STUDY FOR THE EVALUATION OF THE QUALITY OF SERVICE OF BROADBAND INTERNET ACCESS

ICP - ANACOM

Methodology Report

Table of Contents

1. Methodology – Mobile Accesses 3

1.1 Target Population 3

1.2 Sample Definition and Selection 3

1.3 Quality control of results 10

1.4 Precision of results 10

1.5 Weighting 11

1.6 Technical Architecture, Operating Mode and Component Detail 11

1.6.1 Technical Architecture 11

1.6.2 Operating mode 13

1.6.3 Component detail 14

2. Methodology – Fixed Accesses 16

2.1 Target Population 16

2.2 Sample definition and selection 16

2.3 Quality control of results 18

2.4 Precision of results 19

2.5 Weighting 19

2.6 Technical architecture, operating mode and component detail 20

3. User experience 24

4. Indicators 27

1. Methodology – Mobile Accesses

1.1 Target Population

The target population is made up of indoor and outdoor locations in the municipalities of Faro, Lisbon and Porto. Indoor locations are deemed to be private households, while outdoor locations comprise public locations such as shopping and leisure areas, airports, and schools, where there is a high usage of mobile broadband Internet.

Each member of the panel was tested for the three mobile service operators - Optimus, TMN and Vodafone. The criterion used for the recruitment of the test panel was based on the existence of proper UMTS coverage for the offerings being analysed.

1.2 Sample Definition and Selection

A longitudinal sample with rotation was used in the municipalities of Lisbon and Porto, where the study had already been carried out in 2008. A contact base was thus set up with the members from these municipalities which participated in the previous study and which showed interest in participating in the same study again. This methodology was applied without prejudice to the sample distribution defined for the overall measurements, regarding the distribution of population in each parish. This option is particularly suitable in this context because it leads to much better precision in the study of the evolution versus what would be achieved by using independent samples.

To feed the part of the sample that was not covered by the 2008 test panel, and for the municipality of Faro, a three-stage selection method was used for the indoor accesses. The first phase involved the selection of the parishes to be included in the sample. Following that, the number of points to be observed in each parish was determined, and these were distributed in proportion to the population of each parish. Afterwards, a first sample of locations (corresponding to the first observations) was randomly selected from a contact base of the households of each municipality. Then the actual observations points were selected using the *snowball* method, thus guaranteeing that no more than one point was selected in the case of streets, squares, etc., and no more than two in the case of avenues. Recruiting was done by phone.

The outdoor accesses (in the municipality of Faro and in the incomplete sample from the 2008 panel in the municipalities of Lisbon and Porto) were selected from a contact base of these locations in each municipality with a view to ensuring geographical dispersion between the evaluated points and variety in the type of location (shopping centres and other leisure areas, universities, schools, airports, other).

The following maps present the actual observation points.

