European Commission

JRC TECHNICAL REPORT

Roaming Performance Study (Smart 2018/0011) Final Report

An assessment of technical performance of mobile networks for Roaming in the EU

Chawdhry P., Folloni G., Lumachi S., Luzardi S.

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Contact information
Name: Pravir Chawdhry
Address: TP723, via E. Fermi 2749, Ispra (VA), I-21027 Italy
Email: Pravir.Chawdhry@ec.europa.eu
Tel.: +39 0332 785823

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Contents

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Authors

Chawdhry P., Folloni G., Lumachi S., Luzardi S.

Abstract

In the context of the review of the EU Roaming Regulation, this document presents results of a study on roaming performance assessment by field measurements on mobile broadband involving 40 mobile networks in 13 EU countries. JRC's mobile app netBravo was used to carry out the measurements and analysis of data. Download speed, upload speed and latency were measured for all roaming tests and results were analysed. The study found mixed results on the quality of service (QoS) in roaming. Customers had better as well as worse QoS than at home. However, customers of 21 mobile networks from 11 countries at least once had worse QoS in roaming compared to at home even when technical conditions were available for better quality. Such cases accounted for 25% of all roaming instances in the tests.

Glossary

Bandwidth (of a network)	The capacity of a network communications link to transmit the maximum amount of data from one point to another in a given amount of time. Available bandwidth are set by the MNO separately for the **downlink traffic** and **uplink traffic** to optimise resource allocation for the overall quality of service in mobile broadband
Customer SIM	The SIM card issued by an operator to a specific customer under a contract
Downlink	The network communications link to carry the traffic from an end-point towards the end-user (the customer)
Download (DL) by an end-user	The customer activity (generated data traffic), which requires the network to deliver data from an end-point (an online service, database, website etc.) to the customer's mobile device
Domestic operator	Home (network) operator
EU	European Union
Home (network) operator	The mobile network operator with which the end-user has a service contract. It provides the user with a SIM to enjoy the electronic communications services specified in the contract.
Home customer / Home user (of a network)	The end-user who has the service contract with a network operator (= MNO customer)
Home user of the visited network	A SIM used in its own country and own network, while the network is being visited by roaming users from other countries
Home country	The country where the end-user's home operator is established and issues a network SIM for its electronic communications services
International roaming	Roaming by an end-user on a mobile network in another country
Jitter	Jitter is the irregular speed of different packets travelling in a telecom network between two end-points. It is important in real-time applications such as voice communications where it can result in packet arriving late and out of sequence, which can cause garbled sounds.
Latency	The time it takes for a data packet to travel from its source to its destination and back to the source in an electronic communications network. Also known as the *round trip time*
Mbps	Megabits per second: a measure of data transfer rate in an electronic communications networks
MNO	Mobile Network Operator, an operator that builds its own network and has full control of domestic usage on its network
MNO customer	The end-user who has the service contract with a mobile network operator
MVNO	Mobile Virtual Network Operator, an operator that rents access to a piece of the domestic operator's network and does not build its own access infrastructure.

ms	Millisecond, a measure of time used in electronic communications networks
MS	Member State
Perceived quality	The quality of service experienced by an end-user while using a mobile service, without measuring it technically
QoS	Quality of Service
QoE	Quality of Experience of an internet access service involving end-to-end customer experience. Also known as QOS-3.
RLAH	Roam like at home, the EU initiative ending additional charges on roaming across the EU countries
Roaming	The ability of an end-user to connect to, and use services of, a mobile network other than (the one of) its own home operator's
Roaming customer	A customer of a roaming provider of regulated roaming services, whose contract or arrangement permits Union-wide roaming
Roaming peers	Two or more roaming customers who happen to be visiting the same MNO abroad in the same location and at the same time
SIM (card)	Subscriber Identification Module, the chip which provides the end-user with authenticated access to a mobile network when it is inserted in the end-user's mobile telephone
Visited (network) operator	The operator that supplies services to the roaming end-user in a visited Member State
Visiting SIM (card)	The SIM card of a roaming user when it is connected to a visited network
Uplink	The network communications link to carry the traffic from the end-user (the customer) towards another end-point
Upload (UL) by an end-user	The customer activity (generated data traffic), which requires the network to transfer data from the customer's mobile device to another end-point (an online service, database, website etc.)
User experience	The QoS of a network as experienced by an end-user in the use of an electronic communications service

List of figures

List of tables

Executive Summary

Regulation (EU) 531/2012 of the European Parliament and the Council of 13 June 2012 on roaming on public mobile communications networks within the Union, amended in 2015 and 2017 (hereinafter the 'Roaming Regulation'), mandates the Commission to conduct a review by December 2019 of the roaming rules. One of the review requirements is to provide an assessment of the availability and quality of roaming services. The Commission's Review report[1] was adopted on 29 November 2019, and is followed by a legal proposal.

Following a request by Directorate-General for Communications Networks, Content and Technology (DG CNECT) for the above review purpose, the Joint Research Centre (JRC) undertook preliminary work, to assess the technical performance and quality of service (QoS) of EU roaming in a small sub-set of EU Member States (MSs) during the first year of the RLAH rules taking effect (i.e. between October 2017 and August 2018). This work served as a scoping exercise for a systematic approach developed later on in the present study for further tests carried out between October 2018 and October 2019.

In the present project, assessment of the performance of roaming has been based on real data from extensive field measurements on mobile networks in a subset of EU MSs. The JRC mobile app netBravo[2] was used to measure mobile network performance. The data thus collected was analysed to help answer relevant policy questions posed by DG CNECT. Results of the analysis are used to further inform the Impact Assessment for the review and prolongation of the Roaming Regulation[3].

Results from the present study by the JRC have contributed in terms of evidence-based assessment of roaming performance to the roaming review led by DG CNECT in 2020. Additional tests measuring the performance of MVNOs SIM cards when roaming were foreseen during the first half of 2020. Due to the COVID pandemic and travel restrictions those measurements had to be cancelled.

The present project complements the work carried out by the JRC.I1 unit on the economic aspects of the roaming markets under the projects SMART 2018/0010 and SMART 2019/0004.

What were the research questions?

(1) Whether roaming customers have different quality of service when roaming compared to the performance on their own home network.

(2) Whether quality of service on visited networks differs between the customers of the visited network and the roaming users visiting the network.

(3) Whether roaming customers have different quality of service on a visited network compared to other visiting roaming customers.

(4) How often did customers have worse quality of service in roaming than at home, even when the visited network was technically and practically able to provide better quality?

[1] Report on the review of the roaming market, COM(2019)616 final, and SWD(2019)416 available here.

[2] For further information and how to download netBravo, see the Annex to this Report and netbravo.jrc.ec.europa.eu.

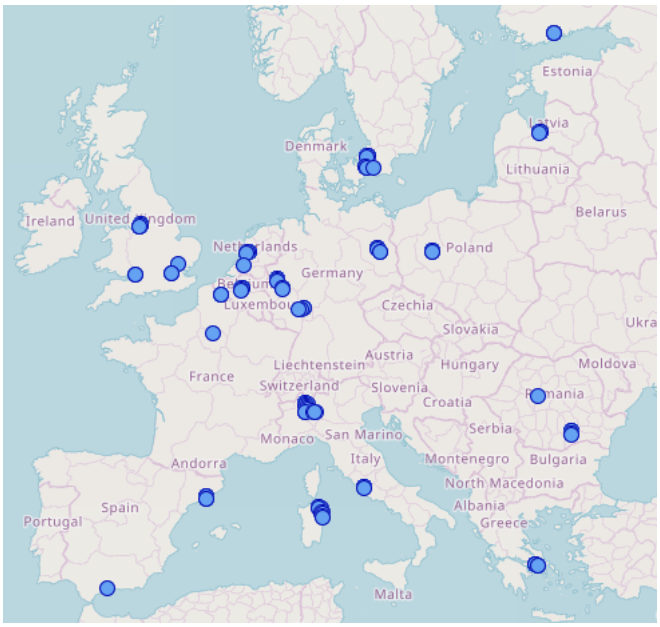
[3] This Initiative is included in the 2020 Commission Work Programme addressing the specific objective "Digital for consumers" and has to be seen in the broader political context of creating a Europe Fit for the Digital Age. The Initiative contributes to the ambition to make the most out of the digital transition to enhance opportunities to connect, communicate, solve societal issues and do business.

What was tested?

In the context of the EU Roaming Regulation, the JRC carried out a series of field measurements on 37 mobile networks in 13 EU countries[4] to assess the performance of roaming. Performance of 29 visiting SIMs from 12 EU countries was evaluated in relation to 1) their own home network, 2) in relation to the domestic SIM of the visited network, and 3) in relation to other visiting SIMs on the visited network.

Where were the tests done?

Altogether, SIMs of 40 different networks were used in field measurements. Three of these networks did not happen to be visited by any visiting SIM therefore number of visited networks was 37.



Number of visited countries:	13
Number of visited networks:	37
Number of visiting countries:	12
Number of visiting SIMs:	29

How were the tests done?

Tests were carried out in a controlled manner using the JRC's mobile app *netBravo*, which is designed to measure the coverage and quality of mobile networks and the performance of mobile broadband. All test data was stored and processed on the *netBravo* server with software adapted to the needs of the project. The app is available for free for smartphones running on Android® and Apple® iOS®.

The measurement equipment used was a set of smartphones of the same model (i.e. the same technical specifications) with netBravo app installed. The handsets used were suitable for a 4G+ network capability.

Tests were done in key city locations with high network availability. All visiting SIMs on the same visited network were tested repeatedly in a common time frame to ensure the network traffic conditions were similar.

The measurement data on download speed, upload speed and latency for various roaming SIMs in visited countries, as well as at home, was collected and analysed. Comparisons were made on the performance of visiting SIMs vs home SIMs (of the visited network) and vs other visiting SIMs on the same visited network and in the same situations. The average values of download speed and upload speed observed in several test samples were used in comparing performance.

[4] At the time of the tests, the Roaming Regulation was still applicable in the UK.

Three types of analysis were performed on the measurement data set obtained in field tests:

(a) Customer-level analysis of roaming performance
(b) Network-level analysis of roaming performance
(c) Cross-correlation analysis between the above sets.

What was found?

Q1 – Do roaming customers have different quality of service when roaming compared to the performance on their own home network?

Looking at the overall data of 177 roaming instances between 37 visited networks and 29 visiting SIMs, the download speed for customer SIMs was worse in roaming than in their respective home network on 39% occasions. The upload speed was worse in roaming than at home on 59% occasions. Latency in roaming was found worse than at home in 62% cases.

Q2 – Does the quality of service on visited networks differ between the customers of the visited network and the roaming users visiting the network?

Across the 37 networks visited by 29 visiting SIMs, results from field tests show that the download speed for visiting SIMs (roaming customers) was worse than the home SIM (home customer) of the visited network in 50% of the roaming instances. The upload speed for the visiting SIMs was worse than the home SIM in 72% of the roaming instances. Latency for visiting SIMs was found worse than the home SIM in 73% cases.

Q3 – Does the roaming customer have different quality of service on a visited network compared to other visiting roaming customers?

In relation to the roaming peers (other roaming users in the same visited network, at the same location and at the same time), there was even distribution of instances of roaming performance with *below average* and *above average* download speeds for the visited networks: 38% had better performance than the average of all roaming users[5], 40% had worse performance and 22% had about the average level of performance. The same was observed for the distribution of upload performance: 35% had better than average performance, 39% had worse than average and 26% had average level of performance. For latency the distribution was 36% above average, 32% below average and 32% average.

The figures were similar when considering only the cases where a network was visited by at least 5 visiting SIMs. It shows that the test results were overall statistically consistent.

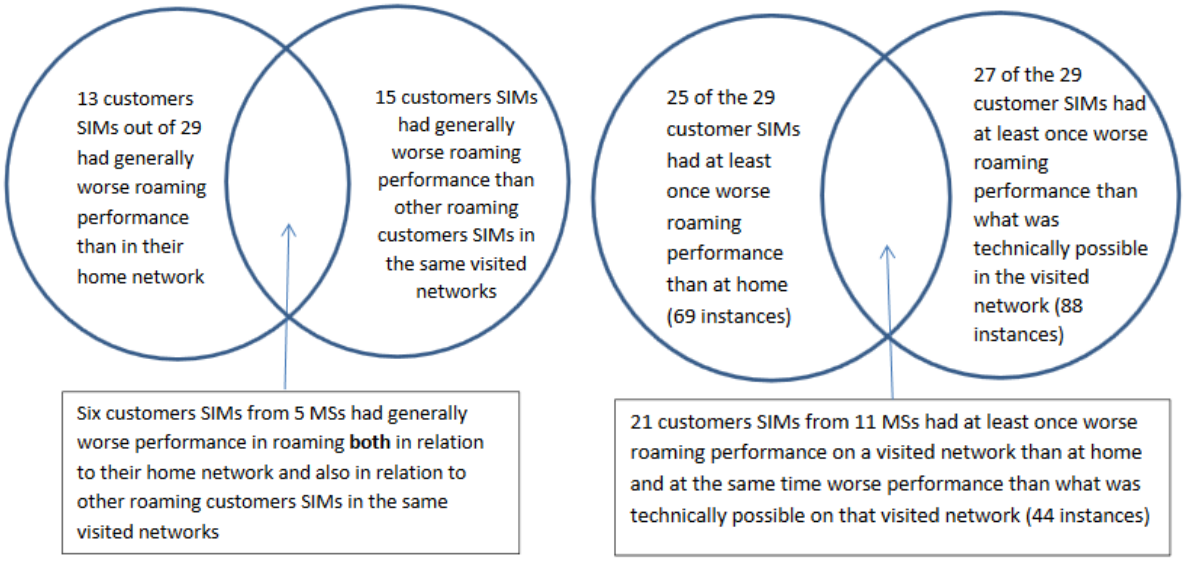
However, it was found that some visiting customer SIMs were generally more likely to have below average performance than others, pointing towards possibly QoS in roaming being offered to them at an unfavourable level.

Q4 – How often did customers have worse quality of service in roaming than at home, even when the visited network was technically and practically able to provide better quality?

On further analysing the results for Q1-Q3, it was found that 20% roaming customers (6 out of the 29 visiting SIMs) had generally worse download performance in roaming than at home and also below average download performance than the other roaming customers in the same visited network.

Detailed analysis showed that 21 customers from 11 countries had worse download speed performance than at home and also worse than what was technically possible on at least one visited network. Altogether, such cases accounted for 25% of all 177 roaming instances.

[5] For a given visited network, the average level of download speed was calculated based on the download speed for all the visiting SIMSs for that visited network.



Conclusions

Objective assessment of roaming performance is a complex exercise. There are several variables such as the QoS of the home network, QoS of the visited network, and contractual terms on the QoS both on wholesale level between the mobile operators as well as for a given customer. Moreover, there are temporal and spatial variables such as the traffic density and user density of the network that cause the network performance to fluctuate over time and across different locations. These result in the roaming performance to vary considerably for the visiting SIMs.

For a single customer, home v. roaming performance can be anecdotal or episodic. The same SIM can have better performance than at home for one visited network and worse than at home for another visited network depending on the test conditions (time, place, traffic) as well as inherent performance specifications of each network and the QoS criteria and constraints that may be applied by the network operators.

Measuring a visiting SIM's performance in relation to the performance of the home SIM of the visited network was found to be a useful yardstick to neutralize the effect of some of the above temporal and spatial variables. Doing so with a number of visiting SIMs added statistical diversity in the data set as well as a broader view of the complexity involved in analysing cross-border roaming.

Measuring the performance of a visiting SIM with respect to other visiting SIMs was yet another way to benchmark relative performance across several spatial locations.

This study is quite unique of its kind in terms of the scope, evidence-based methodology and scale of field tests. The tests had involved nearly half of the EU countries and about a third of all EU networks, taking into account the distribution between inbounder and outbounder roaming countries[6], making them representative and to show a genuine picture of the diversity in roaming performance across the EU.

[6] An outbounder operator has a customer base which consumes more mobile services abroad (i.e. on the networks of partner operators in other EU/EEA countries), than those consumed by the partner operators' customer base on its own network (i.e. when acting as a visited network). Conversely, an inbounder operator has a customer base which consumes less mobile services abroad than those consumed by the partner operators' customer base on its own network.

The relative performance of downloading data in roaming for most of the visiting SIMs was a mix of better/worse/same in relation to the benchmarks devised. However, the upload performance and latency were found overwhelming in favour of the home SIMs.

The study identified 44 instances of download performance in roaming (specific visiting SIMs on specific visited networks) that cannot be explained through variables such as temporal, spatial or technical characteristics alone. For such cases, accounting for 25% of all roaming instances, more transparent information on the QoS applied on a visiting SIM could help to explain the causes for poorer QoS in roaming than at home.

1 Introduction

Since the introduction of the first generation of public mobile networks in the late 1980s, mobile electronic communications today span the globe with all 192 countries covered by one or more national mobile networks. Each national mobile network is operated by a mobile network operator (MNO) licensed to provide mobile services to its customers within the national territory.

Mobile networks are interconnected to allow a customer in one network to place calls to a customer in another mobile network in the same country or in another country. This provides a global reach for customers of a national mobile network operator.

When a mobile customer is located outside the coverage area of its own MNO, the mechanism of roaming allows that customer to use services of another MNO, provided that an arrangement exists for inter-network mobility between the two network operators. In popular terms, it is called **roaming** between mobile networks.

International roaming across national borders is a functional necessity to provide customers with access to mobile services when they travel abroad.

With increased affordability of mobile telecom services through subscriptions or pre-paid contracts and lower cost of mobile telephone handsets, the last 20 years have seen a rapid growth in the uptake of mobile services. Consequently, the demand for international roaming has also soared with consumers travelling abroad on business and holidays.

Since the early years, the cost of international roaming has been generally exorbitant leading to unexpected bills for many customers. Today with greater competition and regulatory intervention, the cost of Union-wide roaming has become more predictable especially in the context of the European Single Market.

Beyond the issue of the cost of roaming, a major question is about the varying level of quality of service for consumers in roaming. This question is particularly relevant in the context of the EU Roaming Regulation. The present project has focused on the assessment of roaming performance for consumers in a number of mobile networks across a number of EU Member States.

1.1 Roaming in the EU

Roaming, as defined by the Roaming Regulation, is a service that allows a customer (consumer or business) of a public Mobile (Virtual) Network Operator (M(V)NO) in one EU country (country A) to have access to mobile services (voice, SMS or data) from a Mobile Network Operator (MNO) when travelling in another EU country (country B).

