port scanning tool to scan the WAN and LAN port of the access network terminal: for LAN scanning, a PC is connected to the LAN and perform the IPv4 and IPv6 scanning for managed IP address; for WAN scanning, a PC is connected to the WAN and perform IPv4 and IPv6 scanning for managed IP address. Record the scanning result.

NOTE 1: The port scanning mentioned above is scanning of TCP and UDP port.

Test 4:

- f) Use the vulnerability scanning tool to scan whether high-risk vulnerabilities exist.

Test 5:

- g) If the access network terminal uses open-source software, download the corresponding source code from the official website. Use scanning tool to scan the source code, record the vulnerabilities and check whether the medium and high-risk vulnerabilities are fixed and announced by the devices.

Test 6:

- h) Log into the access network terminal, access Linux Shell, and check the listening ports. Run the Shell command: `netstat -nap`, to record the PIDs of all processes communicating to the external networks. If the listening address or connecting address of the process for external network is a non-loopback address (127.0.0.1), run the shell command: `ps`, to query the system username corresponding to the dedicated process. Then run the shell command: `cat/etc/passwd`, to query the corresponding user ID (uid) and group ID (gid).

NOTE 2: The commands mentioned above are the standard command in Linux system.

- i) Run the command: `cat /proc/xxx/status/`, to query the corresponding CapEff configuration. Convert the CapEff value to the capability description by `capsh`. Check whether the process providing external services run as a non-root user and has high-risk privileges.

6.1.6.2.6 Measurement result

- 1) In steps a) to c), the access network terminal shall support the secure boot, the signature file shall be downloaded. The signature file complies with Recommendation ITU-T X.509 [5] and signature files of different software versions are inconsistent with each other.
- 2) In step d), the firmware analysis tool cannot recognize the valid information and cannot extract binary programs from the firmware.
- 3) In step e), the system shall not open any ports except the ports specified for the network.
- 4) In step f), the access network terminal does not have high-risk vulnerabilities.
- 5) In step g), medium and high-risk vulnerabilities (if open source is used) are fixed.
- 6) In step i), the process for external service belongs to a non-root user (the uid and gid are not equal to 0). The process does not have high-risk privileges, including `CAP_COWN`, `CAP_DAC_OVERRIDE`, `CAP_DAC_READ_SEARCH`, `CAP_FOWNER`, `CAP_SETGID`, `CAP_SETUID`, and `CAP_SYS_MODULE`.

NOTE: Privileges mentioned above are the standard Linux system privileges.

6.1.6.3 Protection capability of network attack

6.1.6.3.1 Measurement purpose

The measurement evaluates the protection capability of the residential network, mainly on the access network terminal, against network attacks [i.3].

6.1.6.3.2 Measurement condition

To emulate a network attack, construct common packets of DoS/DDoS attack (including Sync flood, UDP flood, Teardrop, and Land attack) using a network protocol analyser. The attacks shall be performed to the residential network WAN port. At the same time, the service data flow is continuously monitored while the attack is taking place. It is expected that the service traffic is not affected during the attack. As long as the service is unaffected by an increased rate of network attacks, this indicates a stronger protection capability.