Figure 1 – Observations points in the municipality of Faro

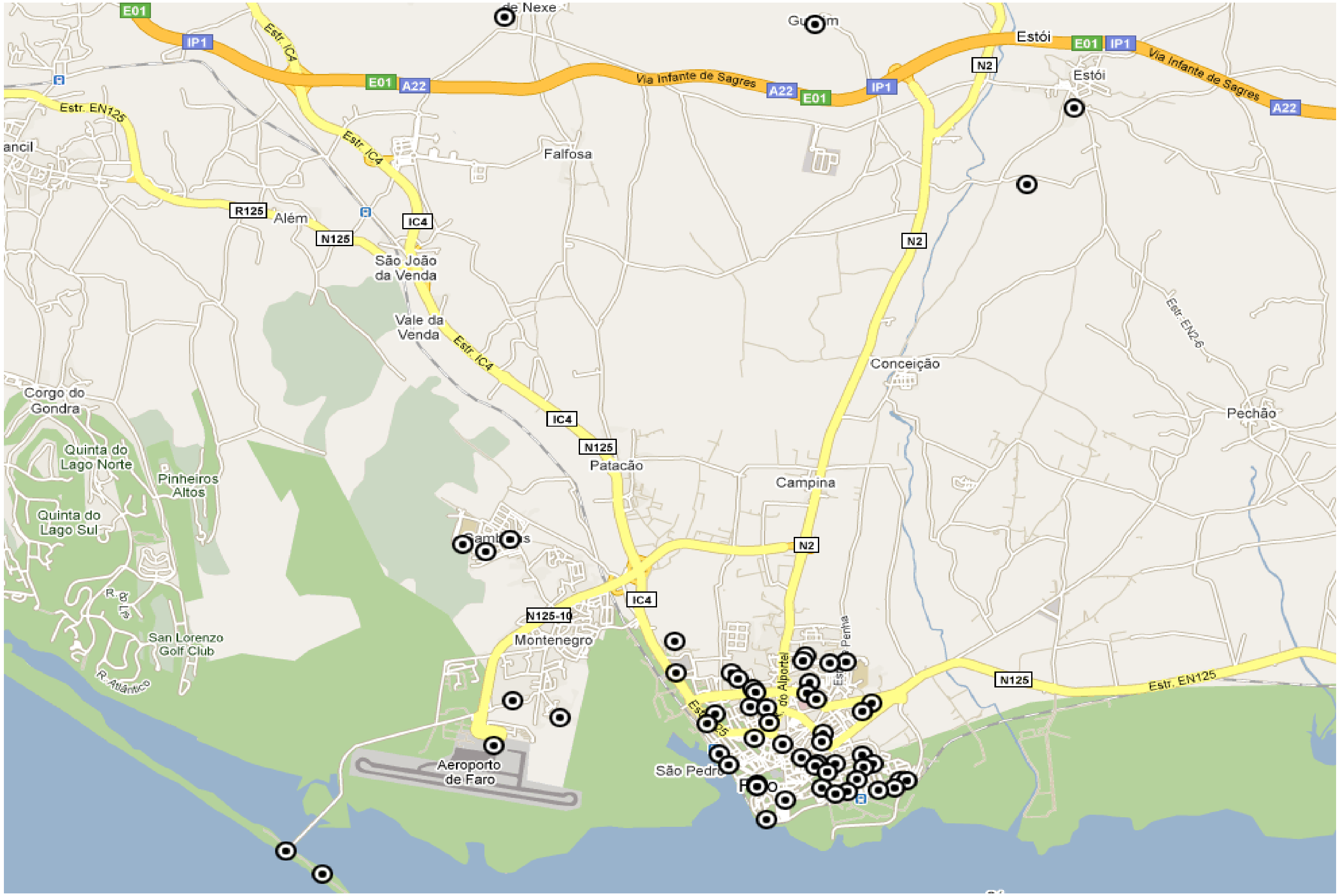


Figure 2 – Observations points in the municipality of Lisbon

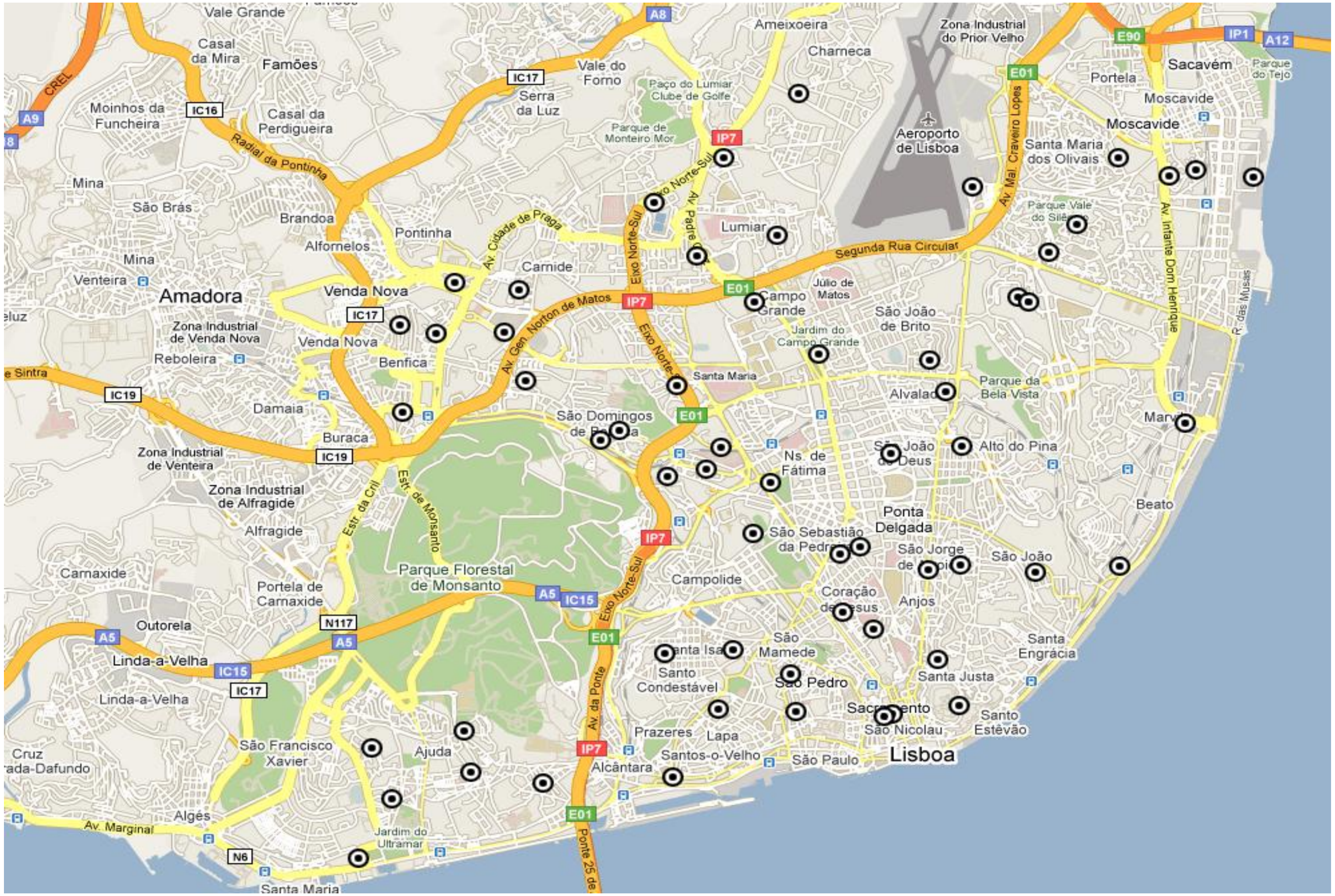


Figure 3 – Observations points in the municipality of Porto

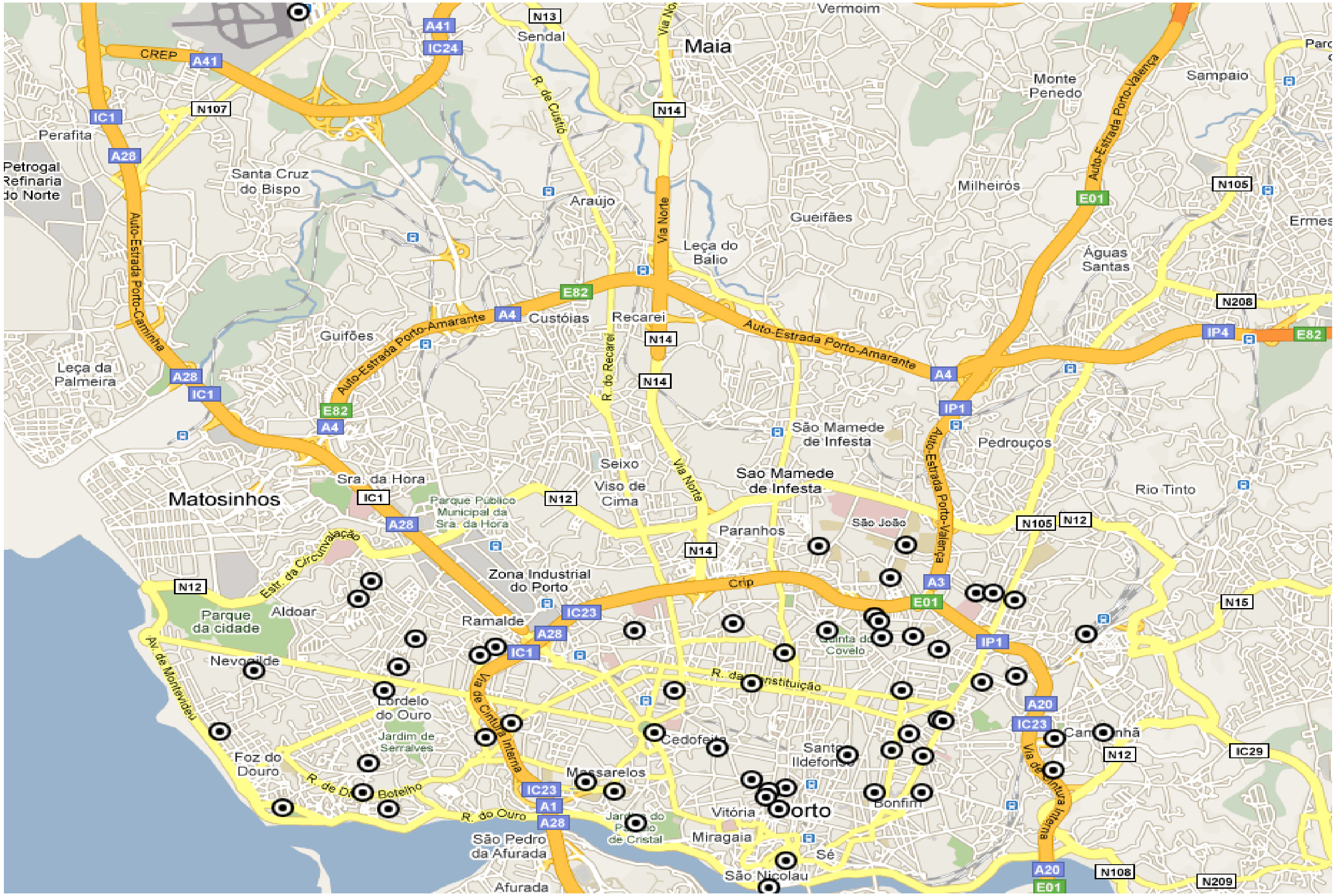


Table 1 shows the sample sizes obtained. It should be noted that a total of 61 measurements were carried out in each location of the panel: 9 for each day of the week and 8 for each day of the weekend.

Table 1 – Sample size by segment

Segment	Sample
UMTS users	540
UMTS users per Operator	180
Measurements: per indicator and operator	32,940
Measurements: per indicator, operator and city	10,980

We can see from the above table that a panel of 180 locations was set up, evenly spread between the municipalities of Lisbon, Faro and Porto (60 users per municipality). The three operators were evaluated at each location, which made it possible to set up a total sample of 540 users.

Regarding measurements per indicator and operator, at least three tests were carried out for each time period (one test for the FCCN server and two tests for international ISP servers, one of them in Europe and the other in the USA), meaning 3 tests X 61 periods X 180 households. This yielded 32,940 measurements per indicator and operator, and 10,980 measurements per indicator, operator and city (3 tests X 61 periods X 60 households).

The study focused on the commercial offerings of each operator, as follows.

Table 2 – Commercial offering under study per mobile access operator[1]

Mobile operator	Technology	Commercial offering trade name	Maximum Download speed (Mbps)	Maximum Upload speed (Kbps)
Optimus	UMTA-HSDPA[2]	Kanguru Basic	2	384
TMN	UMTS-HSDPA	10/25 Pre-paid Broadband	2	384
Vodafone	UMTS-HSDPA	Vita Net Plus	2	384

Tests were carried out on weekdays and at weekends between 27 November 2009 and 7 February 2010[3], according to the following schedule:

[1] The operators have different understandings of the maximum download speed of the offering under study. Although the commercial offering analysed indicates maximum downlink speeds up to 2 Mbps, and 384 Kbps uplink speeds, the profiles recorded in the HLR have different speeds for each operator. TMN's SIM cards have defined speeds of 2560 Kbps for downlink and 5824 Kbps for uplink. Vodafone sets the profiles for its SIM cards with maximum speeds of 2432 Kbps for downlink and 384 Kbps for uplink. Optimus has defined the maximum speeds of 2432 Kbps for downlink and 576 Kbps for uplink. It is possible to see that all operators allow higher download speeds than those commercially advertised, and that TMN and Optimus also allow higher uplink speeds than those defined commercially.