The Operator A ensures that its customers remain connected to a mobile network of the Operator B when travelling abroad while using the same mobile handset (or possibly laptop or tablet in case of data roaming) and the same phone number. Operator A, that wants to offer roaming services to its customers ("retail roaming services") in country B, has to buy these services from a Mobile Network Operator (MNO) (Operator B) located in the visited country B through commercial wholesale roaming agreements ("wholesale roaming services").

In practice, when a customer of Operator A places a call or uses mobile data while roaming abroad in country B, that service is provided by an Operator B in the visited country B. The roaming customer's home Operator A has to pay the visited Operator B for that service. ("Wholesale roaming charges"). The level of wholesale roaming charges is capped by the Roaming Regulation (for data the price caps is decreasing each year, since there is a glide path).

1.2 Regulatory context

In October 2015, the European Parliament and the Council adopted Regulation (EU) 2015/2120, amending the Roaming Regulation (EU) 531/2012, and mandating the end of retail roaming surcharges in the EU from 15 June 2017, subject to fair use policy and sustainability derogation (also known as "Roam-Like-At-Home" or RLAH rules).

Regulation 531/2012 of 13 June 2012 of the European Parliament and the Council on roaming on public mobile communications networks within the Union, amended in 2015 and 2017 (hereinafter the 'Roaming Regulation'), mandates the Commission to conduct a review by December 2019 of the Roaming Regulation.

The Roaming Regulation mandates the Commission to submit biennial reports to the European Parliament and the Council, accompanied, if appropriate, by a legislative proposal. Moreover, the Roaming Regulation specifies the list of elements to be assessed by the Commission in this report. One of them is the availability and quality of roaming services in the EU.

The Commission's Review report[7] was adopted on 29 November 2019, and is followed by a legal proposal.

The present project contributed to the review of the quality of roaming services and to inform the Impact Assessment on the review and prolongation of the Roaming Regulation[8]. In view of the roaming review requirements, a number of tasks for scientific and technical support were identified by DG CNECT where the JRC agreed to contribute and bring its expertise in evidence-based performance evaluation and data analysis.

1.3 Research questions

The two main research questions addressed in the present study were:

1. **Whether roaming customers have different quality of service when roaming compared to the performance on their own home network.**
2. **Whether quality of service on visited networks differs between the customers of the visited network and the roaming users visiting the network.**

As part of the research methodology, the following two questions were added:

3. **Whether roaming customers have different quality of service on a visited network compared to other visiting roaming customers.**
4. **How often did customers have worse quality of service in roaming than at home, even when the visited network was technically and practically able to provide better quality?**

In a related experimental work[9], network configuration for roaming was assessed for 11 mobile networks in six countries. Authors investigated the roaming performance in voice-over-IP (VoIP) networks as well as content access policy of the operators. Latency penalty of c. 60ms was observed for roaming. However statistical comparison of quality of service in roaming vs home for downloads and uploads speeds was not reported.

[7] Report on the review of the roaming market, COM(2019)616 final, and SWD(2019)416 available here.

[8] See the Inception Impact Assessment on the roaming review initiative for more information, here.

[9] Experience: Implications of roaming in Europe, Anna Maria Mandalari*, Andra Lutu, Ana Custura, Ali Safari Khatouni, Özgü Alay, Marcelo Bagnulo, Vaibhav Bajpai, Anna Brunstrom, Jörg Ott, Marco Mellia, Gorry Fairhurst, MobiCom18 Proceedings of the 24th Annual International Conference on Mobile Computing and Networking, pp 179-189, Oct 2018.

1.4 Research Methodology

An overall research methodology, as shown in Figure 1, was adopted to answer the above questions. It was based on the collection of evidence of roaming performance from field tests on a number of networks, creation of relevant data sets, analysis of the data and finally to draw conclusions. It included development of detailed methodologies for measurements and analysis, described in later sections of the report.

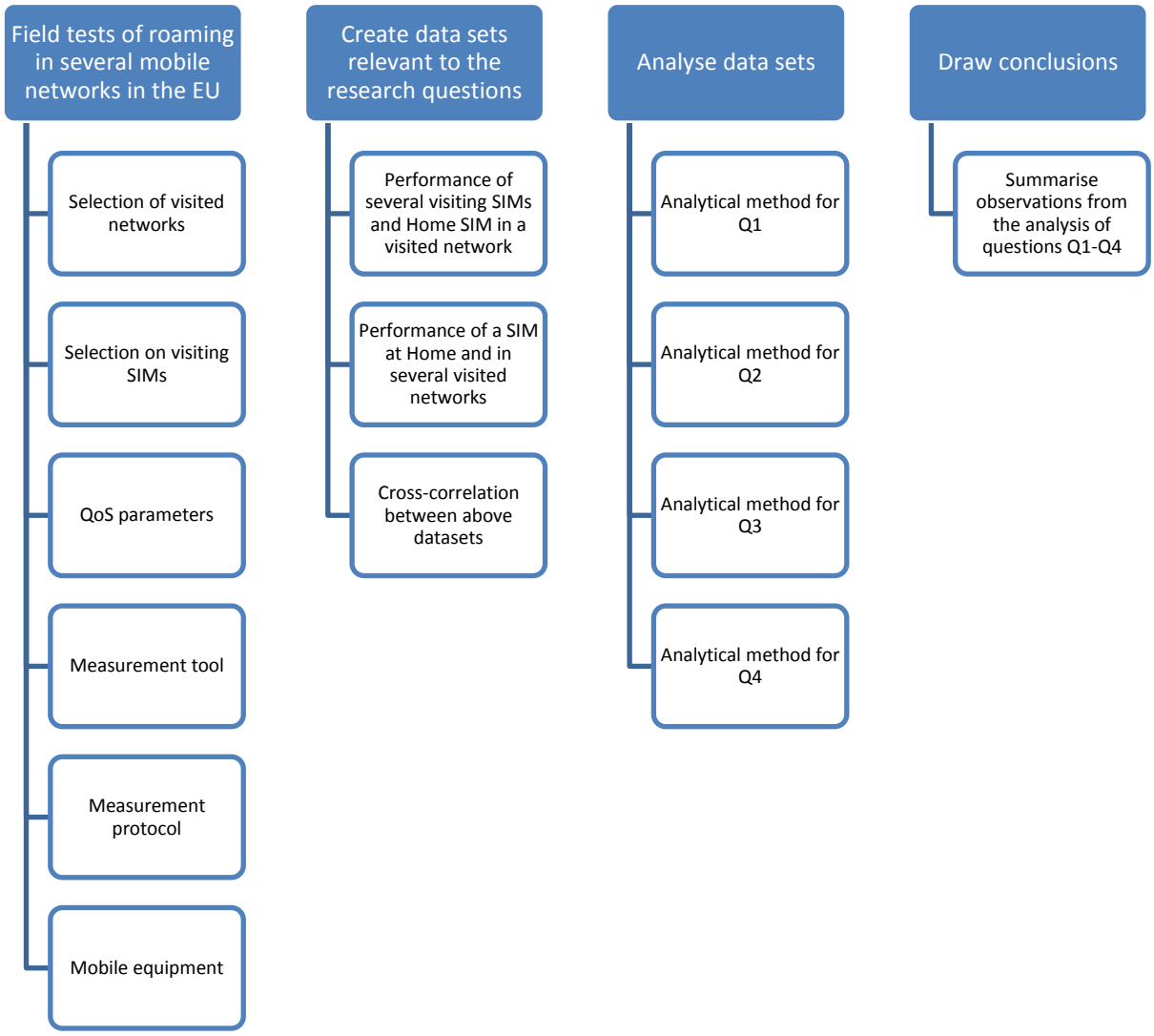


Figure 1. Overall research methodology used to carry out roaming performance assessment

2 Work Description

2.1 WP1: Data Collection

Objective: To carry out field tests on mobile broadband in order to collect data to compare roaming performance in several EU MSs.

Description:

The JRC undertook field test campaigns in the following 13 EU Member States: Spain, Italy, Latvia, Belgium, Greece, France, Germany, Poland, Romania, Finland, Netherlands, Sweden, UK[10].

The JRC procured subscriber identification modules (SIMs) for 40 mobile network operators (MNOs) in the following 13 EU MSs (the number of SIMs for each MS are shown in parenthesis)[11]:

Spain (3), Italy (4), Latvia (2), Belgium (2), Greece (3), France (3), Germany (3), Poland (4), Romania (4), Finland (2), Netherlands (3), Sweden (3), UK (4).

Ten advance generation mobile handsets (Samsung S9®) were procured to run the tests. The JRC's mobile broadband test application *netBravo* was installed on these handsets to carry out roaming test campaigns on mobile networks in those countries.

netBravo was used to measure the performance of visited networks for the visiting SIMs as well as home SIMs of the visited networks.

These test campaigns were organised to collect adequate data at suitable locations to allow objective analysis of the relative performance of mobile networks and their compliance with the roaming regulation.

JRC elaborated appropriate test and measurement procedure for structured field test campaigns, according to project objectives and regulatory requirements for robust and comprehensive roaming performance assessment.

Results of test campaigns were shared with DG CNECT on an on-going basis for which JRC adapted its web application for netBravo for interactive visualization of roaming test data. Security mechanism was implemented limiting access to the roaming test data for authorised users only.

Activities carried out:

1. Adapting JRC's mobile application netBravo for roaming performance tests;
2. Acquisition and pre-paid subscription management of SIMs for various mobile networks in the 13 visited countries,
3. Definition of the exact measurement protocol for field tests;
4. Organisation of test campaigns and collection of mobile broadband performance data using netBravo mobile application for SIMs of various national mobile networks in home and roaming mode;
5. Rendering of collected roaming data on the JRC's netBravo web application in tables and graphs.

[10] At the time of the tests, the Roaming Regulation was still applicable in the UK. The roaming traffic in the UK was therefore still treated as Union-wide roaming traffic.

[11] Of the 40 SIMs, only 29 were used as the visiting SIMs in roaming; the others were used only as home SIMs of visited networks

2.2 WP2 : Data Analysis

Objective: Processing and analysis of individual and relative performance of mobile broadband in various mobile networks for their home and roaming users.

Description:

JRC carried out this work in consultation with DG CNECT to formulate and answer analytical questions, based on field evidence collected in WP1, on roaming performance assessment.

The work under this work package consisted of building a database from the data collected from tests on individual mobile network operators (MNOs) during field tests. DG CNECT advised on the analytical criteria used to assess both individual and relative performance of mobile networks.

The two main initial research questions addressed in this analysis were:

(a) Whether roaming customers have different quality of service when roaming compared to the performance on their own home network.
(b) Whether quality of service on visited networks differs between the customers of the visited network and the roaming users visiting the network.

As part of the research & analysis methodology, the following two questions were added:

(c) Whether roaming customers have different quality of service on a visited network compared to other visiting roaming customers.
(d) Did customers have worse quality of service in roaming than at home, even though the visited network was technically and practically able to provide better quality?

The JRC adapted its netBravo database and website to perform data processing, analysis and visualization in order to provide a fair assessment of the mobile broadband regime in roaming across the EU, based on the statistical evidence collected during field tests. For this purpose, the analysis framework applied to the data was jointly agreed between DG CNECT and the JRC.

Results were produced in appropriate tables, charts, and where possible maps, to appropriately visualise the data and analytical results from a policy perspective.

The relevant results, analyses, and the associated tables, charts and maps, were used by DG CNECT in the Impact Assessment Report accompanying the legal proposal on roaming on public mobile communications networks within the Union.

Activities and Deliverables:

1. Adapting netBravo website to create a database of roaming performance tests;
2. Statistical analysis of test results to answer the review questions on the performance of mobile broadband roaming in the EU;
3. Production of tables, graphs and accompanying explanation along with online visualization of the analytical results.

2.3 WP3: Report

Objective: Drafting a report describing the methodology, analysis and conclusions of the work done by JRC.E2

Description:

The present report was prepared describing the test methodology, analytical results and technical conclusions of mobile broadband roaming performance. Relevant parts of the report were used by DG CNECT in the impact assessment report accompanying the roaming legislative proposal. JRC produced tables and graphs on an ad-hoc basis to be included in relevant policy documents. JRC has also contributed with explanatory text within the scope of this project, to the drafting of such documents by the Commission services.

Activities carried out:

1. Methodological and analytical Report;
2. Tables, charts, and explanatory text for the Commission's reports related to the roaming review and impact assessment;
3. The present Final Report of the project.

3 Test Methodology

A systematic process was followed to develop and apply a test method to carry out roaming performance assessment in the project.

3.1 Definition of the scope of tests

The scope of roaming tests was to measure quality of service of mobile broadband for *roaming customers* on a visited network and to compare it with that for the *home users* of the visited network.

In particular, EECC[12] Article 104 deals with the quality of service related to internet access services; EECC Annex X sets out the QoS parameters for internet services as defined in ITU standard ITU-T Y.2617. BEREC guidelines[13] contribute to a consistent application of Article 104(2) and Annex X.

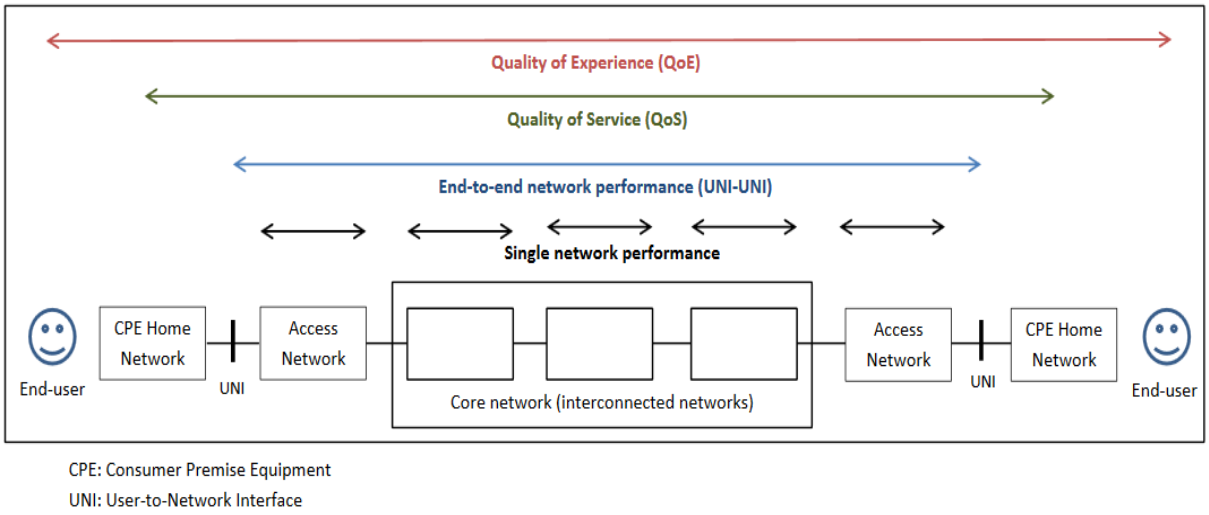


Figure 2. Quality of Service in an end-to-end telecommunication network (Source: BEREC)

In the present study, the focus was on mobile broadband roaming rather than on voice communication. Hence data transfer speed for download and upload activities were measured. Latency was also measured to highlight the effect of traffic steering often used by operators for roaming which would introduce additional end-to-end delay. Jitter was not measured for mobile broadband tests as it is more relevant for voice communication rather than for data communication.

In addition, net neutrality tests[14] were carried out however those tests are beyond the scope of the present report. This report therefore presents the speed results and latency. During the study it was found that apart from the volume of data transfer allowed, speed was usually the only QoS parameter publicised in retail offers to pre-paid consumers.

[12] DIRECTIVE (EU) 2018/1972 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 establishing the European Electronic Communications Code https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L1972&from=EN

[13] BEREC Guidelines detailing Quality of Service Parameters https://berec.europa.eu/eng/document_register/subject_matter/berec/download/0/9043-berec-guidelines-detailing-quality-of-se_0.pdf

[14] Net neutrality refers to the principle of equal treatment of data traffic being transmitted over the internet, i.e. that the 'best efforts' are made to carry data, no matter what it contains, which application transmits the data ("application-agnosticism"), where it comes from or where it goes. (see About BEREC guidelines https://berec.europa.eu/files/document_register_store/2016/8/NN%20Factsheet.pdf)

3.2 Development of a detailed test method

A detailed test method was developed and implemented in two phases involving in-field measurements, as follows:

(a) Feasibility tests

The goal of the feasibility phase was to develop and refine the test methodology in both technical and logistical sense and validate it in the light of in-field performance and preliminary data analysis.

(b) Detailed tests

After validation of the test methodology, a more comprehensive set of roaming tests was undertaken.

Figure 3 shows the various steps that were followed to implement and validate the testing methodology leading to a comprehensive set of test data that were finally analysed for the assessment of QoS of mobile broadband in roaming. These steps are outlined below.

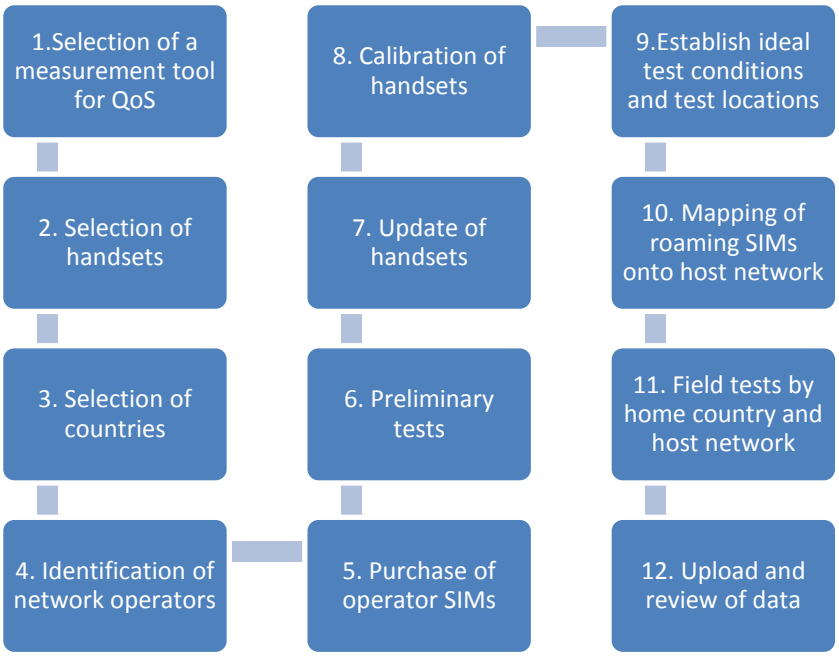


Figure 3. Detailed test procedure adopted for roaming performance assessment

1) Selection of a measurement tool for QoS

The QoS measurement tool forms the most important part of data collection. The project decided to use *netBravo*[15], an in-house android app developed at JRC. It allows the test engineer to query current technical parameters of the host mobile network, carry out broadband speed test, visualize and store the test data and upload test results to the netBravo server for data aggregation and further analysis.