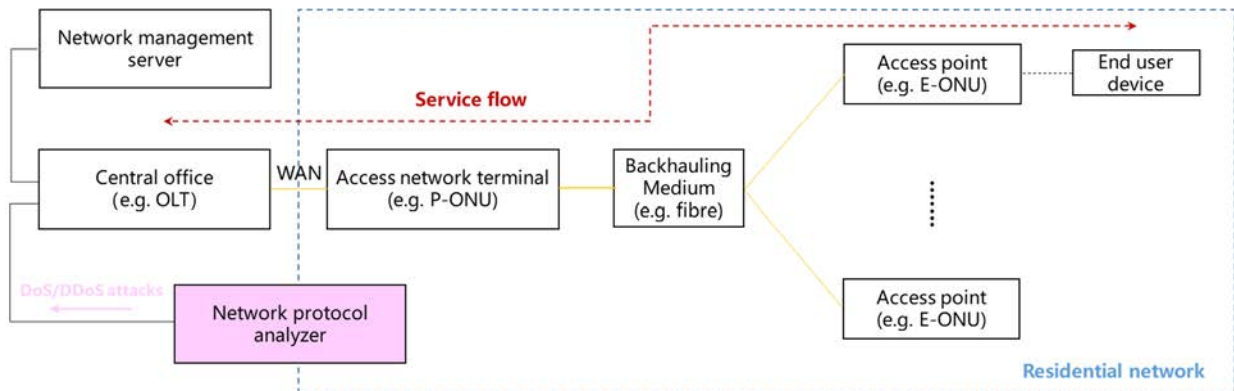


Figure 13: Measurement setup for network attack

6.1.6.3.3 Measurement configuration

The measurement setup shall follow the configuration below for the protection capability measurement:

- 1) Power on all the devices in the setup, shown in Figure 13. Set the access network terminal in the routing mode.
- 2) Configure the management WAN and the service WAN to enable the device management by the network management of the server and of the access to the public network.
- 3) The network protocol analyser shall be able to create DoS/DDoS attack (including Sync flood, UDP flood, Teardrop, Land attack).

6.1.6.3.4 Measurement procedure

The measurement procedure shall follow the steps below for the protection capability measurement:

Test 1:

- a) If the protection function is not open by default, enable the DoS attack protection function of the access network terminal. Let the end user device subscribe to a normal connection (i.e. a laptop, to continuously ping a network server every second).
- b) Send the attack packet (created by the network protocol analyser or DoS attack software) to the access network terminal WAN port. The source IP address, the source port and the destination port of the attack packet should be continuously changed. The attack packet is a UDP packet. In this case, each source IP address is seen as an attack source. Each attack source sends 100 attack packets (68 bytes [8] of payload) per second. The attack in this step lasts for 5 minutes.

NOTE: 68 bytes is the minimum size of MTU based on IPv4.

- c) Increase the number of the attack sources, record the maximum number of attack sources until the ping fails.

Test 2:

- d) Terminate the attack and wait for the system to recover. Send attack packets (created by the network protocol analyser or DoS attack software) to the WAN of the access network terminal. The source IP address, the source port and the destination port of the attack packets should be continuously modified. The attack packets are UDP packets. Each source IP is seen as an attack source. Create 1 000 attack sources, each sending 1 attack packet (68 bytes of payload) per second. The attack in this step lasts for 5 minutes.

- e) Increase the number of the attack packets of each attack source, record the maximum number of attack packets until the ping fails.

6.1.6.3.5 Measurement result

According to the measurement of the protection capability in step c) and e) in above procedure, obtain the classification of the protection capability based on ETSI GS F5G 015 [1]. The network classification is determined in clause 6.1.8.

6.1.7 Smart O&M

6.1.7.1 Automatic services provisioning

6.1.7.1.1 Measurement purpose

The measurement verifies whether the residential network supports the automatic services provisioning, the management platform governance, and the automatic upgrades user intervention.

6.1.7.1.2 Measurement condition

The measurement configuration shall be as follows:

- a) The broadband network has been activated.
- b) The management platform has received a configuration request and has completed the service configuration.
- c) The engineer has obtained the work request and received the registered account of the access network terminal and the access points.
- d) The access network terminal and the access point are powered on.

6.1.7.1.3 Measurement procedure

The measurement procedure shall follow the steps below in the measurement:

Test 1:

- a) The engineer or the user can connect to the Wi-Fi[®] SSID of the access network terminal through the end user device, such as a smart phone. Open the management/installation application (APP) or log into the configuration website without entering the authentication account. Trigger the registration process with the authentication and the service enabling process between the access network terminal and the OLT/management platform. Investigate whether the registration, the service enabling process and other key status information are visible.

Test 2:

- b) Connect to the access network terminal through a smart phone or STB and investigate whether the new network services, including the public internet access and IPTV, have been activated.