[2] High-Speed Downlink Packet Access

[3] Measurements were interrupted between 23 December 2009 and 3 January 2010 since this was considered to be an atypical period.

Table 3 – Distribution of mobile access tests

Order	Week days	Weekends
From 8h00 to 10h00	X	X
From 10h00 to 12h00	X	X
From 12h00 to 16h00	X	X
From 16h00 to 18h00	X	X
From 18h00 to 20h00	X	X
From 20h00 to 21h00	X	
From 21h00 to 23h00	X	X
From 23h00 to 1h00	X	X
From 1h00 to 4h00	X	X

1.3 Quality control of results

Rigorous quality control was ensured for the work carried out during all stages. During the information collection stage, data collected was regularly monitored to detect any anomalies that could affect the quality of measurements. Later, quality control of the information collected included the analysis of atypical values. Outliers were identified on several measurements, explained by the servers' downtime. These values were excluded.

1.4 Precision of results

The precision of the results[4] obtained for an average, with a 95% confidence level, for one of the collected indicators (download speed, in this case) is described in the table below:

[4] The *Absolute Precision* of results, also named (Absolute) Error Margin, corresponds to half the amplitude of the confidence interval for the variable under study. *Relative Precision* corresponds to the Absolute Precision divided by the estimate obtained for that variable.

Table 4 – (Absolute and relative) precision for the download transfer speed, per operator, server and municipality

		Absolute Precision (kbps)			Relative Precision		
		OPTIMUS	TMN	Vodafone	OPTIMUS	TMN	Vodafone
FARO	USA	5.05	2.44	4.86	0.5%	0.3%	0.5%
	UK	17.49	5.75	16.66	1.1%	0.5%	1.0%
	National	19.77	7.27	19.90	1.3%	0.6%	1.2%
LISBON	USA	4.61	2.15	5.17	0.4%	0.3%	0.5%
	UK	18.19	5.82	17.15	1.0%	0.5%	0.9%
	National	19.36	7.00	19.09	1.0%	0.5%	1.0%
PORTO	USA	4.79	1.83	4.24	0.5%	0.3%	0.4%
	UK	13.84	6.36	12.17	0.9%	0.5%	0.7%
	National	13.19	7.58	15.07	0.8%	0.6%	0.7%

It should be noted that a formula corresponding to a simple random sample was used for calculating the error margin, since the weight of the crossing variables was unknown.

For a more detailed reading of the error margins see the report in Annex 4.1.

1.5 Weighting

Results were adjusted so that after the adjustment the sample observations weighted by the *Week day* and *Period* variable modes had the same weight within each operator, server and municipality.