2) Selection of handsets

Mobile handsets (smart phone) differ in terms of their sensitivity to the network signal and performance. Therefore it was decided to select a set of identical smartphones that could operate up to the maximum rated speed of the host network. Initially, a number of Samsung S4® handsets were selected due to their ready availability in the project. During the feasibility phase, it was found that some host networks were able to deliver speeds above that of Samsung S4® (70 mbps). As a result, handsets of higher specifications were tested. Eventually ten identical Samsung S9® handsets were

[15] netbravo.jrc.ec.europa.eu

used for field tests and data collection as these could operate even on the so called 4G+, the enhanced version of 4G networks.

3) Selection of MSs

For a Single Market, at that time consisting of 28 Member States, it was considered sufficient to carry out tests in roughly half as many countries in different geographic regions, taking into account the distribution of inbounder and outbounder roaming countries, to get a general picture of roaming performance. For the sake of scientific neutrality, the paper refers to them through country codes.

For a Single Market, at that time consisting of 28 Member States, it was considered sufficient to carry out tests in roughly half as many countries in different geographic regions, taking into account the distribution of inbounder and outbounder roaming countries, to get a general picture of roaming performance. For the sake of scientific neutrality, the paper refers to them through country codes.

Thirteen EU Member States as shown in Table 1 were selected for tests:

Number of visited countries: 13

Number of visiting countries: 12

Table 1. Mobile Networks and SIMs included in the tests

Country	MNO Anon. Code	Used as Visited Network	Used as Visiting SIM	Pre-paid with roaming
Belgium	BE_A	Yes	Yes	Yes
	BE_B	Yes	Yes	Yes
Finland	FI_A	Yes	Yes	Yes
	FI_B	Yes	No	No
France	FR_B	Yes	Yes	Yes
	FR_C	Yes	No	No
	FR_A	Yes	Yes	Yes
Germany	DE_A	Yes	Yes	Yes
	DE_B	Yes	Yes	Yes
	DE_C	Yes	Yes	Yes
Greece	EL_A	Yes	Yes	Yes
	EL_B	Yes	No	Yes
	EL_C	Yes	No	Yes
Italy	IT_B	Yes	Yes	Yes
	IT_C	Yes	Yes	Yes
	IT_D	Yes	Yes	Yes

	IT_A	No[16]	Yes	Yes
Latvia	LV_A	Yes	Yes	Yes
	LV_B	Yes	No	No
Netherlands	NL_A	Yes	Yes	Yes
	NL_B	Yes	Yes	Yes
	NL_C	Yes	Yes	Yes
Poland	PL_A	Yes	No	No
	PL_B	Yes	No	No
	PL_C	Yes	No	No
	PL_D	Yes	No	No
Romania	RO_A	No[16]	Yes	Yes
	RO_B	Yes	Yes	Yes
	RO_C	Yes	Yes	Yes
	RO_D	Yes	Yes	Yes
Spain	ES_A	Yes	Yes	Yes
	ES_B	Yes	Yes	Yes
	ES_C	Yes	Yes	Yes
Sweden	SE_C	Yes	No	No
	SE_B	Yes	No	No
	SE_A	Yes	Yes	Yes
UK	UK_A	Yes	Yes	Yes
	UK_B	Yes	Yes	Yes
	UK_C	No[16]	Yes	Yes
	UK_D	Yes	Yes	Yes

[16] None of the visiting SIMs selected this network in roaming

4) Selection of network operators

There were typically between two and four mobile network operators (MNO) per country. Subject to the availability of their SIMs, MNOs were selected to test QoS of visiting SIMs and home users.

Altogether, 40 SIMs were used over various tests, but not all of them were used on all the locations. This was due to gradual procurement of SIMs as each country was visited one after another. Of these, 37 SIMs corresponded to the visited networks and 29 to the visiting networks. 26 SIMs corresponded to both the categories. Three networks acted as *visiting only* as no visiting SIM chose them as a visited network. Similarly, eleven networks acted as *visited only* as they did not have roaming options but were used by visiting SIMs for their roaming performance.

Total number of Network SIMs used: 40

Number of visited networks: 37

Number of visiting networks (visiting SIMs): 29

Number of networks which acted as both visiting & visited: 26

The study does not include tests for MVNOs. Additional tests measuring the QoS of MVNOs SIM cards when roaming were foreseen during the first half of 2020. Due to the COVID-19 pandemic and travel restrictions those measurements had to be cancelled.

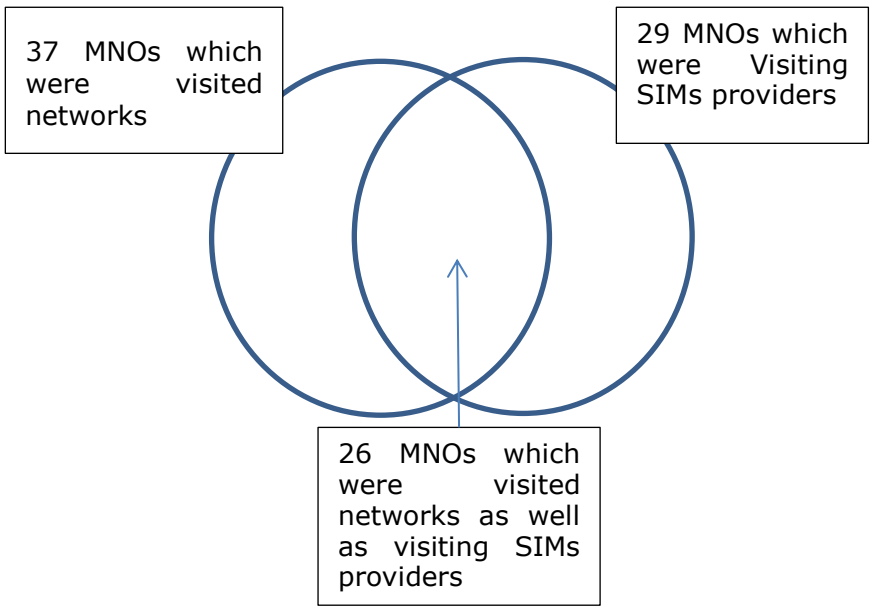


Figure 4. Sets of Visited and Visiting Networks

5) Subscriber identification modules (SIMs)

The project used pre-paid SIMs wherever they were available for the MNOs within the selected countries. Each such SIM represented a unique user belonging to a given MNO. When a SIM was used in its own country and own network, it acted like a '**home user for the visited network**' whereas when it was used in a country other than its home, it acted like a '**roaming user**'. Altogether 40 SIMs issued by different MNOs were deployed in roaming tests. These are listed in Table 1 above.

6) Preliminary tests – identification of logistic and technical issues

In preliminary tests, several logistic and technical challenges were identified. Among these were the issues such as pre-paid contract period, manual or auto-renewal, costs and data traffic allowance, top-up procedures, language of the MNO web site and app, etc. There were important constraints such as maximum data rate allowed in a pre-paid contract, the data allowance and roaming restrictions.

In most countries, an EU passport or identity card was sufficient to buy a pre-paid SIM. The pre-paid contract period was typically one month after which the contract terms and top-up procedure varied considerably from automatic renewal to manual top-up and selection of a data package. The data allowance varied across the SIM operators from 500 MB to several GB per month. In some cases data-only packages were available, in others data plus voice calls plus SMS. In some cases, prep-paid packages were available for only national traffic (home use) but not in roaming. In some cases, only a credit card issued in the home country could be used for top up. Such issues presented a continuous challenge to top up SIMs and keep them active during the course of project.

7) Update of handsets

For the upgrade of test equipment, advanced handsets (Samsung S9®) were selected, capable of speeds up to 300 Mbps on a 4G+ network.

Ten identical Samsung S9® units were purchased to be able to test operating network performance for up to ten SIMs in a single test session, consisting of one home SIM and 9 visiting SIMs, all hosted on the same operating network.

The reason to choose identical handsets was to eliminate variations of performance between different models of smartphone.

8) Calibration and software updates of handsets

Even though the test handsets were of the same type, to eliminate variations between them, all handsets were tested in a benchmarking and calibration process.

All handsets were tested on the same network and using the same SIM in a session. Each handset performed the speed test ten times and results were compared for minimum, maximum and average speeds registered by each handset.

The tests were carried out in a commercial 4G network cell within the JRC on a Saturday morning. At this time, the occupancy of the site was very low and background network cell traffic was expected to be low.

Furthermore, any updates to the system software on handsets were checked for availability and downloaded before each test campaign.

9) SIM top up, verify test conditions and test locations

Before start of a test campaign, all the SIMs were topped up for the expected amount of data traffic consumed by netBravo. On a 4G network it is typically 50+ MB per speed test requiring a minimum of 500 MB for a test campaign consisting of 10 cycles of speed tests.

To make a reliable comparison between the QoS of a home user's SIM and roaming users' SIMs – all accessing the same network – network conditions play an important role. First of all, the test location needs to have good network coverage with high bandwidth available. That would usually mean a city centre (outdoor) or airport location where cells are provisioned with high capacity and nearby base stations by most of the network providers.

Test location: In case of poor quality network signal, indicating poor network coverage, the speed of networks would be sporadic and poor for everyone. A comparison of such 'roaming performance' with 'home performance' of a visiting SIM would be meaningless. Any difference in performance in such a situation would be statistically insignificant and results will not be technically representative.

Timing of tests: Similarly, even in case of good quality network signal, the network traffic tends to be sporadic during busy hours i.e. it varies substantially from one moment to the next, as well as the network speed being generally a lot slower than the rated speed. For example, at an airport or in a city centre location, high user density during peak hours would mean the network conditions to be far from ideal to make meaningful comparative tests between roaming and home user SIMs. On the other hand, tests during peak hours could provide a clue towards equitable treatment of the visiting SIMs and home network SIMs. However, the variation of results from one speed test to the next was so much that this option was not considered very useful.

Above all, the location should have 4G (or 4G+) network available with a high capacity for broadband traffic.

By experience, the ideal test environment to test a commercial network in a reproducible way would satisfy the following conditions:

- Availability of 4G or 4G+ signals (to allow any 3G vs 4G roaming policy)
- good signal quality: -85 dBm or better
- high network capacity: e.g. city centre, airport arrivals/departure hall; shopping mall
- low traffic congestion in the network cell: e.g. late evening or early morning
- logistical feasibility to set up test equipment without disturbance for one hour or more per visited network.

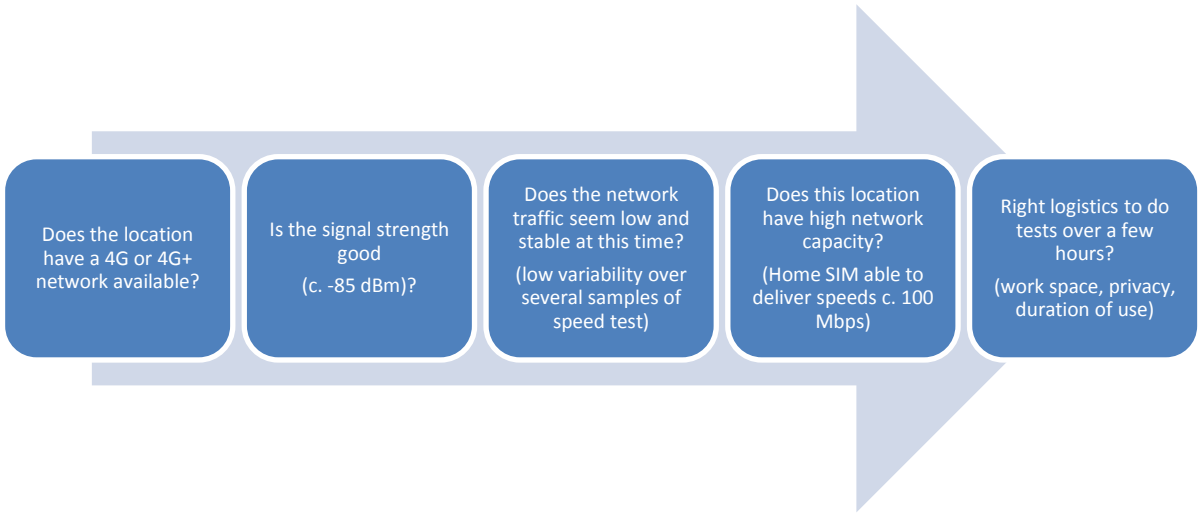


Figure 5. Checklist for test site selection

10) Mapping of roaming SIMs onto host networks

The home vs roaming tests required, first of all, to identify the preferred visited network for each of the visiting SIMs. After the visiting SIM was placed into the test phone, the phone was restarted, as required by Android. In most cases, the visited network was selected automatically. In some cases, the visited network was set quickly on restarting the test phones. In some cases, it took a few minutes. In some cases, automatic selection did not work and the visited network had to be found manually by trial and error.

The mapping process allowed a common round of testing all the visiting SIMs preferring the same visited network. That meant keeping a common time window (and common network conditions) for comparative tests and avoiding statistical variations due to changes in network conditions. It also allowed real time observations on the performance of various SIMs in the same visiting network.

All visiting SIMs were mapped in this way to a specific visited network. A mapping table was prepared in this way per visited network before commencing a test session.

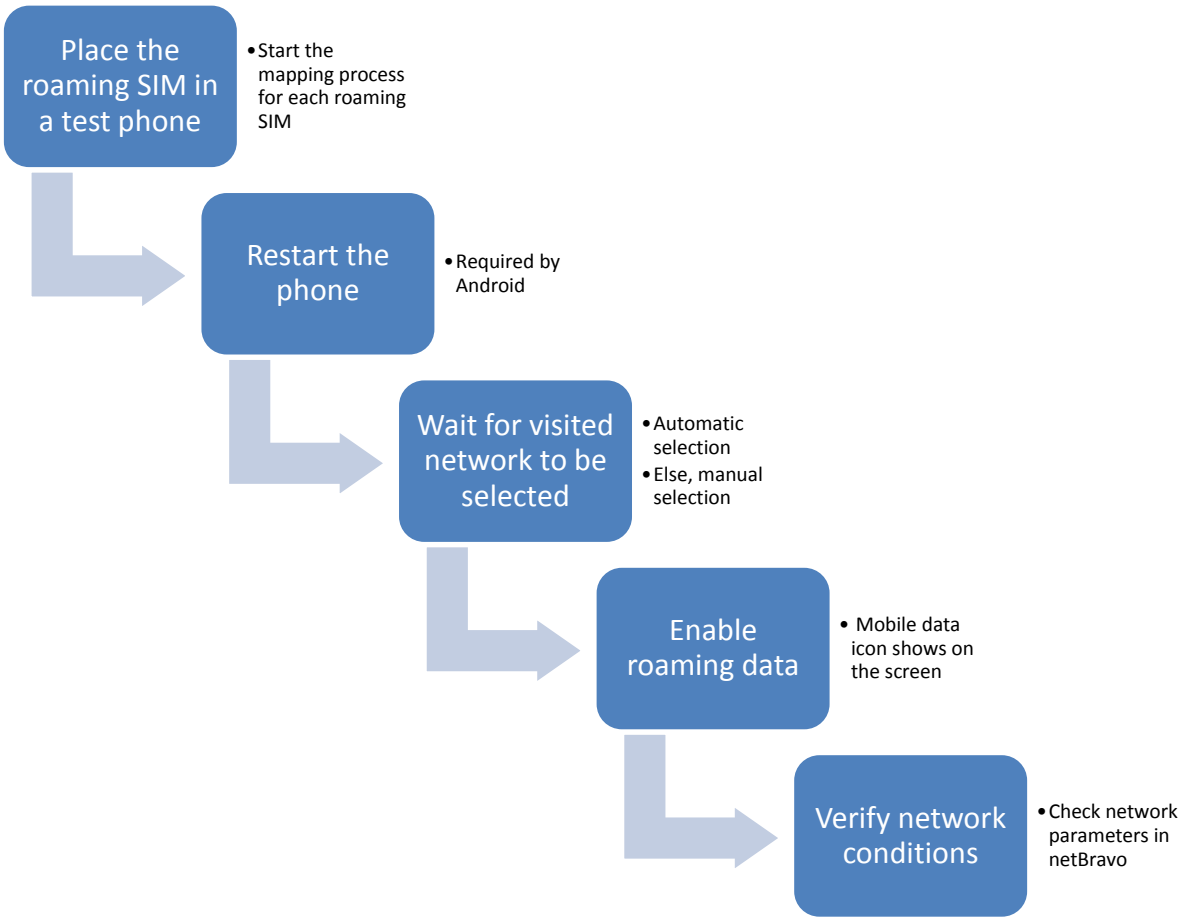


Figure 6. Mapping the visiting SIMs on visited networks in a test location

Set 1 Visited Country X Operating Network NetX1	Set 2 Visited Country X Operating Network NetX2	Set 3 Visited Country X Operating Network NetX3
•Roaming SIM 1 •Roaming SIM 2 •Roaming SIM 5 •… •Home SIM Op Net X1	•Roaming SIM 3 •Roaming SIM 6 •Roaming SIM 7 •… •Home SIM Op Net X2	•Roaming SIM 4 •Roaming SIM 8 •Roaming SIM 9 •… •Home SIM Op Net X3

Figure 7. Mapping table between visiting SIMs and visited networks in a test location

11) Preparation of phones for field tests in a visited host country

Once all visiting SIMs have been mapped to the visited networks (one of the operating networks (MNOs) in the visited country), each set of SIMs per visited network is prepared for testing in a single batch. In the figure above, assuming there being three MNOs in the visited country, three sets of SIMs were identified – one for each visited network. Numbers of visiting SIMs for each visited network were not the same; it depended on the roaming agreements between cross-border MNOs.

There were ten test phones available therefore a set of up to 10 SIMs for a given visited network (one home SIM of the visited network and the rest visiting SIMs on the same network) was prepared at a time as follows.