Test 3:

- c) Through the management platform, investigate whether the access network terminal is online and whether the basic information including the device model, the software version, the user ports status, and the WAN status can be queried. Investigate whether the network device can be managed by the management platform.

Test 4:

- d) Connect the access point by fibre or copper (including phone line, Ethernet cable and coax) to the access network terminal.
- e) Investigate whether the new network services including the public Internet, IPTV, are available from the access point.

Test 5:

- f) Use the management application (APP) for the broadband acceptance, and investigate whether the topology acceptance, the networking connection quality acceptance, the speed measurement and the signal level acceptance are supported.

Test 6:

- g) Modify the Wi-Fi[®] SSID and the password of the access network terminal through the APP or the management platform and implement the new SSID and the password to connect to the Wi-Fi[®] by the smart phone. Investigate whether the connection is successful, and the public broadband is available.
- h) Investigate whether the network topology and relevant end user devices connected to the network are visible through the management platform.

Test 7:

- i) Add a new access point to the residential network. Power on the device and investigate whether the other devices status normal and whether the new access point is plug-and-play.

Test 8:

- j) Create an upgrade policy through the management platform: perform the upgrade when the residential network service is not busy.
- k) Keep the end user devices connected and stop all network services. Investigate whether the management platform triggers remote upgrade tasks, and check whether the broadband network is still running normally after the upgrade is completed.

6.1.7.1.4 Measurement result

- In step a), the process of the registration and the service enabling is visual. The status of key information is clearly described.
- In step b), the service is activated, and the user can successfully access the network services.
- In step c), the new device can be managed by the management platform.
- In step d), the access point is able to be plug-and-play.
- In step f), the management APP supports the network service acceptance.
- In step g), the access point can automatically synchronize the configuration of the access network terminal.
- In step i), the access point can automatically be enabled without any interaction.
- In step k), the access network terminal and the access point can be upgraded remotely and automatically when the network is not busy.

The functional test results shall be recorded in the report (see Annex A). The network classification is determined in clause 6.1.8.

6.1.7.2 Fault identification, diagnostic & recovery

6.1.7.2.1 Measurement purpose

The measurement verifies whether the residential network supports the automatic fault identification, the diagnosis, and the fault recovery.

6.1.7.2.2 Measurement condition

The measurement is conducted under a normal E2E connection (see clause 6.1.2.2).

6.1.7.2.3 Measurement configuration

Ensure that the E2E link could be established, and the end user device could access the public internet. Ensure that the management platform functions normally and configures the residential network.

6.1.7.2.4 Measurement procedure

The measurement procedure shall follow the steps below for the fault identification, the diagnostic and the recovery:

Test 1:

- a) Simulate a connection fault between the access network terminal and the access point. Check whether the fault alarm disconnection is indicated in the management platform or the management application (APP) in the end user device. The type of the connection fault shall be recorded in the report (see Annex A).

NOTE 1: The connection fault can be a fibre break, a disconnection of Ethernet cable, a large attenuation in the Wi-Fi® backhaul link).

- b) Analyse the root cause on the management platform to identify the exact causes of the connection fault, including a fibre break, a cable disconnection, or a weak Wi-Fi® signal.
- c) Check whether the residential network supports at least one method to recover the data link. The recovery method shall be recorded in the report (see Annex A).

NOTE 2: An example of the recovering a data link is to initiate the Wi-Fi® backhaul while a fibre break occurs.

Test 2:

- d) Simulate a low throughput fault by introducing a packet loss rate (i.e. 5 % bidirectional) between the server and the OLT. This makes the actual application data throughput lower than the physical connection. Check whether the fault alarm of the low data rate is indicated in the management platform or the management application (APP) in the end user device.
- e) Analyse the root cause on the management platform to identify the exact causes of the low data rate. The management platform should conduct a link quality check through a speed test over different network segments. The management platform should be able to locate the place where the fault occurred.