1.6 Technical Architecture, Operating Mode and Component Detail

1.6.1 Technical Architecture

TEMS™ Automatic was the technical solution used to assess the quality of the mobile broadband access service.

TEMS™ Automatic is an autonomous system that makes it possible to assess the quality perceived by the end user. It provides a large volume of information that can be used for a clear and precise statistical comparison of the performance of several mobile operators or several commercial offerings within a mobile operator. It also makes it possible to obtain details for the identification/resolution of problems and analyses. Measurements are carried out without human intervention.

The architecture of the TEMS™ Automatic system implemented for this study comprised:

a. 30 remote measurement units: MTU
b. 1 central server for data collection and processing
c. 1 FTP/HTTP server installed at FCCN
d. 2 international servers (Houston, London)

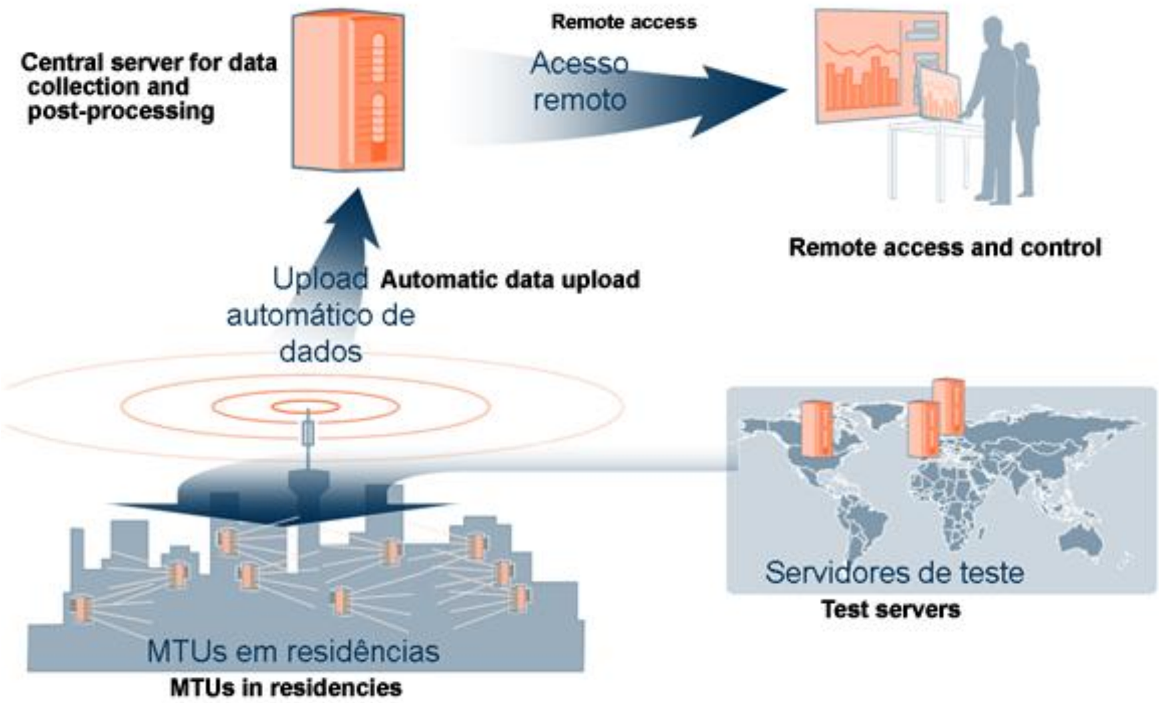


Figure 4 - Test Architecture

The remote measurement units (from here on designated MTU) were placed motionless in the indoor and outdoor accesses, where they carried out the tests automatically during the previously determined schedules.

Tests were carried out by assessing the connections from the MTU to each of the three servers. After the MTU has collected the test data, this information is sent to the central server, for post-processing.

The work orders were sent to the MTUs automatically, once they were installed in the various accesses. The collected data is also sent to the central server automatically, at regular intervals.

Data post-processing is carried out when this information is received at the central server, where it is added to the system's database for later analysis. From this point a massively populated database was created using all collected data that could allow a robust statistical comparison between operators.

1.6.2 Operating mode

MTU placement was preceded by coverage verification, guaranteeing a minimum RSCP – Received Signal Code Power of -90 dBm for the UMTS signal. The existence of HSDPA technology for the three operators was also confirmed.

The tests were then carried out for one week in each location, fulfilling the same criteria for all accesses that were part of the sample for the cities of Faro, Lisbon and Porto, 60 locations in each municipality in a total of 180.

Units were kept motionless (static) and unobstructed during the collection period.

The test sequences carried out by the measurement units used software applications that made it possible to assess the indicators presented in this study for each operator, using connections to all national and international servers.

The same propagation conditions were guaranteed for the three operators by using a single 3G data card with an external antenna in the measurement unit. Tests were separated by minimum time intervals by using the measurements unit's "SIM Multiplexing" functionality. Thus, a SIM card of each operator used alternately a single 3G data card for transferring the HTTP page, for the upload or download of the binary FTP file, for carrying out the Ping test or the Streaming tests to the targeted test servers.

1.6.3 Component detail

MTU remote measurement unit

The MTU750 unit was used in the study.

A single external antenna connected to the unit’s data card guarantees exactly the same radio conditions for the 3 operators under analysis. Each unit was geographically referenced in order to localise the indoor or outdoor access.

The data card in the MTU750 is compatible with 3GPP specifications, allowing HSDPA speeds up to 7.2 Mbps and HSUPA up to 2Mbps (*Option Globetrotter data card used in MTU750 is a 7.2 Mbps/2Mbps capable data card)*.

The MTU had 3 SIM cards installed in order to carry out the tests for each operator (Optimus, Vodafone and TMN).