1) Insert one SIM per test phone (ten identical test phones were available).
2) Power on (or restart) all the phones with SIMs inserted
3) Check settings on all phones:
    a. Flight mode Off
    b. Mobile data On
    c. Wi-Fi® Off
    d. Bluetooth® Off
    e. Data roaming On
    f. Network mode: auto connect (4G LTE/3G/2G)
    g. Status icon: 'Roaming flag' R visible for visiting SIMs
    h. Status icon: 'Mobile data' icon visible
4) Start test app netBravo on each phone
5) Check network Actual cell details on netBravo on each phone
6) Note the following information per phone
    a. SIM operator name and code
    b. Network operator name and code
    c. Network type (4G/3G)
    d. Cell id
    e. Data state (it should be: 'Connected')
    f. Field strength
    g. Take screenshot or photo of 'Actual cell detail'
7) Set all test phones in an array (side-by-side in one or two rows), along with their SIM card logo
8) Take photo of the test set

12) Field tests on visited networks

At a time, one visited network was selected. For the selected network, the visiting SIMs (identified in the mapping process above) as well as the home SIM of the visited network were installed on the test phones. With 10 identical test devices available, one home SIM plus up to 9 visiting SIMs could be tested in **one round**. In some cases the testing had to continue into another round when the number of mapped SIMs on a visited network was more than 9.

During each round of tests, Wi-Fi® was set to OFF on all test devices. netBravo was started on all test devices. First of all the network parameters on each phone were checked and recorded in the netBravo network configuration screen, showing information such as SIM operator code, network operator code, type of network (3G or 4G), cell id and signal quality parameters.

Speed test with netBravo was run sequentially on the test devices, one device at a time in a **test cycle**. The **test cycle** was repeated ten times.

At the end of 10 test cycles the **test round** for a visited network was concluded.

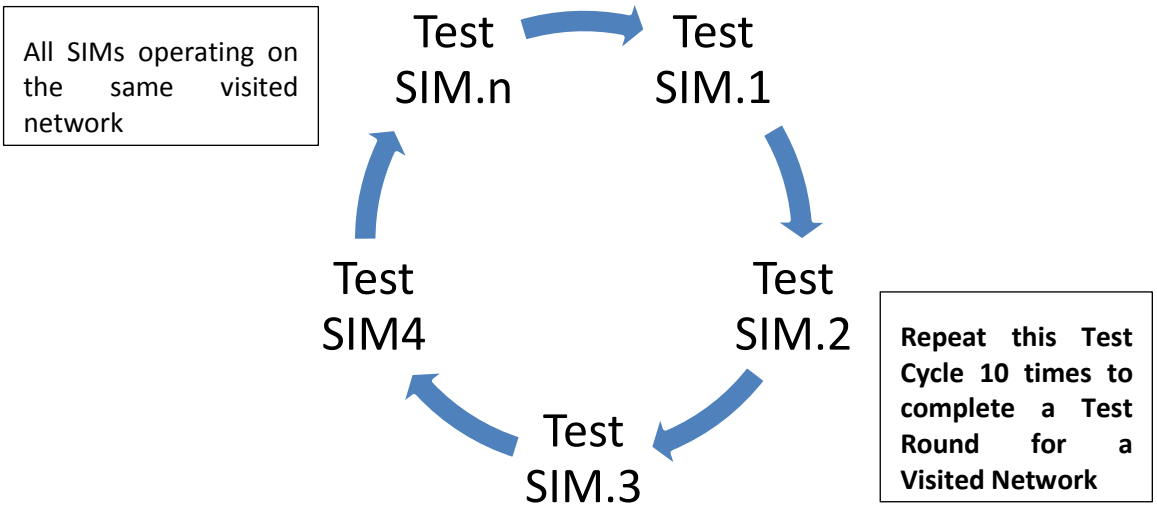


Figure 8. Test Round on a visited network, made of 10 Test Cycles

The procedure of a test round per visited network is described below.

On each phone in the test set up, set netBravo on **Test dashboard:**

a) Zoom-in on Start Test screen on all test phones

b) Click on 'Start Test' button on one test phone

   i. The test starts with basic network tests (Net name, Net type, Net IP. Server, Ping, ICMP, SIP)
   ii. Then, occurs Download Test (DL)
   iii. Then, occurs Upload Test (UL)
   iv. At the end, the button 'Start Test' reappears. The test results are shown on the screen.
   v. Note the following in the log book: Location, Date, Time of test, phone Id, DL, UL, ping

c) Repeat Step b) on the rest of the test phones, one at a time

d) That completes one test cycle of speed test in a round-robin fashion

e) As a visual record, take a sample photo of the test set up showing Speed Test results

f) Note any anomalies observed during the test cycle (specific to a SIM or generally in the test conditions)

g) Repeat Steps a) to f) for the next test cycle

h) Repeat step g) ten times

i) The above procedure completes one Test Round for a visited network (i.e. the visited network's SIM and all the visiting SIMs in the same visited network)

Repeat Steps a) to i) above for each visited network in the visited country.

13) Upload and review of data

The data from the tests is stored locally on each phone by the netBravo app automatically. At the end of the process, the data is uploaded from each test phone's netBravo to the JRC server.

The uploaded data is reviewed and compared with that in the Log Book, recorded during the tests. This is part of the verification process to ensure the uploaded data is correctly received on the server.

The netBravo application on the server website allows visual and graphic inspection of test results, in a set of analytical graphs and tables.

4 Data collection

In the context of the EU Roaming Regulation, the JRC carried out a series of field measurements on 37 mobile networks in 13 EU countries[17] to assess the performance of roaming. Performance of 29 visiting SIMs from 12 EU countries was evaluated in relation to 1) their own home network, 2) in relation to the domestic SIM of the visited network, and 3) in relation to other visiting SIMs on the visited network.

The map below shows the various locations where tests were carried out to collect roaming performance data.

Number of visited countries:	13
Number of visiting countries:	12
Number of visited networks:	37
Number of visiting SIMs:	29
Total number of SIMs used:	40

Figure 9. Map of roaming test sites

[17] At the time of the tests, the Roaming Regulation was still applicable in the UK.

5 Analysis and Findings

5.1 Data analysis

5.1.1 Q1. Do roaming customers have different quality of service when roaming compared to the performance on their own home network?

Scenario:

A travelling sales woman from Member State X has a network SIM of Operator X1**.** For seamless broadband connectivity, she uses her mobile phone for mobile broadband access wherever in the EU she visits. In her visited countries, she is able to roam like at home without surcharges and finds it convenient and cost effective. However the quality of her mobile broadband service varies considerably and is often worse than what she is used to getting in her mobile network back home.

Does her home network operator X1 have any policies on QoS in roaming? To figure out she decides to run speed tests on visited networks in various countries that she visits. She runs speed tests also when she gets back home from her business trip.

To address the above question, speed test measurements carried out by netBravo were analysed for 29 customer SIMs for which speed test data was available both at home and in roaming.

Speed tests with netBravo consisted of three parts: Download of a large file, upload of a large file and a test on network latency. The analytical procedure and results of the analysis are summarized below.

(A) Download performance

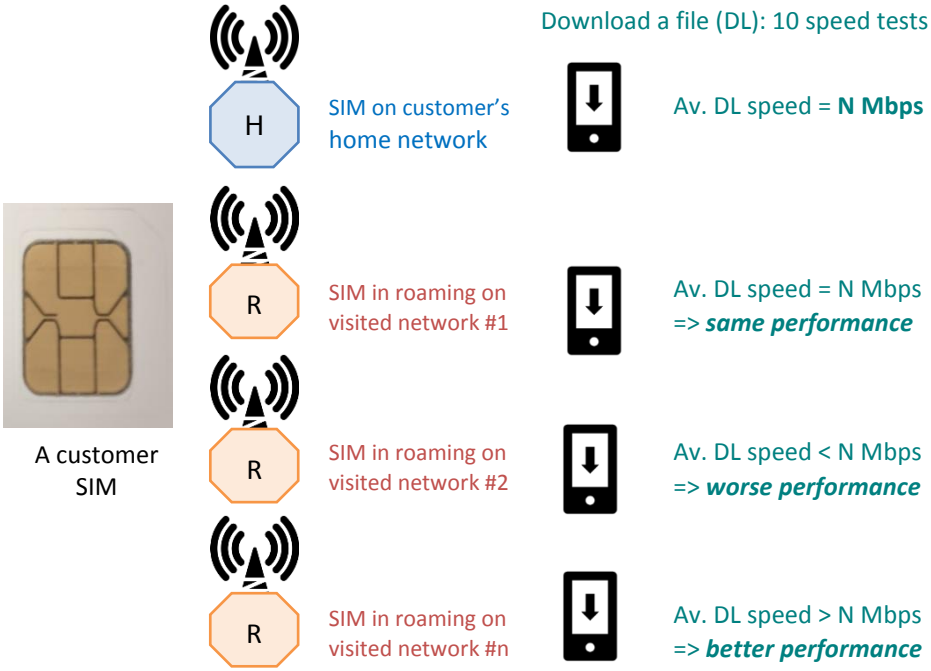


Figure 10. For each customer SIM, its download performance on a visited network was assessed in relation to that on its home network

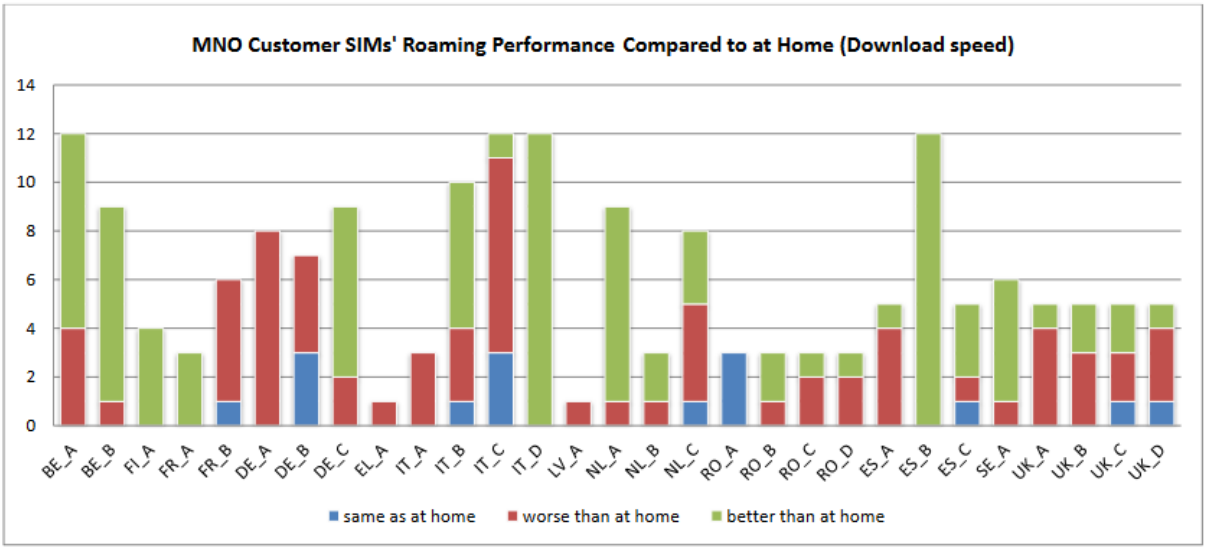


Figure 11. MNO customer SIMs' roaming performance compared to at home – Download speed

X-axis: Customer SIM (Home network operator)

Y-axis: Number of visited networks

For four of the 29 SIMs, the download performance was always better in roaming and for four SIMs, it was always worse in roaming than in their respective home network. For the other 21 of the 29 SIMs, there was a mixed picture of download performance in roaming as compared to in their respective home network: On some occasions they had worse download performance in roaming than in their respective home network and on some occasions similar or even better download performance in roaming than in their home network.

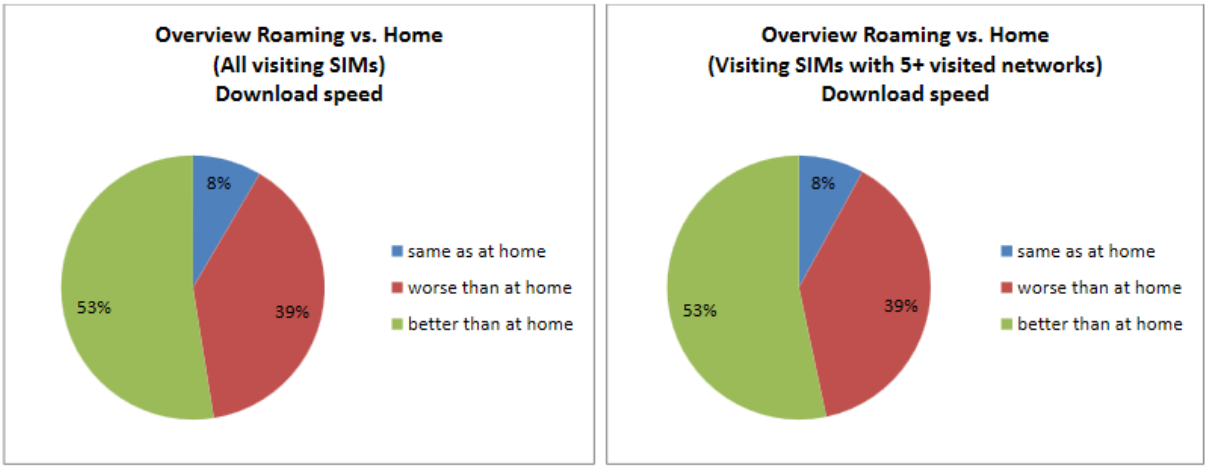


Figure 12. Overall distribution of download performance of visiting SIMs in relation to their performance at home

Looking at the overall data for all the 29 SIMs going through 177 unique roaming instances between them, on 53% occasions the average download speed of a SIM was found to be better in roaming than in its home network; on 8% occasions the download performance of a SIM was similar in roaming as in its home network; and on 39% occasions (69 instances out of 177), a SIM had worse download performance in roaming than in its home network.

The number of visited networks on which a SIM was tested varied between 1 and 12. This was because the total number of operational pre-paid visiting SIMs grew over the course of the project and also

because sometimes the top-up process from abroad for a pre-paid SIM did not work for logistic reasons. As a result, in case of two particular SIMs, the number of visited networks was only one whereas for five SIMs, the number of visited networks was ten or more. For the 29 SIMs, the total number of unique pairs of roaming instances (visiting SIM, visited network) was 177, with the average number of visited networks per visiting SIM being 6.

When considering only those 19 SIMs for which the number of visited networks was five or more with a total of 150 unique roaming instances, on 53% occasions SIMs had better download performance in roaming than at home, on 8% occasions they had the same performance and on 39% occasions they had worse performance in roaming than in their respective home network. The distribution was thus similar to the pattern for the overall set of 29 visiting SIMs.

Overall, out of the 29 visiting SIMs, 25 SIMs had, at least once, worse download performance in roaming than at home. These accounted for 69 of the 177 roaming instances.

(B) Upload performance

The process of analysing the data for upload performance was similar to the one used for download performance. It is shown in the figure below.

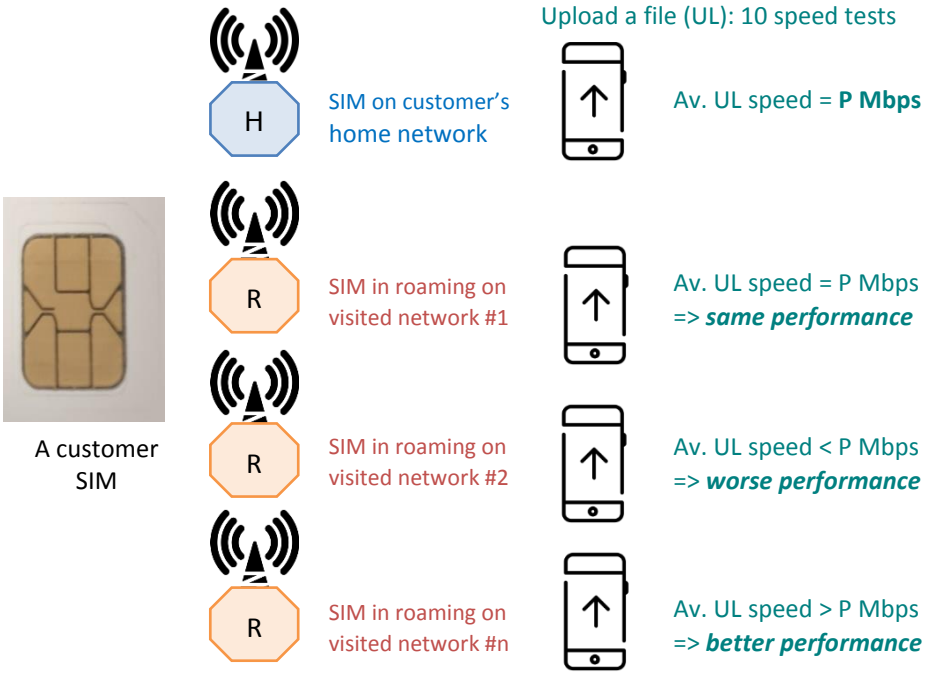


Figure 13. For each customer SIM, its upload performance on a visited network was assessed in relation to that on its home network

Out of the 29 SIMs, for six SIMs the upload performance was always better or same in roaming as compared to in their respective home network and for 10 SIMs, it was always worse in roaming than in their respective home network.

For 13 of the 29 SIMs, there was a mixed picture of upload performance in roaming as compared to in their respective home network. In other words, for 45% of the SIMs, on some occasions they had worse upload performance in roaming than in their respective home network and on some occasions similar or even better upload performance in roaming than in their home network.