Test 3:

- f) Simulate a low-quality link between the end user device and the network access terminal or access points in the residential network. The RSSI of the received power of AP is around -70 dBm. Establish a 4K or a 8K video streaming from the service operator server, and create an interference source working on the same Wi-Fi® channel (running for 120 seconds at 500 Mbps data stream every hour). Make sure that the video freezing occurs. Check whether the fault alarm of low-quality event is indicated in the management platform or the management application (APP) in the end user device.
- g) Analyse the root cause on the management platform to identify that the exact cause is due to co-channel Wi-Fi® interference.
- h) Check whether the management platform can automatically perform the channel optimization for the residential network.

6.1.7.2.5 Measurement result

- In step a), the management platform or the user APP shall generate an alarm to indicate the link disconnection.
- In step b), the management platform or the user APP shall accurately locate the disconnection fault cause.
- In step c), a backup link should be available when the main backhaul link is no longer available.
- In step d), the management platform or the user APP shall generate an alarm to indicate low data rate.
- In step e), the management platform or the user APP shall demarcate the low data rate cause.

- In step f), the management platform or the user APP shall generate an alarm to indicate the low-quality connection.
- In step g), the management platform or the user APP shall accurately determine the cause of the low-quality connection.
- In step h), the low-quality fault should be automatically rectified and improved.

The functional test results shall be recorded in the report (see Annex A). The network classification is determined in clause 6.1.8.

6.1.7.3 Network optimization

6.1.7.3.1 Measurement purpose

The measurement verifies whether the residential network has the capability of network optimizations, including the transmission parameter optimization of a single AP, multi-AP optimization or the optimization under the interference.

6.1.7.3.2 Measurement condition

The measurement is performed using a normal E2E connection (see clause 6.1.2.2).

6.1.7.3.3 Measurement configuration

Ensure that the E2E link could be established, and the end user device could access the public internet. The management platform functions normally and configures the residential network.

6.1.7.3.4 Measurement procedure

The measurement procedure shall follow the steps below for the network optimization:

Test 1:

- a) Adjust the attenuation between the access network terminal and the access points. Ensure that the RSSI between the two network devices (the access network terminal or the access point) is within -55 dB.
- b) Let the end user device perform the handover procedure according to the measurement methodology defined in the Handover measurement clause in the present document (clause 6.1.4).

Test 2:

- c) Increase the RSSI threshold of the handover and repeat step b). Record the handover status.
- d) Associate the two end user devices with the access network terminal. Run a file downloading for one end user device while run a latency sensitive service (an on-line game or a video conferencing) for the other. Establish a co-channel interference source (i.e. using a pair of AP and the end user device working on the same channel, using a Wi-Fi[®] signal generator) near the access network terminal and make sure that the network services freezes.
- e) Configure the service-based SLA strategies for the above two dedicated network services (i.e. downloading and latency sensitive service).
- f) Check whether the latency sensitive service has recovered.

Test 3:

- g) Set the measurement environment as per step a) above.
- h) For each network device (including the access network terminal and the access point), associate an end user device for each of them. Run downloading services simultaneously. Record the total aggregated downlink throughput.

- i) If the network device supports network optimization function (i.e. the multi-AP optimization and the optimization under interference), enable the network optimization function and record the improvement of the network throughput according to step h).

6.1.7.3.5 Measurement result

- 1) In step b) of the procedure above, the signals between the access network terminal and access points are strong. Therefore, no handover procedure takes place and the expected outcome is recorded as not fulfilling the requirement.
- 2) In step e) of the procedure above, little or no freezing is observed. This indicates that the configured strategy has been performed correctly and implies the network performance is acceptable.
- 3) In step h) of the procedure above, the management platform and the home intelligent networking devices are expected to support the multi-AP optimization capability, identify the current service characteristics, and coordinate the allocation of air interface resources and system resources on the entire network. The aggregate throughput should increase by at least 20 %. Otherwise, the test should be marked as "failed".

The functional test results shall be recorded in the report (see Annex A). The network classification is determined in clause 6.1.8.