Figure 5 - MTU750

National and International FTP/HTTP Servers

In order to assess the indicators for each operator, the MTUs carried out HTTP, FTP, Streaming and Ping tests to a Portuguese server and 2 international servers with the following characteristics:

Portugal (Lisbon FCCN):	Sun Solaris 10
	RAM 16GB
USA (Houston):	Microsoft Windows Server 2003 SP2
	Intel Xeon CPU 2.4GHz
	RAM 2GB
UK (London):	Microsoft Windows Server 2003 SP2
	Intel Core2 Duo CPU 2.93GHz
	RAM 2GB

2. Methodology – Fixed Accesses

2.1 Target Population

The target population is made up of Mainland Portugal households with at least one individual using the Internet from home, having one of the following Operators, and corresponding packages, as their ISP (Internet Service Provider):

Table 5 – Commercial offering studied by Fixed Access Operator

Target ISPs	Technology	Commercial offering under analysis	
		Maximum download speed	Maximum upload speed
Cabovisão	**Cable**	10Mbps	512Kb
Clix	**ADSL**	24Mbps	1Mbps
Sapo	**ADSL**	4Mbps	1Mbps
Vodafone	**ADSL**	12Mbps	1Mbps
Zon	**Cable**	10Mbps	512Kb

The offerings analysed are the Operator's most representative Offering.

2.2 Sample definition and selection

The sample was chosen by probability sampling. {0>One of the main decision-makers in choosing the Internet service was selected in each household. The study excluded all households where at least one of the members worked for entities or departments related to: ICP-ANACOM, telecommunications or market studies. Recruiting was done by phone.

A stratified random sample was designed by region (table 6) and, within each region, by NUTIII, having been selected from address listings included in the regions considered for this study. The stratification by region was distributed in proportion to the number of customer households of the operators and to the offerings under study in each region.

One of the main decision-makers in choosing the Internet service was selected in each household. The study excluded all households where at least one of the members worked for entities or departments related to: ICP-ANACOM, telecommunications or market studies. Recruiting was done by phone.

In each household, only one access was selected in the test period (seven days), which was reserved for carrying out the tests (see 0). After quality control, 258 measurements were considered valid, and they had the following distribution:

Table 6 – Sample size by segment (ISP and Region)

ISP	No. of measurements
Cabovisão	52
Clix	52
Sapo	51
Vodafone	53
Zon	50

Region	No. of measurements
Algarve and Alentejo	25
Centre	57
Lisbon	102
Greater Porto	39
North	35

It should be noted that the distribution per region had the sole purpose of guaranteeing the geographical dispersal of measurements rather than to achieve statistical representativeness.

The regions presented correspond to an aggregation of the NUTIII regions:

- **Algarve to Alentejo**: Alentejo Central; Alentejo Litoral; Alto Alentejo; Baixo Alentejo; Lezíria do Tejo; Algarve.
- **Centre**: Baixo Mondego; Baixo Vouga; Beira Interior Norte; Beira Interior Sul; Cova da Beira; Dão-Lafões; Médio Tejo; Oeste; Pinhal Interior Norte; Pinhal Interior Sul; Pinhal Litoral; Serra da Estrela.
- **Lisbon**: Greater Lisbon; Setúbal Peninsula.
- **Greater Porto**
- **North:** Alto Trás-os-Montes; Ave; Cávado; Douro; Entre Douro e Vouga; Minho-Lima; Tâmega.

A total of 61 measurements (9 per week day and 8 per weekend) were carried out in each household. At least 3 tests were carried out in each indicator, operator and time schedule (one test for the FCCN server and two tests for the international ISP servers); therefore, 3 tests X 61 periods X 52 households, giving an average of 9,516 measurements per indicator and operator.

Tests were carried out on weekdays and at weekends between 5 December 2009 and 17 March 2010[5], according to the following schedule:

Table 7 – Distribution of fixed access tests

<table>
<tr><th>Order</th><th>Week Days</th><th>Weekends</th></tr>
<tr><td>From 8h00 to 10h00</td><td>X</td><td>X</td></tr>
<tr><td>From 10h00 to 12h00</td><td>X</td><td>X</td></tr>
<tr><td>From 12h00 to 16h00</td><td>X</td><td>X</td></tr>
<tr><td>From 16h00 to 18h00</td><td>X</td><td>X</td></tr>
<tr><td>From 18h00 to 20h00</td><td>X</td><td rowspan="2">X</td></tr>
<tr><td>From 20h00 to 21h00</td><td>X</td></tr>
<tr><td>From 21h00 to 23h00</td><td>X</td><td>X</td></tr>
<tr><td>From 23h00 to 1h00</td><td>X</td><td>X</td></tr>
<tr><td>From 1h00 to 4h00</td><td>X</td><td>X</td></tr>
</table>

2.3 Quality control of results

The work being carried out was subject to a rigorous quality control throughout all stages of the study. In the first stage, during the data collection period, collected data was regularly monitored in order to detect any anomalous situations. Some examples include the identification of maximum speeds faster than those declared by participants, therefore outside the sample under study, or very low speeds justified by reasons related to the test panel member. At the same time all test panel members were asked to send their bill, not only where there were some doubts, but in order to confirm the commercial offering under analysis during the test period.

After the measurements, Outliers were identified for later analysis. Extreme values explained by server downtime or by faults attributed to test panel members were eliminated. The remaining values, even if extreme, were kept since they could not be traced to any other sources apart from the operator´s service.

[5] Measurements were interrupted between 23 December 2009 and 3 January 2010 since this was considered to be an atypical period.

2.4 Precision of results

Result precision obtained for an average, with a 95% confidence level, for one of the collected indicators (download speed in this case) is described in the table below:

Table 8 – (Absolute and relative) precision for the download transfer speed, per operator and server

		Absolute Precision					Relative Precision				
		Cabovisão	Clix	Sapo	Vodafone	Zon	Cabovisão	Clix	Sapo	Vodafone	Zon
Server	USA	42.18	34.53	45.44	20.30	55.74	2.3%	1.8%	2.2%	1.0%	2.6%
	UK	68.69	64.95	57.78	59.74	92.58	1.7%	2.0%	2.4%	1.5%	2.3%
	National	102.98	164.45	59.17	186.08	120.04	1.4%	2.6%	2.2%	2.0%	1.5%

It should be noted that for calculating the error margin a formula corresponding to a simple random sample was used, since the weight of the crossing variables was unknown.

For a more detailed reading of the error margins please see Annex 6.1.

2.5 Weighting

Each element of the sample was given a weight that made it possible to establish a statistical inference for the entire target population. The method used to determine these weights, or extrapolation factors, was the adjustment by margins, which adjusts the results obtained to known totals of support variables, in order to correct possible distortions registered in the sample.

First of all each test panel member was weighted according to the region and the operator they belong to, based on the information supplied by the ISP on the weight of each region in the total amount of customers of the offering under analysis.