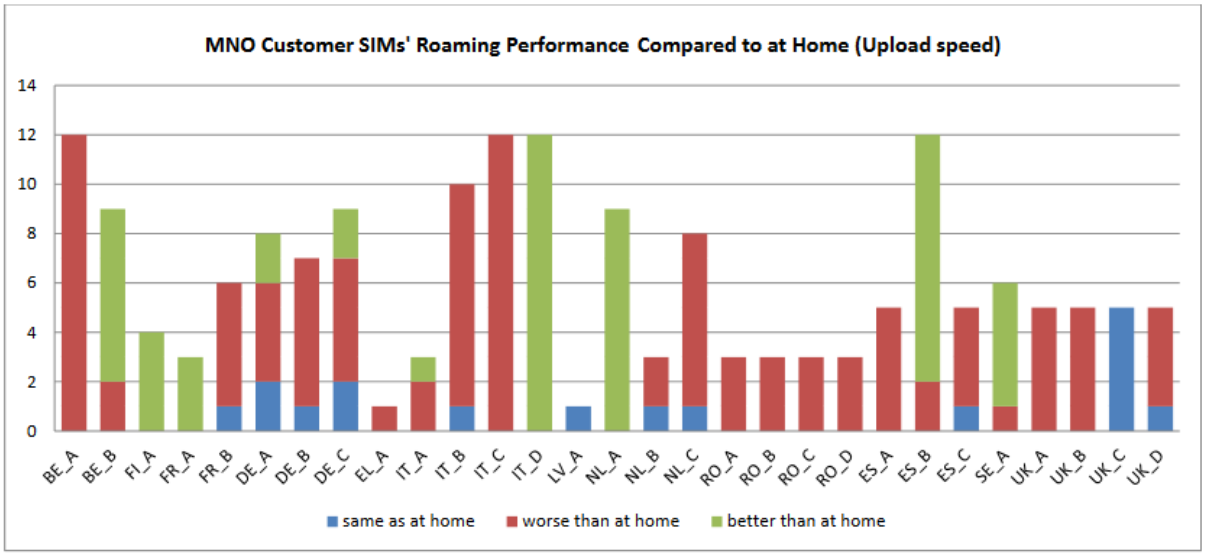


Figure 14. MNO customer SIMs' roaming performance compared to at home – Upload speed

X-axis: Customer SIM (Home network operator)

Y-axis: Number of visited networks

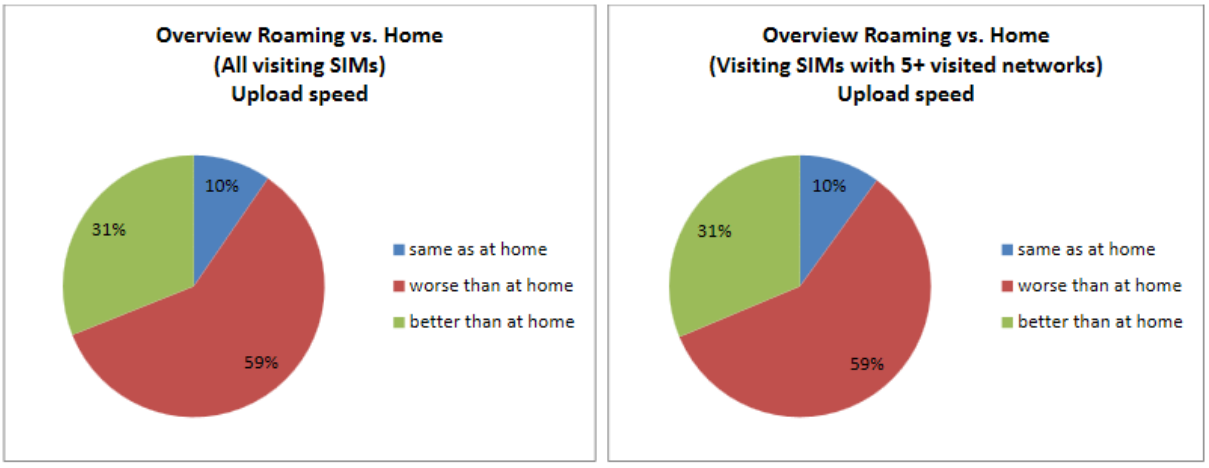


Figure 15. Overall distribution of upload performance of visiting SIMs in relation to their performance at home

Looking at the overall data across all the 29 SIMs going through 177 collective roaming performances between them, on 31% occasions the average upload speed of a SIM was found to be better in roaming than in its home network; on 10% occasions the upload performance of a SIM was similar in roaming as in its home network; and on 59% occasions, a SIM had worse upload performance in roaming than in its home network.

The number of visited networks on which a SIM was tested varied. This was because the total number of operational pre-paid visiting SIMs grew over the course of the project and also because sometimes the top-up process from abroad for a pre-paid SIM did not work for logistic reasons. As a result, in case of two particular SIMs, the number of visited networks was only one whereas for five SIMs, the number of visited networks was ten or more. For the 29 SIMs, the average number of visited networks was 6.

When considering only those 19 SIMs for which the number of visited networks was five or more with a total of 150 unique roaming instances, the distribution was similar to that observed for the whole set of 29 visiting SIMs.

(C) Latency performance

Recalling that latency in a network signifies the time delay in round-trip information flow, the shorter the latency the better it is for the internet customer's experience of quality of service.

The process used to analyse the data for latency was similar to the one used for download performance. It is shown in the figure below.

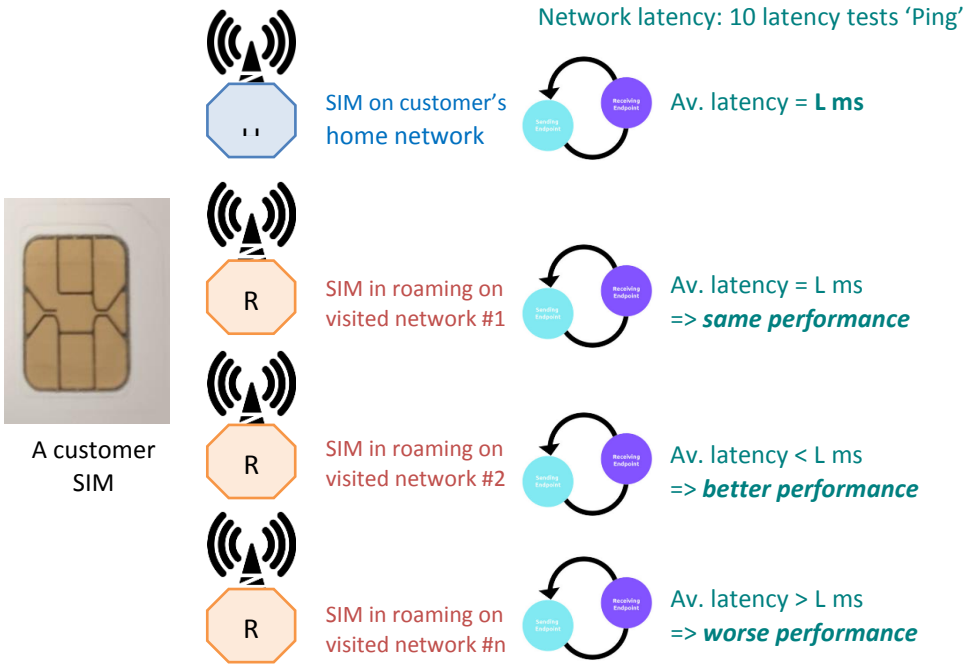


Figure 16. For each customer SIM, its latency performance on a visited network was assessed in relation to that on its home network

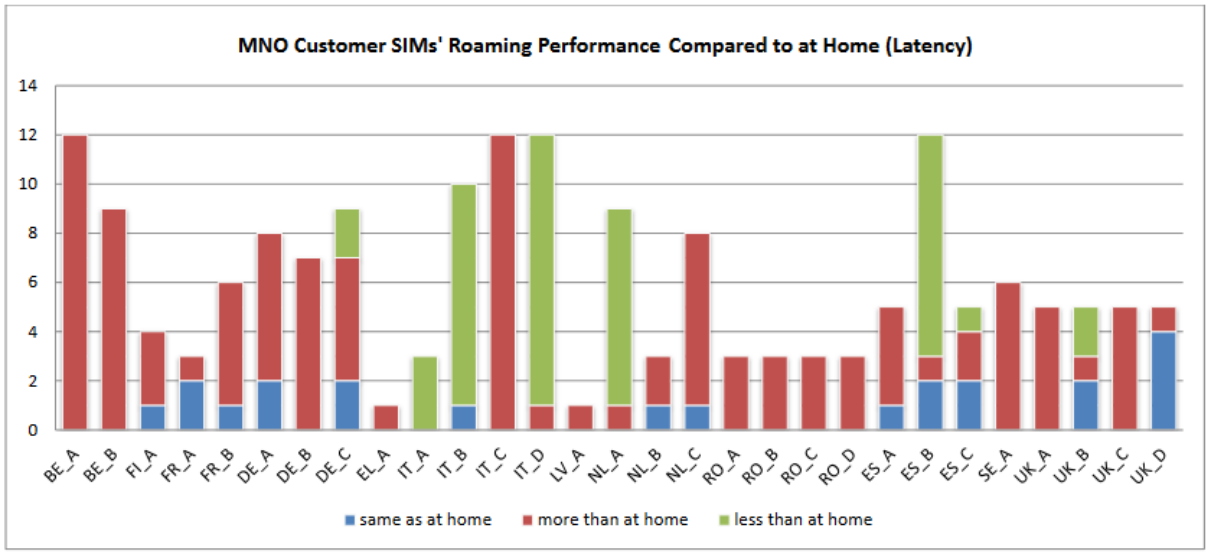


Figure 17. MNO customer SIMs' roaming performance compared to at home - Latency

X-axis: Customer SIM (Home network operator)

Y-axis: Number of visited networks

Out of the 29 visiting SIMs, for 16 (55%) SIMs the latency was always or nearly always worse in roaming than in their respective home network. However, for five SIMs the latency was generally better or same in roaming as compared to in their respective home. It suggests that latency as a QoS parameter could depend on the SIM operator's roaming policy or the technical implementation such as traffic steering.

Looking at the overall data for all the 29 SIMs with 177 collective roaming instances between them, on 25% occasions the latency for a SIM was found to be better in roaming than in its home network; 13% occasions it was similar in roaming as in its home network; and on 62% occasions, a SIM had worse latency in roaming than in its home network.

When considering only those 19 SIMs for which the number of visited networks was five or more with a total of 150 unique roaming instances, on 28% occasions SIMs had better latency performance in roaming than at home, on 12% occasions they had the same performance and on 60% occasions they had worse performance in roaming than in their respective home network. The distribution was thus similar to that observed for the whole set of 29 visiting SIMs.

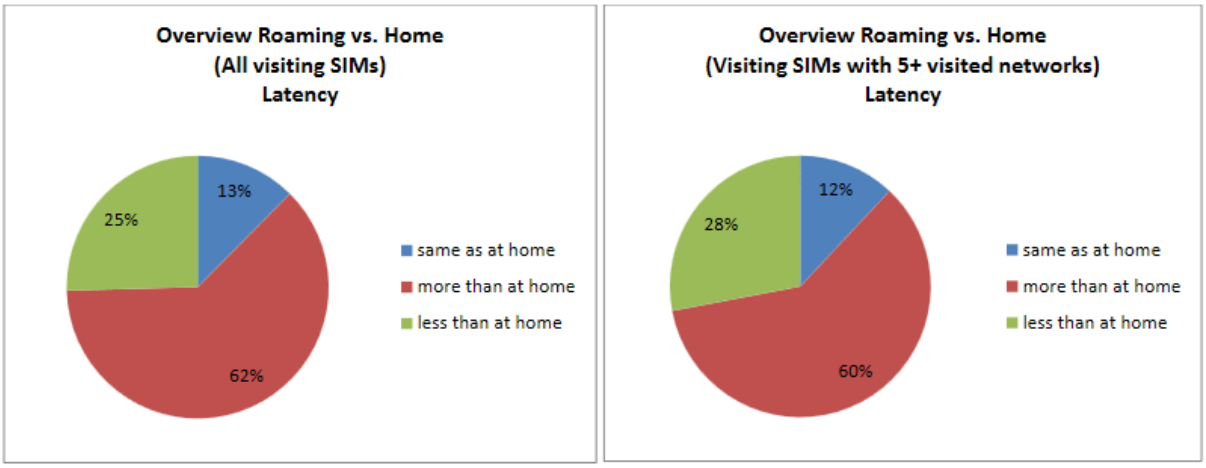


Figure 18. Overall distribution of latency performance of visiting SIMs in relation to their performance at home

To summarise the findings in regard to Q1, the download performance of roaming customer SIMs was worse than in their respective home network on 39% occasions. The upload performance was worse in roaming than at home on 59% occasions. The latency performance was worse in roaming than at home on 62% occasions.

Overall, of the 29 visiting SIMs, 25 SIMs had at least once worse download performance in roaming than at home. These accounted for 69 of the 177 roaming instances.

5.1.2 Q2. Does the quality of service on visited networks differ between the customers of the visited network and the roaming users visiting the network?

Scenario:

A number of business people from different EU countries are participating in an annual Technology Conference in City X**.** For network security reason, they prefer to use mobile network for broadband access rather than the free 'Guest Wi-Fi®' network of the conference centre. There are two MNOs operating in City X. Some visiting delegates are automatically routed on MNO X1 and some are automatically routed on MNO X2. Several visiting users of MNO X1 seem to be getting generally slow network performance so they ask a conference organizer, also a customer of MNO X1, if there are any

problems with MNO X1. Some of them, including the conference organiser, decide to run speeds tests in front of the conference centre premises to compare their broadband performance on MNO X1 to figure out the problem. Does MNO X1 offer better QoS to its home customers as compared to the visiting (roaming) users?

In order to answer ***Q2*** speed test measurements carried out by netBravo were analysed for 37 visited networks. For each of these visited networks, to compare relative performance, a home customer SIM had to be available and there had to be at least one visiting SIM that had registered on it as a visiting SIM.

There were 40 SIMs deployed in all. However, not all of them could be used in every visited country for logistics reasons as explained below. Out of the visiting SIMs used for tests in a visited country, some visiting SIMs would automatically choose to roam on one visited network while some others on another visited network and so on. For this reason, the number of visiting SIMs tested in a visited network varied from one network to another.

The number of existing MNOs per visited country varied between 2 and 4. Out of the 40 MNOs, in three cases a network in the visited country was selected by none of the visiting SIMs. Therefore in practice, there were only 37 visited networks, with a minimum 1 and maximum 4 visited networks per visited country.

The total number of visiting SIMs over the course of the project was 29. The number of visiting SIMs tested on a visited network varied between 1 and 15. This was (a) because the total number of operational pre-paid visiting SIMs available at the time of roaming test in a given network varied over the course of the project; (b) due to the automatic selection of the *preferred visited network* during roaming by each visiting SIM. As a result, as noted before, three of the operating networks were not chosen by any of the visiting SIMs. In case of six visited networks, the number of visiting SIMs was only one whereas for another six visited networks, the number of visiting SIMs was nine or more. For the 37 visited networks, the average number of visiting SIMs per visited network was about 5.

Analytical method

1. The netBravo test data was analysed for each of the visited network.
2. For each visited network, download and upload speeds were compared for its visiting SIMs (roaming customers) *vis a vis* those of the visited network's own SIM (home customer).
3. A visiting SIM's speed performance on a given visited network was classed as *better / the same / worse* depending on the above comparison. This counted as one instance of roaming performance.
4. Numbers of instances of better / the same / worse performance were counted for each of the visited networks.
5. The relative performance is plotted in a graphical form (bar chart), for all visited networks. Each single bar corresponding to a visited network, shows the distribution of the three types of performance on it by visited SIMs.
6. Total numbers of instances of better / the same / worse performance were summed for all of the visited networks.
7. The overall performance of the visiting SIMs for all visited networks is shown in a pie chart.
8. Steps 5 and 7 above, allowed analytical observations and conclusions to be drawn based on field tests on mobile networks.

(A) Download Performance

Speed tests with netBravo consisted of three parts: Download of a large file, upload of a large file and a test on network latency. Results for these tests are analysed below.

For most of the visited networks, there was no clear cut case of uniformly worse or better performance by the visiting SIMs as compared to their respective home SIM. In other words, for a typical **visited network**, some of the visiting SIMs had worse performance than that by its home SIM, some visiting SIMs had the same performance as the home SIM and some visiting SIMs had even better performance than the home SIM of the visited network.

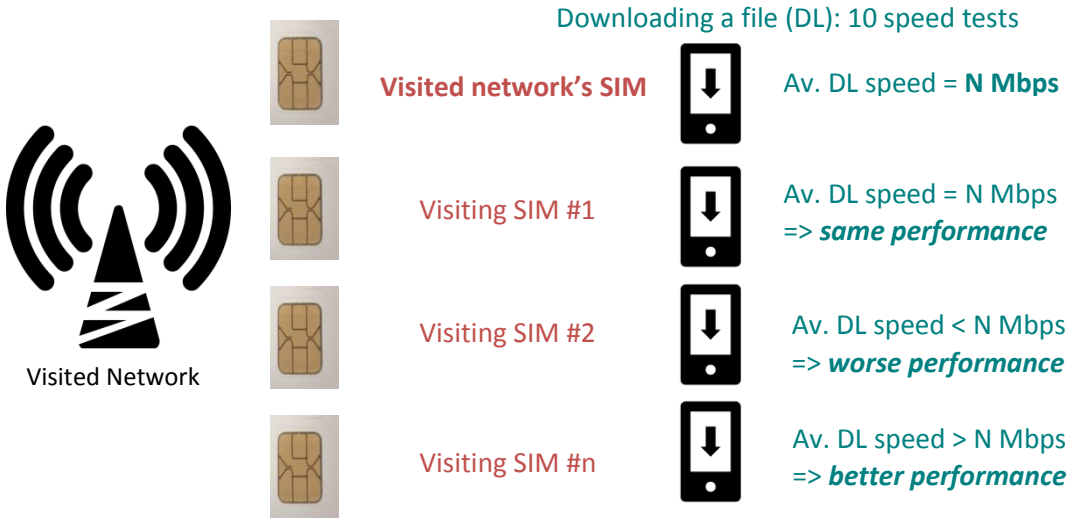


Figure 19. For each visited network, download performance of visiting SIMs was assessed in relation to that of the own SIM of that visited network

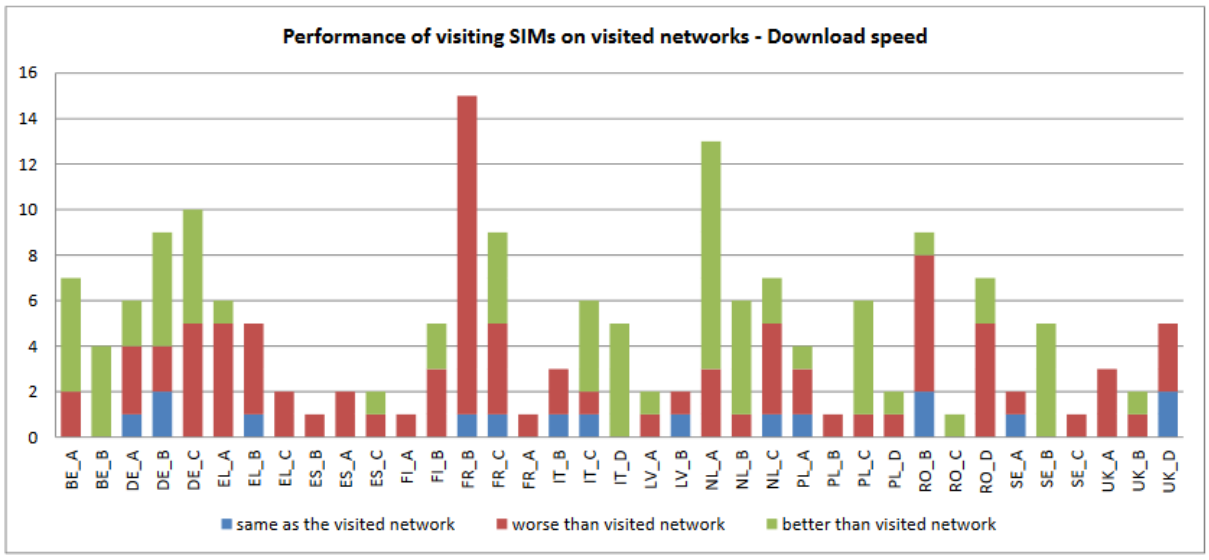


Figure 20. Download performance of visiting SIMs compared to the own SIM of the visited network

X-axis: Visited network

Y-axis: the number of visiting SIMs that had better/same/worse download speed than the visited network operator's own SIM

Looking at the overall data across all the 37 visited networks in 13 countries, with varying number of visiting SIMs between 1 and 15 per visited network, there were 177 unique roaming instances of pairs *(visiting SIM, visited network)*. The average number of SIMs per visited network was about 5.