6.1.8 Classification levels of residential services

The record shall show the comparison of the measurement result with the requirement of each network KQI in clause 8.3 of ETSI GS F5G 015 [1]. The overall network is classified into lowest level of the six measured network KQIs. For example, if the throughput, the latency, the connectivity, the handover, the green & security, and the smart O&M are fulfilling the requirements of L1, L2, L2, L2, L2, L2 respectively then the classification is L1.

6.2 Basic network evaluation

6.2.1 Measurement purpose

The present clause provides measurement methodologies for basic network evaluation, defined in ETSI GS F5G 015 [1], in which simplified network indicators from the end user device (including a mobile phone and a laptop) are considered in order to help users, a service operator or a third party to quickly evaluate the network by leveraging the application data.

In the present clause, there are a few additional measurements, which could be of interest to the end user or the operator, but which does not affect the level classification as defined in ETSI GS F5G 015 [1].

6.2.2 Measurement condition

To facilitate a consistent and a fair measurement, the following requirements shall be fulfilled:

- 1) For the end user devices, to prevent the negative effect due to the poor performance of the end user device, a laptop should be used as the end user device in the measurement. The configurations are as follows:
 - The CPU shall be at least dual-core with a clock speed greater than 1 GHz.
 - The end user device has at least 4 GB memory.

The measurement report shall record the end user device information including the operating system and the browser used (see Annex A).

- 2) For the measurement duration:
 - The measurement shall be conducted during the residential busy hours of the day.

The measurement report shall include the information of the exact measurement time and the time duration (see Annex A).

3) For the measurement stability:

- To have a fair comparison across different time within the busy residential period and for different users. The measurement shall be conducted over several different times and the time shall be recorded. For each time, the measurement should be conducted in a different location within the residential area, and a minimum of three measurements shall be performed to derive the average result.

6.2.3 Measurement configuration

To collect the data that reflects the network capability and the actual residential environment where the user frequently connects to the network, the measurement should be performed in different residential locations:

- Scenario 1: The location near the access network terminal or the access point. In this scenario, maximum the Wi-Fi® throughput is obtained. The end user device is located approximately 1 m from the access network terminal or the access point. Similar height between the end user device and the AP is required.
- Scenario 2: The end user device is located in the living room possible on a sofa or in the bedroom possible on a bed. The end user device should be put in a specific direction to mimic the end user normal posture. During the measurement, it is assumed that there will be no obstacle (such as a human body) between the end user device and the AP.

NOTE: The scenario includes the independent measurement for both the living room and the bedroom.

- Scenario 3: The end user device is located on the desk in the home office. The end user device should be put in a specific direction to mimic the end user normal posture. During the measurement, it is assumed that there will be no obstacle (such as human body) between the end user device and AP.

6.2.4 Measurement Record

The record shall indicate the results collected in clause 6.2.5.

6.2.5 Measurement of network KQI

6.2.5.1 Throughput

6.2.5.1.1 Overview

The throughput measurement focuses on measuring the actual E2E throughput that the end user can obtain. The measurement of the signal coverage is as a reference for further analysing the Wi-Fi® quality.

6.2.5.1.2 Actual throughput in real environment

The throughput measurement shall follow the methodology defined in reference [2]. The server is connected to the BRAS (or BNG). The data stream is carried over an E2E network, including the server, the aggregation network, the access network, the residential network and the end user device.

There are two methods to perform the measurement of the actual throughput:

1) Initiation from the end user device:

- The measurements shall be performed in each of the scenarios defined in clause 6.2.3. For each of the scenario, the measurement shall be performed at least three times.

2) Analysis through the service provider network:

- The throughput can be calculated from network elements, which can analyse the service stream of the end user. In this case, the forwarding packet of the specific end user in a one second period is calculated in the dedicated time. According to the measurement condition, obtaining multiple measurements in different time is utilized to estimate the throughput measurement accuracy.
- Record the method and the average throughput of each scenario.

6.2.5.1.3 Signal coverage

The Wi-Fi[®] signal level is the key factor affecting the throughput. The Wi-Fi[®] signal coverage therefore directly impacts the QoE of the dedicated service.