An adjustment was carried out later by replacing the initial weight factors of the sample individuals with the final adjusted weight factors, using a distance factor subject to the following restrictions: for the *Week day* and *Period* variables, the weighted observations of these variables' modes in the sample after the adjustment keep the same weight within each operator and server.

The determination of the weight factors is thus an optimization issue, whose purpose is to reduce the distance between the initial weights and the final adjusted weights, subject to the conditions that guarantee that the extrapolated support variables with final adjusted weights are equal to the known population totals.

2.6 Technical architecture, operating mode and component detail

The IxChariot tool was used to assess the quality of the fixed broadband access service.

Aiming to test and evaluate ISP quality of service, the IxChariot made it possible to measure the performance of the Internet access service in order to identify characteristics describing the user's experience.

IxChariot generates and analyses traffic by creating with precision data flows of client/server transactions, providing real traffic flows between network endpoints, for the most relevant transport protocols (TCP, UDP, RTP, IPX).

Figure 6 - IxChariot system components

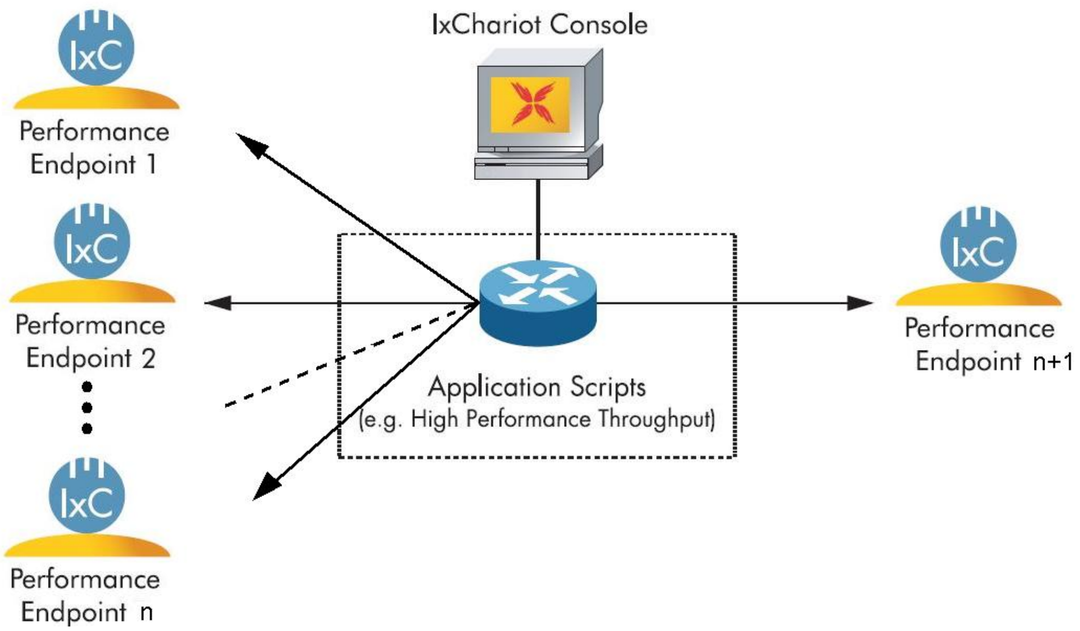


Figure 6 represents the components of the IxChariot system. Tests are carried out from one Endpoint to another Endpoint, with test scheduling and execution orders being sent by the “IxChariot Console”. Endpoint n+1 Performance corresponds to the software agents installed on the national and international servers.

For this service the solution was to place a “Performance Endpoint” on the national and international target servers allocated for this evaluation. The remaining Endpoints are hardware agents that were installed in the households of the test panel members with the broadband connections to be evaluated. The “IxChariot Console” managed and scheduled the tests between the several “Performance Endpoints” distributed on the networks and the “Performance Endpoint” installed on the national and international servers (Performance Endpoint n+1), whose description was already included in the mobile tests details (common target servers).

The “IxChariot Console” scheduled, collected and stored the data obtained during the tests carried out, together with the “Aptixia Test Conductor” application.

As a result one obtains detailed measurements of the end user experience, as well as measurements that indicate the network’s performance.

Application traffic on a network has a dynamic character which translates into a statistical variety of performance measurements undergoing constant change. Through the distribution of network endpoints (IxChariot endpoints), IxChariot makes it possible to have an image of the network at each moment, thus making it possible to identify possible network performance problems.