For the download, in 50% cases (88 instances) the **download speed** for a visiting SIM was found to be worse than that for the respective home SIM; in 9% of the cases, the performance for a visiting SIM

was similar to the respective home SIM; and in 41% cases, a visiting SIM had better performance than the home SIM.

When considering only those 19 visited networks where the number of visiting SIMs was five or more, out of 141 unique roaming instances, in 45% cases visiting SIMs had better download performance, in 8% cases they had the same performance and in 47% cases they had worse performance than the visited network's home SIM.

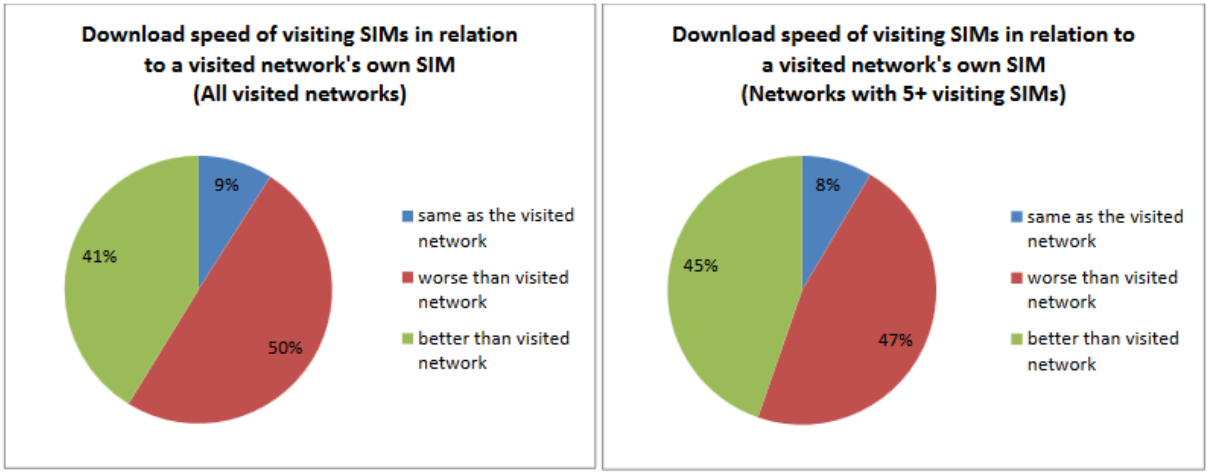


Figure 21. Overall distribution of download performance of visiting SIMs in relation to visited network's own SIM

(B) Upload performance

The process of analysing the data for upload performance was similar to the one used for download performance. It is shown in the figure below.

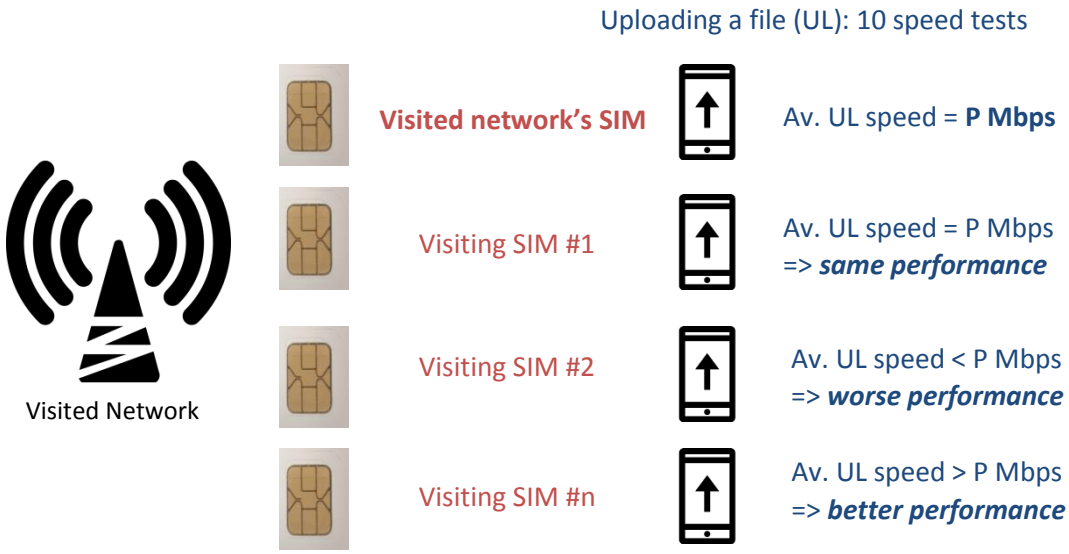


Figure 22. For each visited network, upload performance of visiting SIMs was assessed in relation to that of the own SIM of that visited network

As the graph below shows, there was a clearer picture for the upload performance of the visiting SIMs in relation to the home SIM of respective visited network.

On 19 of the 37 visited networks, the **upload performance** of visiting SIMs in relation to the home SIM of respective visited network was always worse whereas on five visited networks, it was always better. For the remaining **visited networks**, it was a mixed result where some of the visiting SIMs had worse upload performance than that of the home SIM, some had the same performance as the home SIM and some visiting SIMs had still better upload performance than the home SIM of the visited network.

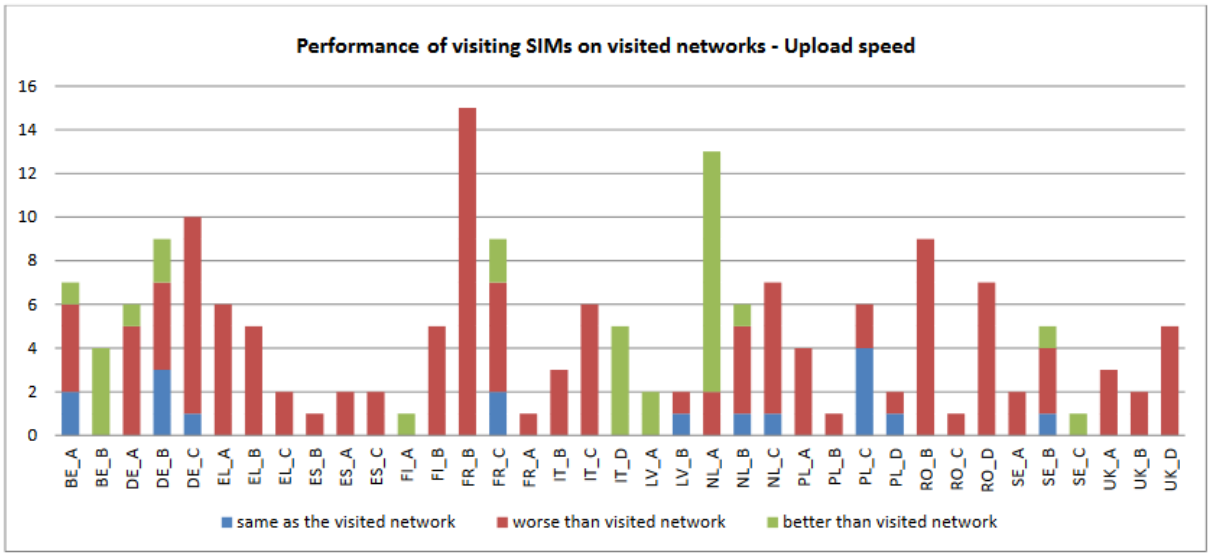


Figure 23. Upload performance of visiting SIMs compared to the own SIM of the visited network

X-axis: Visited network

Y-axis: the number of visiting SIMs who had better/same/worse upload speed than the visited network operator's own SIM

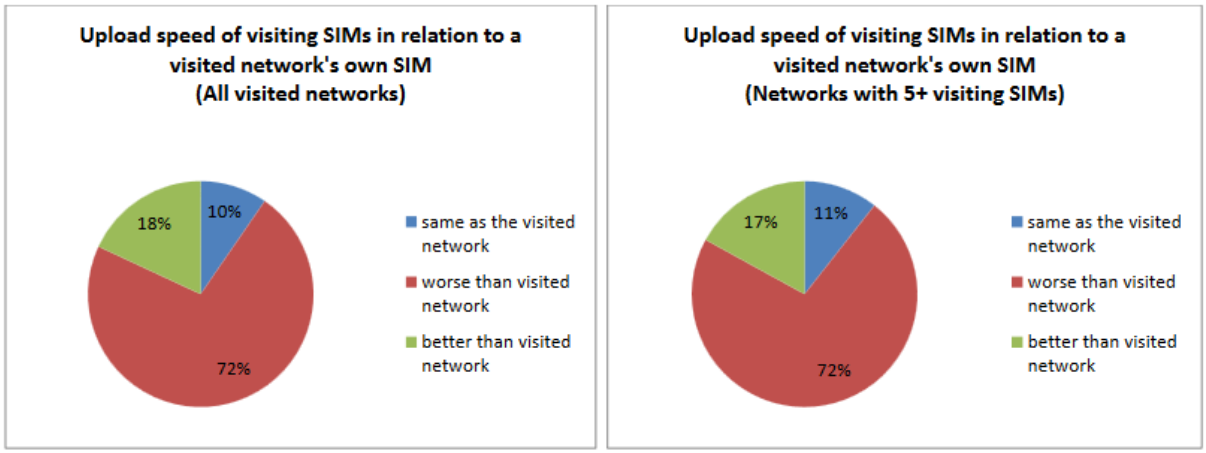


Figure 24. Overall distribution of upload performance of visiting SIMs in relation to visited network's own SIM

Looking at the overall data across all the 37 visited networks with 177 unique instances of *(visiting SIM, visited network)*, in 72% cases the upload speed for a visiting SIM was found to be worse than that for the respective home SIM; in 10% of the cases, the upload performance of a visiting SIM was similar to the respective home SIM; and in 18% cases, a visiting SIM had better upload performance than the home SIM.

When considering only those 19 visited networks where the number of visiting SIMs was five or more, out of the 141 unique roaming instances, in 17% cases visiting SIMs had better upload performance, in

11% cases they had the same performance and in 72% cases they had worse upload performance than that of the visited network's own SIM.

(C) Latency performance

Recalling that latency in a network signifies the time delay in round-trip information flow, the shorter the latency the better it is for the internet customer's experience of quality of service.

The process of analysing the data for latency was similar to the one used to assess download performance. It is shown in the figure below.

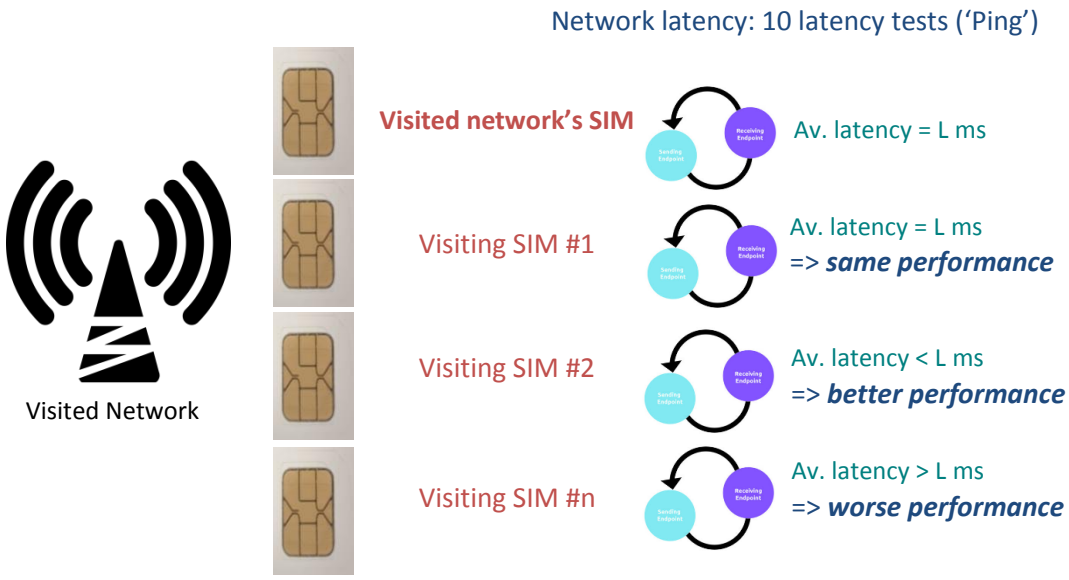


Figure 25. For each visited network, latency for visiting SIMs was assessed in relation to that for the own SIM of that visited network

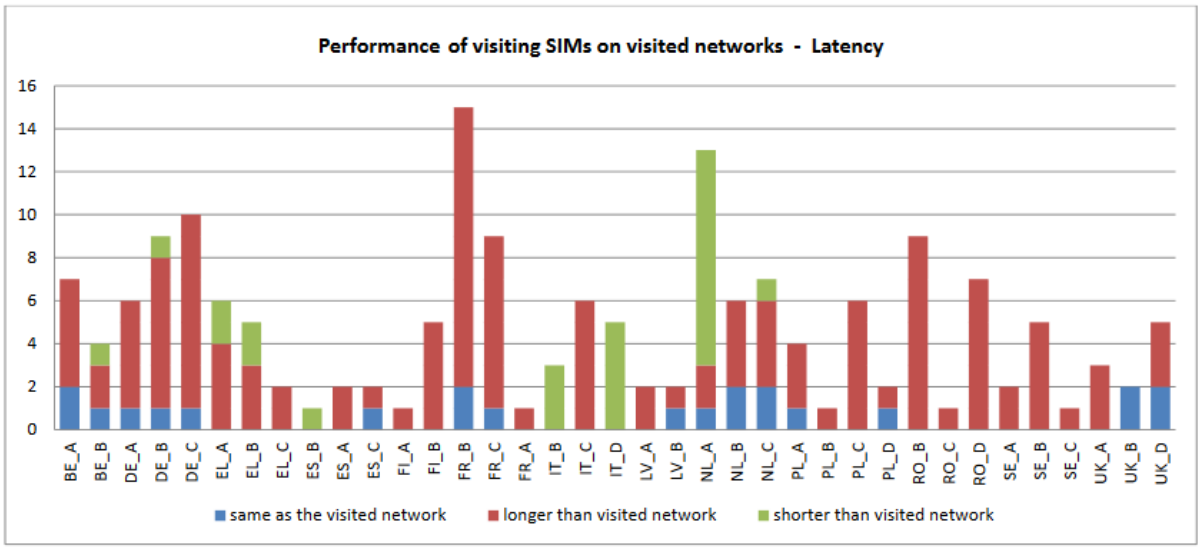


Figure 26. Latency for visiting SIMs compared to the own SIM of the visited network
X-axis: Visited network
Y-axis: the number of visiting SIMs who had better/same/worse latency than the visited network operator's own SIM

As the graph above shows, there was a clear picture of the latency for the visiting SIMs in relation to the home SIM of respective visited network.

On 16 of the 37 visited networks, the **latency** for visiting SIMs in relation to the home SIM of respective visited network was always worse whereas on three visited networks, it was always better or the same. On the rest, it was generally a mixed result between better, worse or the same as that for the home SIM of the visited network.

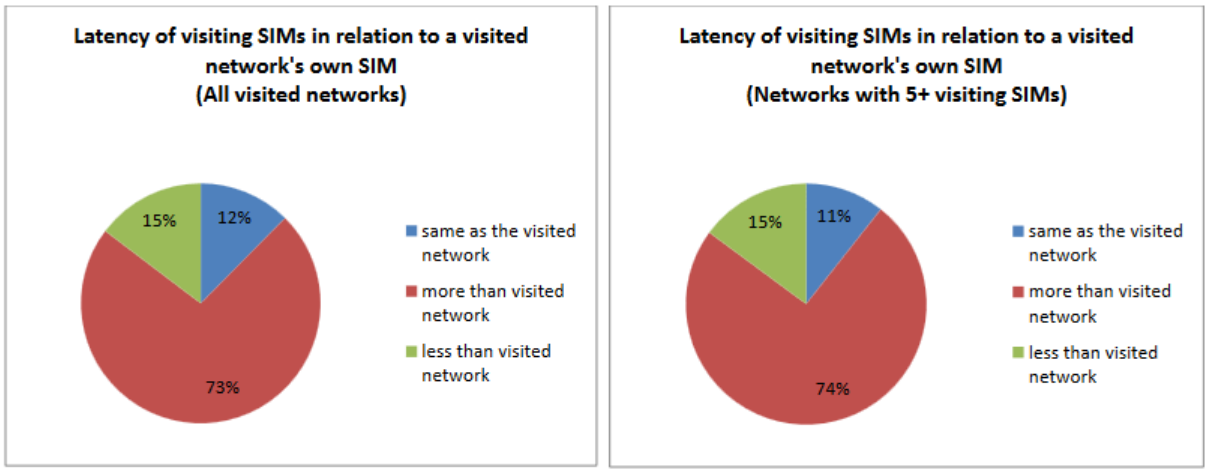


Figure 27. Overall distribution of latency for visiting SIMs in relation to visited network's own SIM

Looking at the overall data for all the 37 visited networks with 177 unique instances of *(visiting SIM, visited network)*, in 73% cases the latency for a visiting SIM was found to be worse than that for the respective home SIM; in 12% of the cases, the latency for a visiting SIM was similar to the respective home SIM; and in 15% cases, a visiting SIM had better latency than the home SIM.

When considering only those 19 visited networks where the number of visiting SIMs was five or more, out of the 141 unique roaming instances in 15% cases visiting SIMs had better latency, in 11% cases they had the same latency and in 74% cases they had worse latency than that of the visited network's own SIM.

In summary, on Q2, results from field tests show that the download performance of visiting SIMs (roaming customers) was worse than the home SIM (home customer) of the visited network in 50% cases (88 of the 177 roaming instances). The upload performance of the visiting SIMs was worse than the home SIM in 72% of the roaming instances. The latency of the visiting SIMs was worse than the home SIM in 73% of the roaming instances.