There are two methods to perform the measurement of the signal coverage:

- 1) Initiation from end user device:
 - In the real residential environment, the end user device is moved around while the throughput is continuously measured. The signal level and the actual throughput are recorded. For each scenario, the measurement shall be conducted for at least 30 seconds.
- 2) Analysis through the service provider network:
 - The signal level is dynamically collected through the network elements (i.e. the received signal level of the APs).

6.2.5.2 Latency

There are two methods to perform the measurement for the latency:

- 1) Initiation from the end user device:
 - According to the measurement configuration for each scenario, the end user device triggers the ICMP PING test to the IP address of the data server (i.e. the CDN IP of the video data segment). The PING test shall be performed 100 times with an interval of 200 ms. Record the round-trip delay for each PING test. It is required that the server shall support PING test.
- 2) Analysis through the service provider network:
 - According to the measurement configuration for each scenario, the latency measurement can be conducted by analysing the pair of request and response message of the dedicated service. The round-trip delay can be obtained by analysing the time of the three-way handshake. The interval between the time of sent SYN and received SYN ACK in the end user device is seen as the estimation of round-trip delay. At least 10 measurements of the three-way handshake shall be performed and the average value shall be calculated. Such measurement is only suitable for the TCP based service.
 - Record the maximum, the minimum and the average round-trip delays. Calculate the variance of the different scenarios. A smaller variance indicates a more stable connection.

6.2.5.3 Packet Delay Jitter

The packet delay jitter reflects the variation of packet latency. It is an indicator of the network stability. The packet delay jitter can be calculated as the difference between the transmission latency of two consecutive received packet. The measurement of the packet delay jitter shall be done in each of the scenarios defined in clause 6.2.3.

There are two methods to perform the measurement of the packet delay jitter:

- 1) Initiation from the end user device:
 - Referring to the latency measurement of the PING test, continuously calculate the different round-trip delay between two consecutive PING tests. Then, the maximum, the minimum, and the average packet delay jitter can be obtained. The total measurement time shall last for at least 30 seconds.
- 2) Analysis through the service provider network:
 - Referring to the latency measurement by using the three-way handshake procedure mentioned above, calculate the difference between two consecutive latency tests shall be performed at least 10 times. Then, the maximum, the minimum, and the average packet delay jitter can be obtained. Such measurement is only suitable for the TCP based service.
 - Record the maximum, the minimum and the average packet delay jitter. A smaller packet delay jitter reflects a more stable network.

6.2.5.4 Interference

The interference is evaluated to assist the diagnostics of the packet delay jitter issues in the network. The interference is mainly obtained in the access network terminal or the access points by calculating the duty cycle of the interference signals compared to the air interface.

6.2.5.5 Packet loss rate

The packet loss rate reflects the packet loss between the server and the end user device.

There are two methods to perform the measurement of packet loss rate:

- 1) Initiation from the end user device:
 - According to the measurement configuration for each scenario, the end user device triggers a PING test to the data server IP address. The PING test shall be performed over a 200 ms interval. To consider the measurement accuracy, if the resolution of the testing is a %, the measurement times of the PING test shall be greater than $1/a$ %. Calculate the packet loss rate by dividing the number of lost packet(s) to the total number of sent packets in the test.
- 2) Analysis through the network of service provider:
 - According to the measurement configuration for each scenario, monitor the status of all received service packets. Calculate the packet loss rate by dividing the total number of loss packet(s) to the total sent packets. Such measurement is only suitable for the RTP based service.

6.2.5.6 Handover

The handover time is the service recovery time when the end user device switches its connection from one AP to another AP.

There are two methods to perform the measurement of the handover:

- 1) Initiation from the end user device:
 - One method is to continuously monitor the loss packets (see professional measurement of handover in clause 6.1.4) in the server while the end user device is moving. Record the handover time by calculating the duration of continuous packet loss.
 - The alternative method is to monitor the received packet loss in the end user device side.
- 2) Analysis through the service provider network:
 - Calculate the time difference between the connections of the end user device to different AP during the handover.