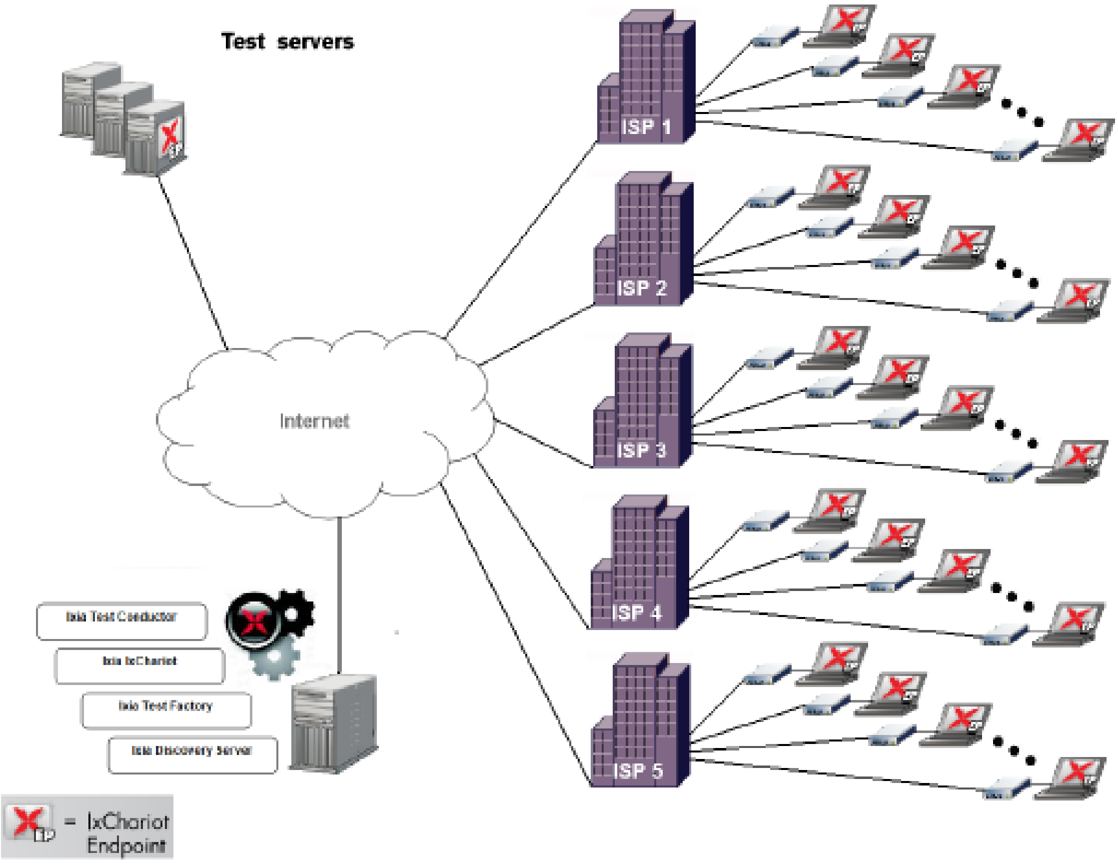
In the particular case of file transfers through the Bittorrent (Peer-to-Peer tests), a test topology similar to an FTP transfer was implemented, i.e., only 2 peers were included in each transfer (one was installed on a test customer/residence, and the other on a target server). As with the remaining ones, the tests were carried out through the IxChariot (Bittorrent emulation). There is no centralized broadband control of the tool, rather, each peer is responsible for trying to maximize its download bandwidth by means of a variant of a known mechanism called "tit-for-tat"[6]. This mechanism is simply based on a reciprocity effect between peers when all collaborate in file sharing. Meaning, if one peer who starts a file download shows interest in cooperating, allowing other peers to upload that file simultaneously, it will automatically benefit from a higher download speed. When the download process is started for the first time, the peers are optimistic by default and they all rely on the cooperation amongst them. After the first seconds of file exchanges, if this initial optimism is not sustained by some peers (available for upload), then it triggers the mechanism, named choking, of the upload speed of some peers, which means the download for others. In the specific case of the tests carried out only 2 peers were used who were configured in the most optimistic mode in order to maximize the bandwidth in both directions. Regarding the publication of results, the tests relating to download were published, by analogy with the FTP transfer.

System architecture

The measurement units (hardware agents) were installed in the test panel members' households by sending from the hardware agents. The agents will be detected by the Discovery Server solution once correctly installed.

[6] http://en.wikipedia.org/wiki/Nice_Guys_Finish_First

Figure 7 - Architecture of the proposed system



Each software agent was controlled remotely through the "IxChariot Console", at the bottom left of Figure 7, which is installed on an independent machine, carrying out the detailed scheduling together with the "Aptixia Test Conductor", through work orders in the time, operator, technology, type of application, and other domains.

Agent identification

The solution offered identified each customer through the assigned IP. The possible change of IP by means of automatic refreshing of the ISP or other situation such as rebooting the machine was catered for by a dynamic DNS service.

A single code was also used at the time of installation in order to check the records each time the application was executed.

3. User experience

The public's knowledge and experience of telecommunications services and Internet usage are increasing, which also increases the expectations that the services subscribed will perform well. In a growing telecommunications market, where new services are created and implemented rapidly, end users evaluate operators by the service offerings they provide and by their performance.

The quality of service perceived by the user (usually called QoE – “Quality of Experience”) is partially determined by general factors such as the activation/connection time and successful access to the service, and partially by the actual connection, meaning the speed, download and upload times, and latency.

The quality of service is also related to different indicators, depending on the type of software application used, since different applications have different requirements.

The most frequent transactions and the differentiating factors for their performance are presented below.

Web Browsing

Web Browsing quality is normally associated with the time needed to locate and download Internet pages through a given web browser. Speed or bandwidth and latency are the factors that help to improve experience in this type of transaction.

File transfer

It consists of the typical download of files, usually of applications, documents, music and images by using a specific file transfer communications protocol, such as FTP or, sometimes, HTTP. The differentiating factor for a positive perception of file transfer is the upload and download speed.

File sharing (P2P)

File sharing or Peer-to-peer (P2P) is a common mode for transferring different types of files, such as music and movies[7]. Usually associated with 'happy hours', this type of traffic generates high volumes of information and generally reduces the bandwidth available during those periods, where it is also common for operators to implement bandwidth control policies (traffic management mechanisms). The download and upload speeds are differentiating factors in this case.

Gaming

Currently there is a significant variety of on-line games for mobile terminals and for PCs, which require Internet connections that guarantee interactivity with other players. Latency and loss of packets are differentiating characteristics for these connections, in order to ensure a positive perception by users. Upload and download speeds are also important in this perspective.

This study used the applications normally employed for the actual evaluation of the performance indicators from the end user's point of view, viz.:

a. File transfer – FTP protocol

b. File transfer – P2P protocol

[7] The reference to the download of music and movies is made within a context of a legitimate use. It is not the purpose of this study to make any consideration about the contents transferred or the illegal appropriation of copyright. The framework for the assessment of this indicator is strictly within the scope of network neutrality, a fundamental principle that is clearly stated in the European regulatory framework in the field of telecommunications through amendment 46 of the Telecom Package. BEREC is also currently studying the future definition of acceptable and unacceptable practices in the field of traffic management that are currently adopted by the ISPs.

c. Web browsing – HTTP protocol

d. Latency – PING (ICMP protocol)

Below are some **definitions** for a better understanding of this document's technical content.

Download

Transfer of content from an Internet location to a personal computer.

Upload

Transfer of content from a personal computer to a given location on the Internet.

kbps (kbit/s)

Measurement unit for speed (download and upload).

kB (kByte)

Measurement unit for data volume.

Transfer speed / Web browsing speed

Speed at which data is transferred between computers. Since the volumes of data to be transferred are getting larger and larger, a high speed is desired in order to reduce the transfer times. The webpage used in the tests is made up of an initial page and secondary pages implemented separately, in compliance with the W3C (World Wide Web Consortium), with a mix of images, drawings and texts, and the approximate size of 150kB. This page was associated with four links from the homepage, each with text and an image and an approximate size of 100kB.

Data packets

The data packet is made up of a sequence of bits that are transmitted according to a well defined structure. When it has to be transmitted, data is divided according to those data structures (packets) which contain information that enables them to reach their destination (destination computer). However, packets are grouped so as to retrieve the original information.