It is worth noting that the download performance is crucial to the internet activities which involve receiving large files from others (e.g. images or documents in emails and the cloud) and streaming videos. On the other hand, upload performance plays an important role for the user in sending large quantities of information to others such as sending documents, photos or videos. For real time interactions such as in a videoconference, latency as well as both types of transmission activity are important.

5.1.3 Q3. Does the roaming customer have different quality of service on a visited network compared to other visiting roaming customers?

Scenario:

Imagine a number of young persons from different EU countries meeting at a Youth Hostel in a popular tourist city. As it happens, they are all roaming on the same visited network, shown on their smart phones. They decide to watch on their phones, an online video guide about local museums before visiting them the next day. Some of them seem to be getting an uninterrupted video experience while others sitting next to them are finding it frustrating as their video keeps pausing. The frustration shows on some of the faces as they look at each other as if to say '*What's wrong with my*

mobile'? Clearly, the poor experience could not be due to poor network coverage or traffic congestion since network conditions are the same for all these friends. Perhaps there is a different quality of service in the contracts of these customers or the wholesale agreement between their respective home and visited networks differ in terms of the QoS.

The following analysis attempts to provide possible evidence for such a discrepancy.

The performance of visiting SIMs in various visited networks could not be compared in absolute terms vis-à-vis their performance at home, for reasons such as traffic congestion, signal quality on the test site, the planned network capacity and the QoS parameters set by the operators. For this reason, the direct comparison between roaming performance in one network and the home network is necessary but not sufficient for the purpose of full analysis of roaming performance. An additional perspective was needed.

For this reason, this analytical step was devised to benchmark the roaming performance of a visiting SIM in the context of the visited network. Thus if, for example, a visited network had inherently poor performance conditions, one would expect all visiting SIMs to have low performance. Conversely, in high performance conditions of a network, one would expect all visiting SIMs in that network to have high performance. Hence the performance of a specific visiting SIM in relation to other visiting SIMs in the same visited network at the same location and at the same time would be an additional objective assessment of roaming performance in the given context.

(A) Download performance

The assessment of relative download performance of a visiting SIM in the context of a visited network involved the steps shown in Figure 28 below. The assessment process was repeated for all 177 instances of (visiting SIM, visited network) pairs between 29 visiting SIMs and 37 visited networks.

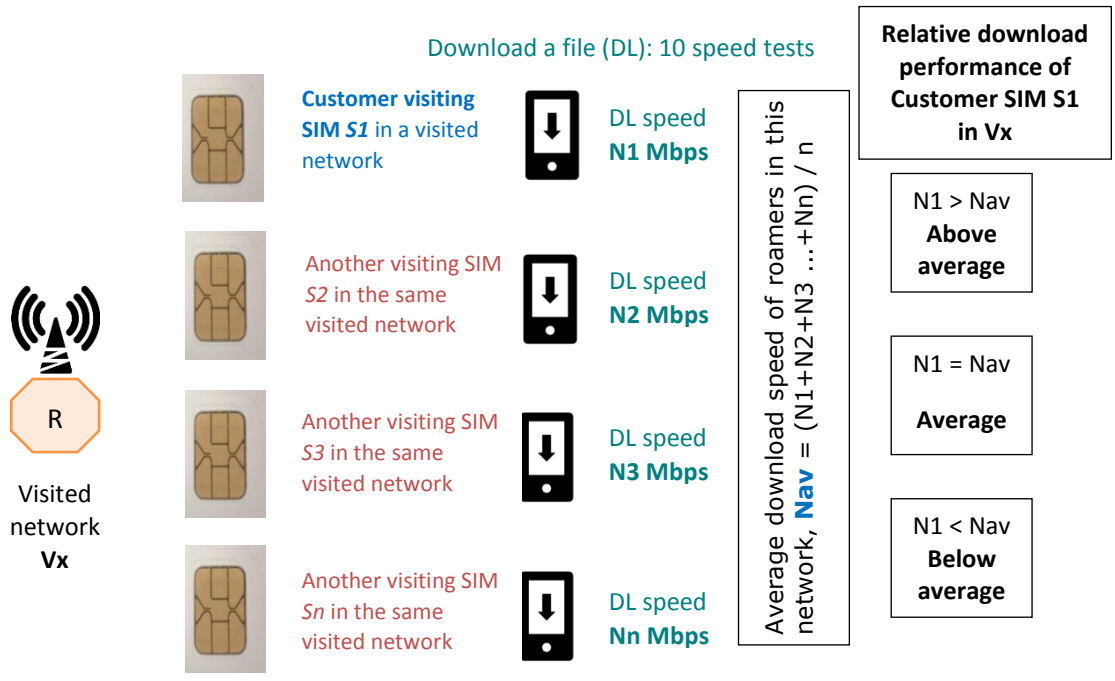


Figure 28. Process of assessing the relative download performance of a visiting SIM in a visited network Vx in relation to the download performance of other visiting SIMs in that network

As the figure shows, the download performance of the visiting SIM ***S1*** in the visited network ***Vx*** was compared with the average level of download performance of all the visiting SIMs in the network *Vx*.

The result was classified as *above average / average / below average,* based on this comparison. This counted as a single unique instance of relative performance ***(S1, Vx)***. The step was repeated for all the visited networks for that Customer visiting SIM.

The numbers of counts for each of *above average/average/below average* were used to represent the overall relative performance of the visiting SIM S1 in all its visited networks. It is represented in Figure 29 by the coloured bar denoted by its home network operator on the X-axis.

Procedure:

Suppose a customer SIM S1 visits several networks (Vx, Vw, … Vz) in roaming. Let's take one such network Vx.

For the Customer SIM S1 visiting network Vx,

(a) The download speeds for all 'n' visiting SIMs S1, S2, … Sn in the visited network Vx were considered;

(b) These speeds are represented by N1, N2, N3, … Nn respectively for the SIMs S1, S2, … Sn;

(c) The average of these download speeds was calculated as Nav = {(N1+N2+ … +Nn) / n}

(d) Compare the download speed N1 of Customer SIM S1 with the average value Nav

If N1 > Nav => above average

If N1 = Nav => average

If N1 < Nav => below average.

(e) Repeat steps (a) – (d) for all networks visited by S1 (Vw, Vy, … Vz).

(f) Count the number of times S1 finds itself 'above average' | 'average' | 'below average'.

(g) Plot the bar for the SIM S1 in Figure 29, represented by the name of its home network. The length of the bar is equal to the number of visited networks in which customer SIM S1 was tested.

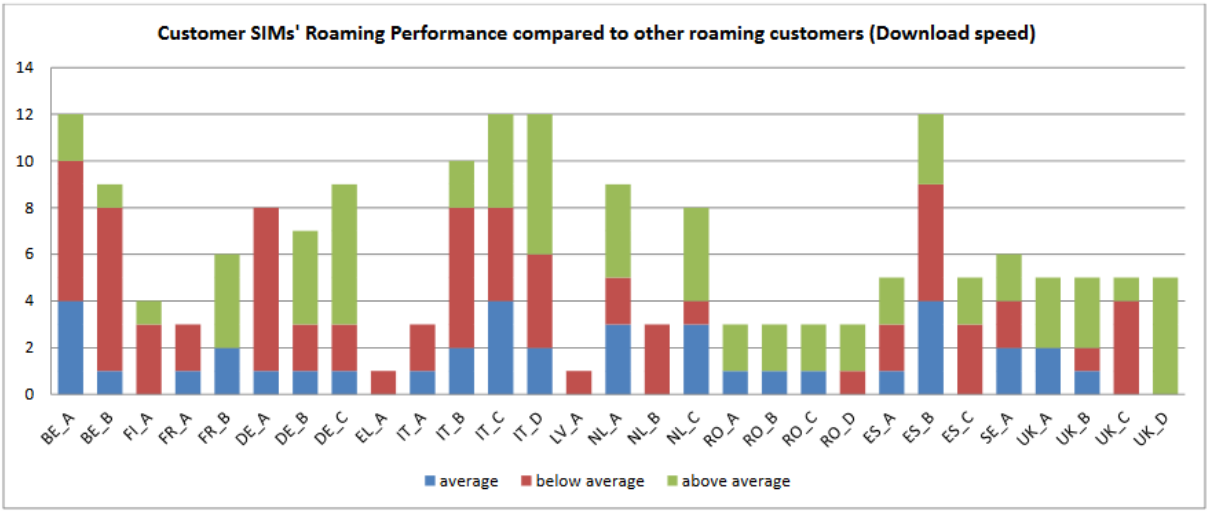


Figure 29. Download performance in roaming of customer SIMs of different MNOs in visited networks in relation to other visiting SIMs in those visited networks

X-axis = the customer SIMs designated by their respective (home) network

Y-axis = the number of visited networks in which the customer SIM of a designated network had above average / below average / average download performance relative to other visiting SIMs tested side-by-side in the same visited network

Looking at the relative performance of download in roaming as per the above criteria, it can be observed in Figure 29 that for some roaming customers (visiting SIMs), the download performance was

more often above average (longer GREEN bars) whereas for some it was generally below average (longer RED bars).

The implication of this finding is that those customers with higher above average count often had superior QoS in download in comparison to the average level of quality enjoyed by all roaming customers in the same visited network at the same time and the same location. For example, among its 12 visited networks, the IT_D customer had superior download performance while roaming in 6 visited networks, below average in four and average performance in two. In contrast, the DE_A customer had below average download performance seven of the eight networks that it visited.

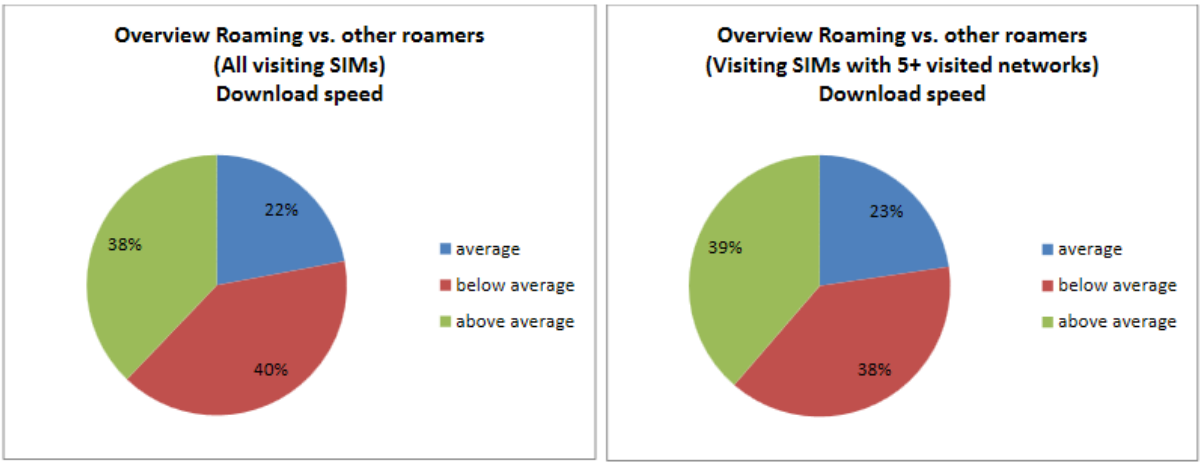


Figure 30. Overall distribution of download performance of visiting SIMs in relation to other roaming SIMs in the same visited network

Looking at the pie chart representing the performance of download for all roaming instances in relation to other roamers, the distribution was nearly even between above average (38%) and below average performance (40%), with 22% classed at the average level. It indicates that the average levels were generally also close to the statistical median. Considering only the roaming instances of 19 SIMs which visited 5 or more networks, the distribution was similar for the three categories: above average (39%) below average (38%), and average (23%).

However, for the customer SIMs whose download roaming performance was always or often below average in their visited networks (visited countries), the graph suggests that their contractual QoS conditions for roaming (and/or respective wholesale roaming agreements) could be less favourable than those customers who had more often above average performance.

(B) Upload performance

The assessment of relative upload performance of a visiting SIM in the context of a visited network involved the steps shown in Figure 31 below. Like for download testing, the assessment process for upload was repeated for every visiting SIM in every visited network.

The upload performance of the customer visiting SIM in that visited network was compared with the average level of upload performance of all the visiting SIMs in that network. The benchmarking result was classified as *above average / average / below average,* based on this comparison.

The step was repeated for all the visited networks for that Customer visiting SIM.

The numbers of counts for each of *above average/average/below average* were used to represent the overall relative performance of the Customer visiting SIM in all its visited networks. It is represented by coloured bars in Figure 32.

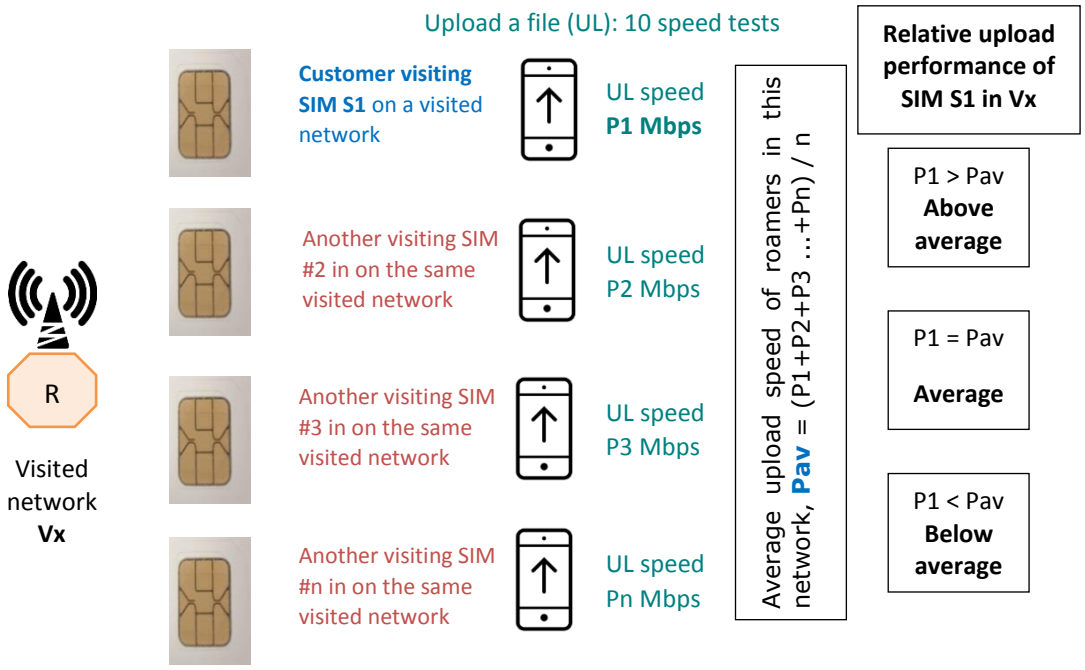


Figure 31. Process of assessing the relative upload performance of a visiting SIM in a visited network Vx in relation to the upload performance of other visiting SIMs in that network

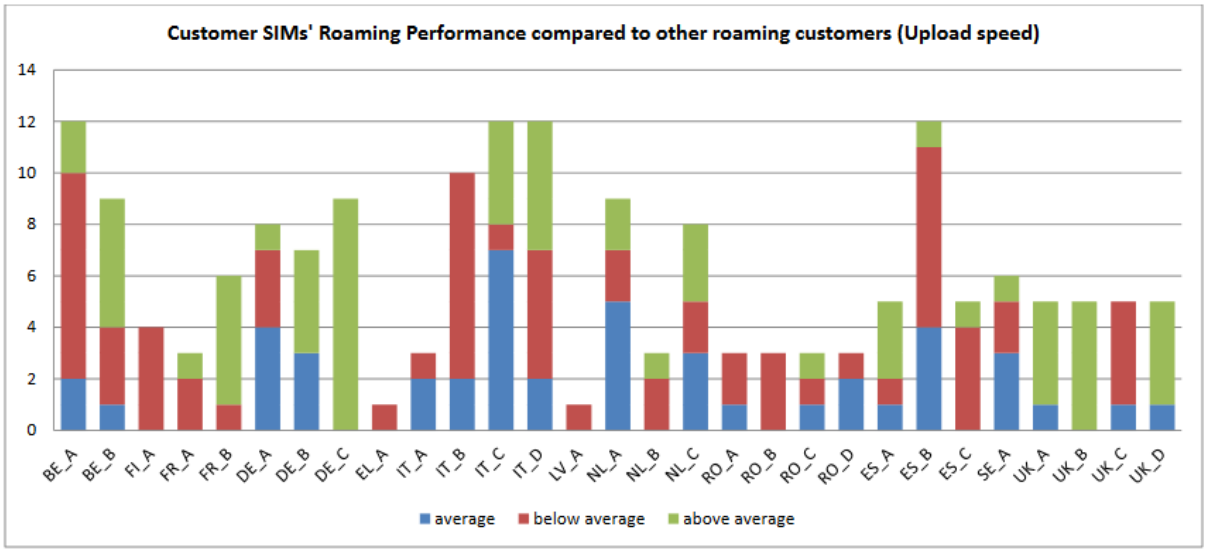


Figure 32. Upload performance in roaming of customer SIMs of different MNOs in visited networks in relation to other visiting SIMs in those visited networks

X-axis represents **the customer SIMs** designated by their respective (home) network

Y-axis represents **the number of visited networks** in which the customer SIM of a designated network had above average / below average / average upload performance relative to other visiting SIMs tested side-by-side

Looking at the relative performance of upload in roaming as per the above criteria, it can be observed in Figure 32 that for some roaming customers (visiting SIMs) the upload performance was more often above average whereas for some it was generally below average.

The implication of this finding is that those customers with high *above average* count frequently had superior QoS in upload in comparison to the average level of quality enjoyed by all roaming customers at the same time and the same location. For example, a DE_C customer, among its 9 visited networks, had superior roaming performance for upload in all its visited networks compared to the average upload performance of all roamers in those networks. In contrast, the IT_B customer had in eight of its ten visited networks, a below average upload performance and on two occasions average performance for upload.