6.2.6 Measurement result

6.2.6.1 Actual throughput

The throughput measurement shall be performed at least 3 times in different time periods. Record the average, the maximum and the minimum values of the actual throughput. According to the throughput measurement, the classification of the network level could be determined according to ETSI GS F5G 015 [1].

6.2.6.2 Latency

Record the average, the maximum, the minimum and the variance values of latency. According to the latency measurement, the classification of the network level could be determined according to ETSI GS F5G 015 [1].

6.2.6.3 Handover

According to the handover time, the classification of the network level could be determined according to ETSI GS F5G 015 [1]. The handover measurement shall be conducted at least three times. The worst case is used as the baseline.

NOTE: The measurement of the packet delay jitter, the packet loss rate, and the interference are not part of the results and are not used in the level classification.

6.2.7 Classification levels of residential services

The record shall show the comparison of the measurement result with the requirement of each network KQI in clause 8.3 ETSI GS F5G 015 [1]. The overall network is classified into lowest level of the three measured network KQI. For example, if the throughput, the latency, and the handover are fulfilling the requirements for L1, L2, L2 respectively then the classification is L1.

7 User privacy protection

Besides the collected data defined in the present document, the measurement of the user experience could collect more information based on the necessity.

While measuring service KQI or network KQI, user information shall be protected and user privacy shall be guaranteed.

Annex A (informative): Record form for measurement result

To have consistent and comparable measurement outcomes, the present annex provides the format to record the measurement setup, the methodology choice, the configuration and the result for service KQI (see Table A-1) and the network KQI (see Table A-2).

Table A-1: Record form for service KQI

Record of end user device (see clause 5.1.1)			
Number of CPU core		CPU frequency	
Mobile phone memory		Wi-Fi® capability	
Additional Record (see clause 5.1.3)			
Measurement methodology (see clause 4.2.1)			
Measurement time period		Measurement location	
User account/MAC address		Network connection interface (Wi-Fi®, Ethernet, etc.)	
Broadband operator		User location (accurate to the city)	
Record time (accurate to ms)		Status of the subscribed broadband network service (success or failure)	
Type of end user device		Model number of end user device	
Operating system and version		NIC driver information (including version number) of end user device (if a PC is used)	
The server information of data source			
Record of service KQI			
Telephony	Call completion ratio	Y_1/X_1	
	Call setup time	$T_2 - T_1$	
	Call drop rate	X_2/Y_2	
	Conversational quality	E model or POLQA model	
Web browsing	Page response time	$T_2 - T_1$	
	First screen display time	$T_3 - T_1$	
	Full load time	$T_4 - T_1$	
	Three web services under measurement		
Data upload/download	Speed measurement software		
	Server		
	Download rate ratio	R_1/R_2	
	Upload rate ratio	R_3/R_4	
IPTV	Interactive experience		
	Viewing experience		
	Video programs record		
	Video resolution		
Terminal-based rendered game	Network start-up time	$20 \times RTT$	
	Operation response delay	$T_2 - T_1$	
	Desynchronization time ratio	Total desynchronization duration/Total game duration	
	Game under measurement		
	Operating system		
Cloud-based rendered game	Frame freezing time ratio	Total freezing duration/Total game duration	
	Operation response delay	$T_2 - T_1$	
	Game under measurement		
	Frame rate		
	Image resolution		
	Measurement time period		

Record of service KQI			
On-line education/telework	Frame freezing time	S	
	Frame freezing time ratio	Total freezing duration/Total game duration	
	Interaction delay	$T_2 - T_1$	
	Measurement time period		
	Service under measurement		
Cloud VR video	Initial buffering duration (including methodology)	$T_2 - T_1$	
	Average percentage of frames freezing	$\sum(t_n) / T_{total} * 100 \%$	
	Average percentage of the low-quality image area	$average(I'_n) / I_{total}$	
	percentage of low-quality image duration	$\sum(t'_n) / T_{total} * 100 \%$	
	Cloud VR platform under measurement		
	Measurement time period		
Cloud VR game	Average percentage of the black edge area	$average(I_n) / I_{total}$	
	percentage of the black edge duration	$\sum(t_n) / T_{total} * 100 \%$	
	Average percentage of frames freezing	$\sum(t'_n) / T_{total} * 100 \%$	
	Operation response delay	$T_2 - T_1$	
	Cloud VR game under measurement		
	End user device		