Latency

In a data network, latency is defined as the time that a data packet takes to travel from one point to another (from origin to destination). It is fairly common to measure latency through the PING application. This application makes it possible to send an echo request packet, to which the response is an echo reply from the destination. The time elapsing from the sending of the echo request to the reception of the echo reply is defined as latency or one-way delay.

4. Indicators

This section presents the indicators analysed within the scope of this study, including measurements for Internet access reliability and application performance, i.e. web browsing, file transfer, etc.

Service access failure

Given that the service is available in a certain area (the possibility of accessing the Internet, guaranteed by the operator’s existing coverage and the availability of the requisite technology), it is important to know that it is ready to be used at any time.

This indicator provides the percentage of cases where it was not possible to establish a connection to the data network. The reasons for failure can be related to network conditions.

Causes of failed service access

This indicator details that fault that is responsible for the service access failure.

The connectivity of mobile networks to external networks (Internet) is based on the creation and maintenance of “PDP contexts” for the relevant mobile and data networks. PDP means Packet Data Protocol. In order to send and receive data the mobile device (mobile phone or card) creates what is called a “PDP Context”. This PDP context enables the transfer of data between the mobile device and the Internet access (a mechanism which establishes, for the system, the authentication and authorization of the user to benefit from that service).

IP means “Internet Protocol” and it specifies how to segment the information by data packets so these can be transferred from one point to another, including the specification of the source and destination addresses from which and to where the packets must be transferred.

In short, and reducing the process to how the analysis is carried out, the mobile device guarantees the connectivity between itself and the operator’s data network through the “PDP Context”, while the connectivity from the operator’s data network to the Internet is guaranteed through the “IP Connection”.

Activation/connection time

This indicator represents the time needed to access the service successfully, i.e., to activate the “PDP Context” and establish a specific access to the service.

Latency

Latency is the time elapsed from the beginning of a transaction and the first reply to that transaction. It is one of the fundamental properties that affects the efficiency of the HTTP and TCP communication protocols.

In order to guarantee a good performance of the connections, it is best to have a low latency (the lower the latency, the better the performance). The latency determines the speed at which a TCP connection can be established, and in some cases the maximum data transfer speed.

For the end user this indicator signifies that if the latency is very high the desired speed may not be reached, or it may take longer to reach it. This indicator is particularly important when loading pages (web browsing) made up of several objects.

PING is the way of measuring a network's latency, using the ICMP protocol's echo command. It sends a data pattern to a network point and requests it to send back a reply with the same pattern. This process allows the PING to measure the time that elapses between the request and the reply. The size of the PING packet used in this study was 256 bytes.

NOTE: latency measured with PING is used as a generic indicator. There are many factors that affect the latency of different protocols and applications.

Time to load a page (web browsing)

Page download times while browsing the web are usually more perceptible for the end user since they represent the time spent waiting to see the entire page requested. Port 80 is used (usual for HTTP over TCP).

File transfer speed

The file transfer speed is defined as the volume of data transferred from one network point to another, in time. It is usually measured in Kilobit/s (Kbps) or Mbit/s (Mbps). It is important to notice that quite big files should be used with respect to the access speed in order to correctly assess it. This is because, in each FTP session for example, there is a number of constant delays due to the connection time and to the start-up of the related protocols (TCP), whose impact should be minimized with respect to the real transfer time. In the case of transfer via Bittorrent, it used a file of the same total size as that used in FTP, although that application divides the file to be transmitted into equal portions of 250 kB, or even into 16 kB sub-portions (when the access is slow).

So in order to guarantee a rigorous evaluation of the upload and download transfers, test files should have a recommended size (in kB) of at least twice the maximum size of the connection in kbps. But whenever possible the size implemented was four times greater.

However, since there was some variability in the actual speeds recorded (lower speeds) versus those advertised, with the immediate repercussion of compromising the time frames available for carrying out the battery of tests, a scheme of adaptive file dimensions was implemented. This way, and regarding the test files used for fixed accesses, their size took into account the average download and upload speed obtained for each access tested (considering the rule about file size described above).

In the case of mobile network accesses, randomly created binary files were used, with a size of 4 MB for download and 1.6 MB for upload. The same file was used for all operators since all their advertised speeds should be similar.

NOTE: the file transfer speed (FTP protocol) is quite different from the web browsing speed (HTTP protocol). The speed reached during an HTTP session is much slower that the one achieved during an FTP session. The reason for this is that the HTTP protocol is greatly affected by latency (RTT), mainly on mobile networks. HTTP transfers require multiple TCP connections, as well as DNS lookup. Each TCP connection requires several RTTs to completely open the TCP sending window, and each DNS lookup requires several RTTs before mapping the domain name to the IP. These RTTs and TCP/DNS considerably degrade the HTTP performance. Considering this difference, web browsing speed and file transfer speed are not directly comparable.

Loss of Packets

The loss of packets can be cause by several factors including data corruption, insufficient bandwidth, and the delivery of packets in the wrong order. Any loss of packets affects the quality of service; but its impact varies according to the application in question. In order to evaluate the loss of packets a streaming script is used; this is an application where the loss of packets has an impact on the quality of service.

Jitter

When a datagram is sent, the issuer adds a timestamp to it. When it is received, the receiver adds another timestamp to it. These two timestamps are used to calculate the datagram's transit time. If the datagrams' transit time for the same test differs for different sessions, the test experiences jitter. In fact, Jitter effects are similar to those of the loss of packets, since the jitter causes "buffer starvation", which is equivalent to the loss of packets.

The volume of jitter in a test depends on the degree of difference between the datagrams' transit times. If the transit time is similar for all datagrams (regardless of the transit time), the test experiences no jitter.

DNS (Domain Name System) resolution time

The quality of the usage experience during web browsing is usually accredited to the time associated with the location (resolution of the page address) and the loading of the requested page by the web browser.

One of the parameters that most contributes to this application's good performance is the response time of the page resolution server (DNS – server response time). One of its most common uses is to translate machine names into their IP addresses and vice-versa.

For it to be possible to evaluate the DNS server resolution time, each battery of tests included the access to about one hundred web pages (top 100 pages most visited by Portuguese users).

The purpose of this test was to evaluate the performance perceived by residential users who usually use the DNS servers provided by their ISPs, using for that purpose a DHCP (Dynamic Host Configuration Protocol) configuration in their network interfaces. This way all local cache mechanisms used for DNS resolution (operating system and Internet browser) were eliminated.