Table A-2: Record form for network KQI

Record of detailed network evaluation					
Measurement configuration	access network terminal				
	access point				
	end user devices				
	backhauling medium				
	Wi-Fi® configuration (including channel, channel bandwidth and authentication)				
Throughput	Test1		Throughput_nt		
	Test2		Throughput_ap		
	Test3		Throughput_concurrency		
Latency	Single user scenario	Test1	Latency_up_nt		
			Latency_down_nt		
			Latency_up_ap		
		Test2	Latency_down_ap		
			Latency_up		
			Latency_down		
		Test4	L1	Latency_up_nt	
				Latency_down_nt	
				Latency_up_ap	
	L2		Latency_down_ap		
			Latency_up		
			Latency_down		
	Multiple user scenario	Test1	L0	average latency CDF99	
			L1	average latency CDF99	
			L2	average latency CDF99	
L0			average latency CDF99		
L1			average latency CDF99		
L2			average latency CDF99		

Record of detailed network evaluation						
Latency	Multiple user scenario	Test2	L0	average latency		
				CDF99		
			L1	average latency		
					CDF99	
				L2	average latency	
					CDF99	
		Test3	L0	average latency		
				CDF99		
			L1	average latency		
			CDF99			
		L2	average latency			
			CDF99			
Connectivity	Number of connected devices	packet loss ratio				
		Number of connected devices				
		L1	packet loss ratio			
	Performance of concurrently connected devices	L2	packet loss ratio			
Handover	Handover time period	Test1		$N_{PL} * 1ms$		
				T_m		
				the maximum of $N_{PL} * 1ms$ and T_m		
		Test2		$N_{PL} * 1ms$		
				T_m		
				the maximum of $N_{PL} * 1ms$ and T_m		
		Test3		$N_{PL} * 1ms$		
				T_m		
				the maximum of $N_{PL} * 1ms$ and T_m		
Green & security	Green (power consumption)	Test1		P_{max}		
		Test2		P_{sm}		
		Test3		P_{idle}		
				P		
	Security of hardware and system	Test1		Pass/Fail		
		Test2		Pass/Fail		
		Test3		Pass/Fail		
		Test4		Pass/Fail		
		Test5		Pass/Fail		
		Test6		Pass/Fail		
	Protection capability of network attack	Test1		maximum number of attack sources		
		Test2		the maximum number of attack packets		
	Smart O&M	Automatic services provisioning	Test1		Pass/Fail	
			Test2		Pass/Fail	
			Test3		Pass/Fail	
Test4				Pass/Fail		
Test5				Pass/Fail		
Test6				Pass/Fail		
Test7				Pass/Fail		
Test8				Pass/Fail		
Fault identification, diagnostic & recovery		Type of connection fault				
		Recovery method				
		Case 1		Pass/Fail		
		Case 2		Pass/Fail		
			Case 3		Pass/Fail	
Network optimization		Test1		Pass/Fail		
		Test2		Pass/Fail		
	Test3		Total aggregated downlink throughput			
			Improvement of the network throughput			

Record of basic network evaluation			
End user devices			
Measurement time and time duration			
Measurement methodology (see clause 4.2.2.1)			
Basic network result	Actual throughput	Full set of results	
		Average value	
		Maximum value	
		Minimum value	
	Latency	Full set of results	
		Average value	
		Maximum value	
		Variance value	
	Jitter	Full set of results	
		Average value	
		Maximum value	
		Variance value	
	Packet loss rate		
	Handover		

History

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