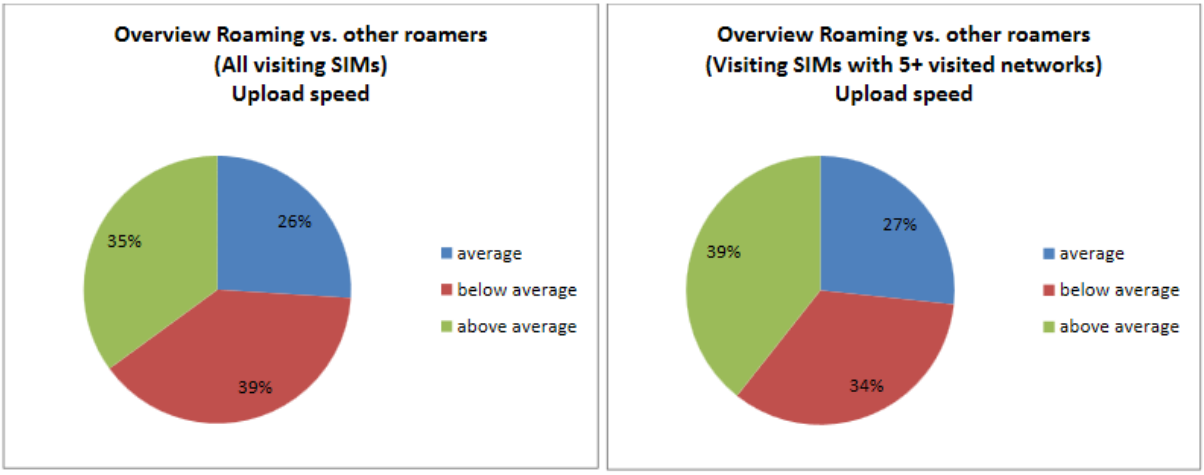


Figure 33. Overall distribution of upload performance of visiting SIMs in relation to other roaming SIMs in the same visited network

Looking at the pie chart in Figure 33, representing the upload performance in all roaming instances in relation to other roamers, the distribution was nearly even between above average (35%) and below average (39%) with 26% clustered around the average. It indicates that the average levels for upload speed were generally also close to the statistical median.

Considering only the roaming instances for 19 SIMs which visited 5 or more networks, the distribution was similar: above average (39%), below average (34%) and average (27%).

For the customer SIMs whose upload roaming performance was always or often below average in their visited networks (visited countries), the graph suggests that their contractual QoS conditions for roaming (and/or respective wholesale roaming agreements) could be less favourable than those customers who had more often above average performance.

(C) Latency

Recalling that latency in a network signifies the time delay in round-trip information flow, the shorter the latency the better it is for the internet customer's experience of quality of service.

The assessment of relative latency of a visiting SIM in the context of a visited network involved the steps shown in Figure 34 below. Like for download testing, the assessment process for latency was repeated for every visiting SIM in every visited network.

The latency of the customer visiting SIM in that visited network was compared with the average level of latency of all the visiting SIMs in that network. The benchmarking result was classified as *above average / average / below average,* based on this comparison.

The step was repeated for all the visited networks for that customer visiting SIM.

The numbers of counts for each of *above average/average/below average* were used to represent the overall relative performance of a visiting SIM in all its visited networks. It is represented by coloured bars in Figure 35.

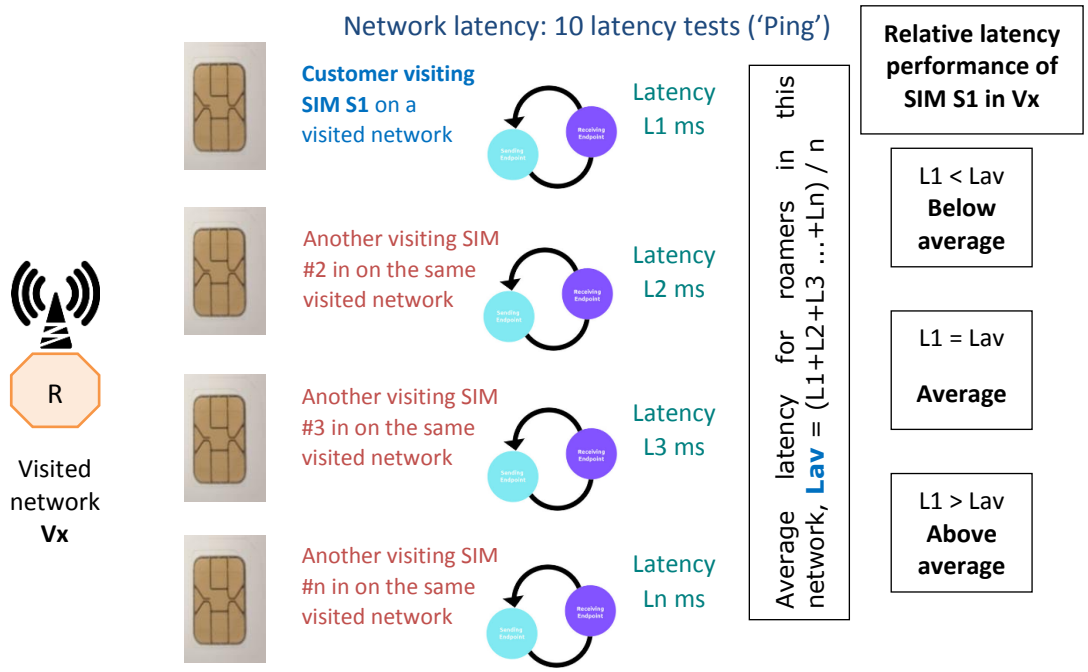


Figure 34. Process of assessing the relative latency performance of a visiting SIM in a visited network Vx in relation to the latency of other visiting SIMs in that network

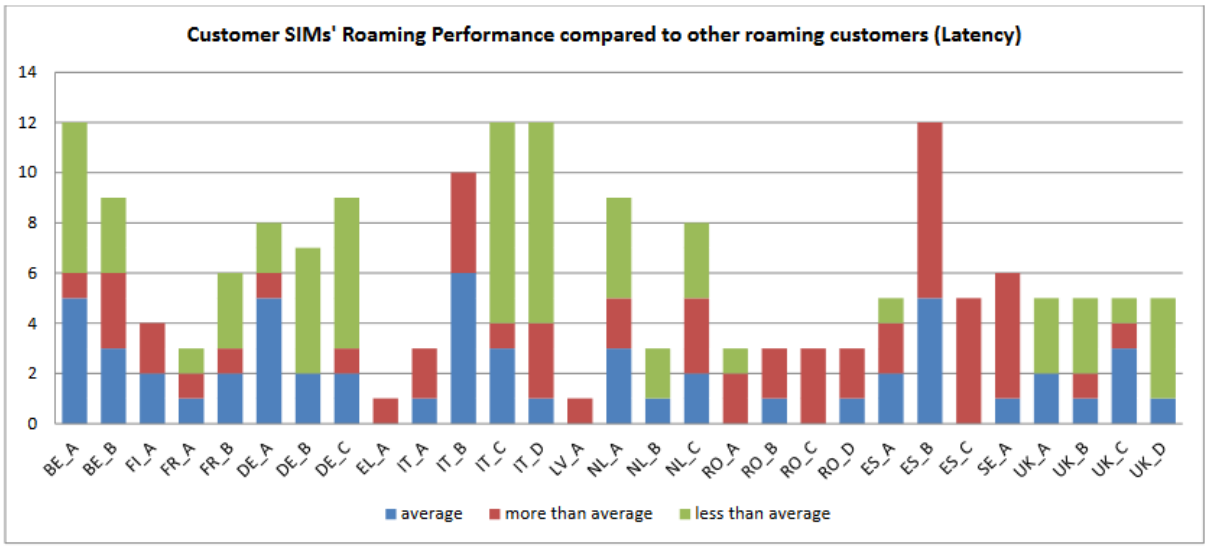


Figure 35. Latency in roaming of customer SIMs of different MNOs in visited networks in relation to other visiting SIMs in those visited networks

X-axis represents **the customer SIMs** designated by their respective (home) network

Y-axis represents **the number of visited networks** in which the customer SIM of a designated network had above average / below average / average latency relative to other visiting SIMs tested side-by-side

Looking at the relative latency in roaming as per Looking at the relative latency in roaming as per the above criteria, it can be observed in Figure 35 that for some roaming customers (visiting SIMs), the latency was more often *more than average* whereas for some it was often *average* or *less than average*.

The implication of this finding is that those customers with high count of *below average* latency frequently had superior QoS in comparison to the average level of quality enjoyed by all roaming customers at the same time and the same location. For example, the DE_B customer, among its 7 visited networks, had superior latency on five occasions compared to the average latency by roamers in those networks. In contrast, the SE_A customer had in five of its six visited networks, a below average latency and only once the average.

Looking at the pie chart in Figure 36, representing relative roaming performances for latency in all roaming instances, the distribution was nearly even between *more than average* (36%) and *less than average latency* (32%) with 26% clustered around the *average* level. It indicates that the average levels for latency were generally also close to the statistical median.

Considering only the roaming instances of the 19 SIMs which visited 5 or more networks, the distribution was: *less than average* (40%), *more than average* (27%) and *average* (33%).

For the customers who often had *more than average* latency in their visited networks, the graph suggests that their contractual QoS conditions for roaming (and/or respective wholesale roaming agreements) could be less favourable than those customers who more often had *less than average* latency.

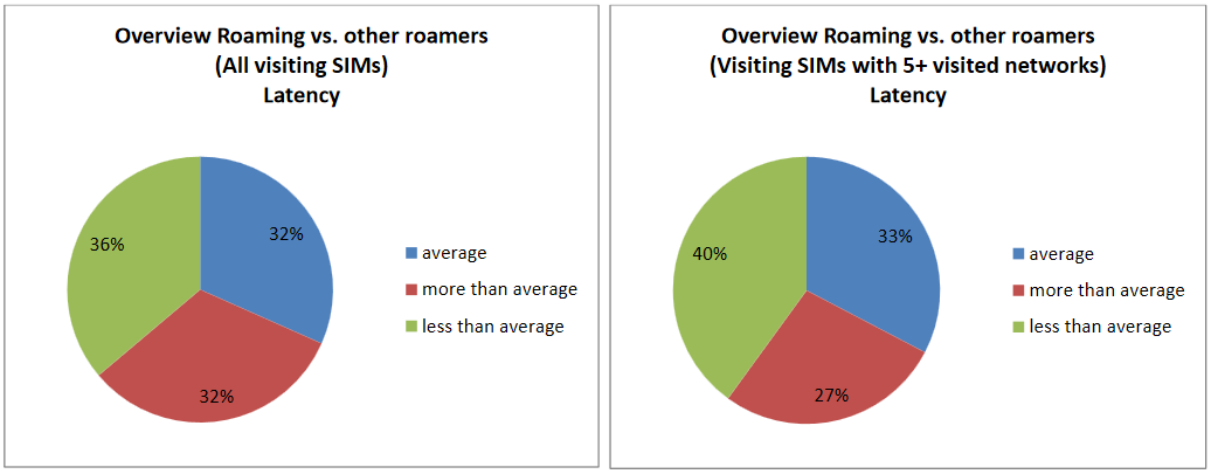


Figure 36. Overall distribution of latency for visiting SIMs in relation to other roaming SIMs in the same visited network

To summarise the analysis on Q3, in relation to the roaming peers (other roaming users in the same visited network, at the same location and at the same time), there was even distribution of instances of roaming performance with *below average* and *above average* download speed. The same was true for the distributions of upload performance and the latency. It shows that the test results were overall statistically valid. However, it was found that some customer SIMs were generally more likely to have below average performance than others, pointing towards possibility of the QoS in roaming being offered to them at an unfavourable level.

Cases with problems

To identify the cases with problems in QoS during roaming, the following cross-correlation analysis was performed, looking at the download speed performance.

(a) Which roaming customers had often worse download speed in roaming than in their home network?

13 such customer SIMs were identified from Figure 11 in Q1.

(b) Which roaming customers had often worse download speed than their roaming peers?

15 such customer SIMs were identified from Figure 29 in Q3.

(c) Which customers fared poorly in both cases (a) and (b)?

Six such customer SIMs were identified

The following Venn diagram shows the result of this analysis:

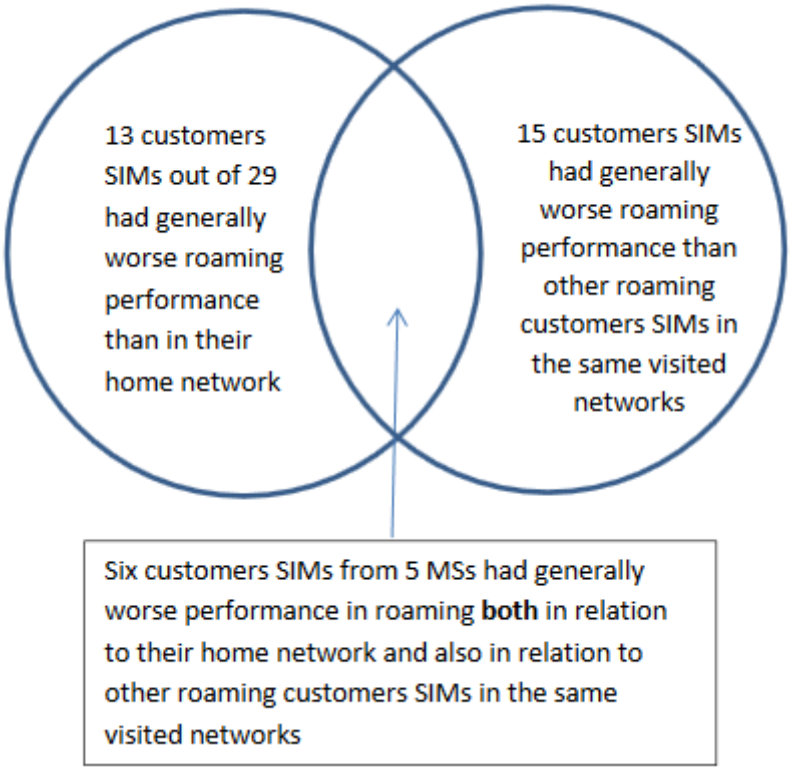


Figure 37. Customer SIMs with generally worse speed performance in roaming

The cross-correlation analysis was extended to answer the fourth question.

5.1.4 *Q4. How often did customers have worse quality of service in roaming than at home, even when the visited network was technically and practically able to provide better quality?*

In the analysis for Q1, it was already observed from Figures 11 and 12, that out of the 29 visiting SIMs, 25 SIMs had, at least once, worse download performance in roaming than at home. It accounted for 69 of the 177 roaming instances.

To answer the above question, data was further analysed for all 177 roaming instances to find out instances where a visited network had better technical conditions available than the QoS received by its visiting SIMs. Therefore the comparisons made in Q2 were analysed and re-mapped on *per visiting SIM* basis.

Results of this analysis are shown in Figure 38.

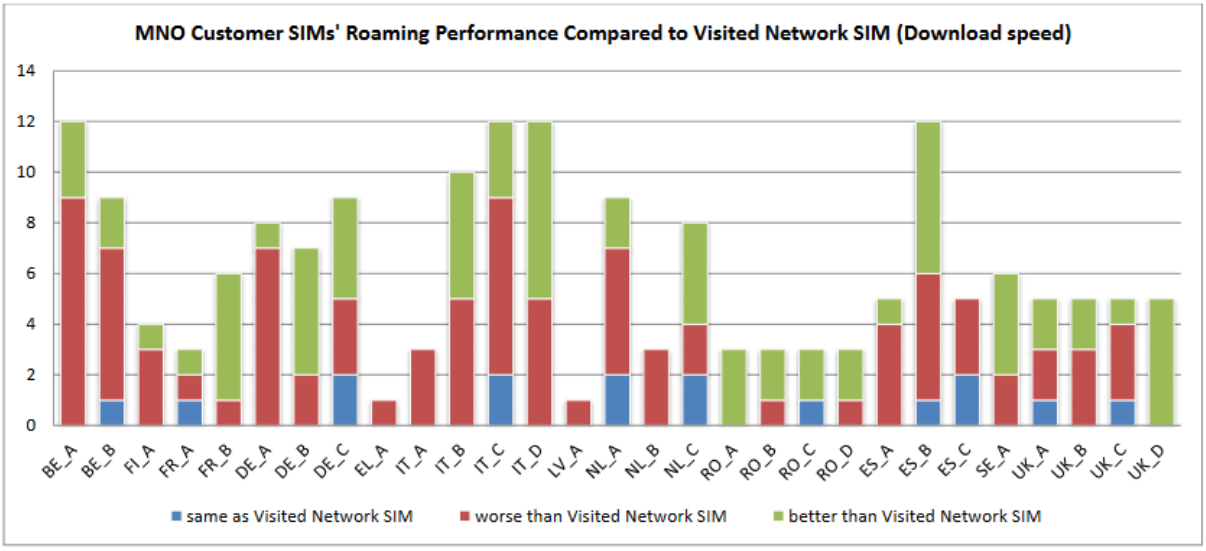


Figure 38. Download performance in roaming of customer SIMs of different MNOs in relation to the own customers of the visited networks

X-axis represents **the customer SIMs** designated by their respective (home) network

Y-axis represents **the number of visited networks** in which the customer SIM of a designated network had better / worse / the same download performance relative to the own SIM of the visited network

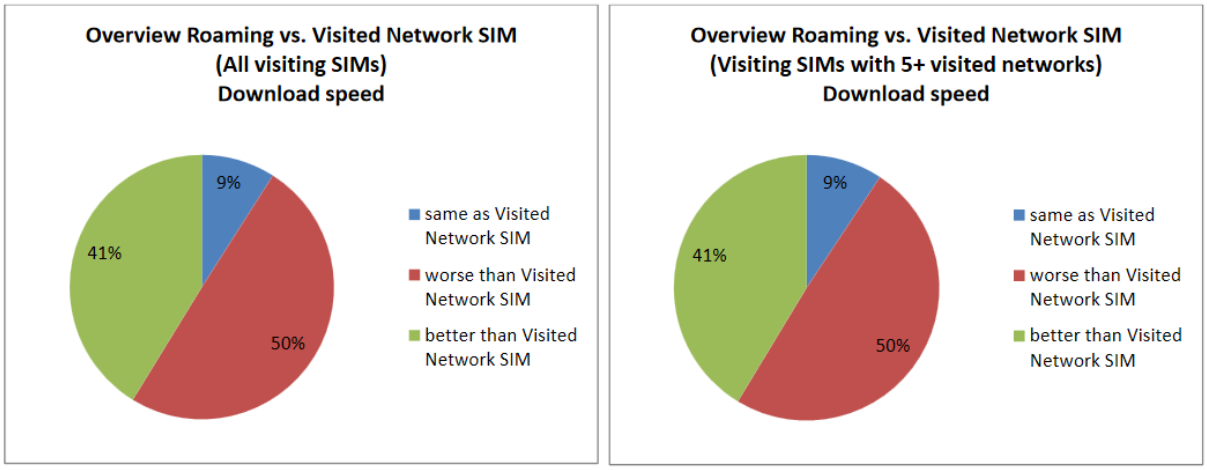


Figure 39. Overall distribution of download performance of visiting SIMs in relation to visited network's own SIM

It can be observed in Figure 38 that 27 Customer SIMs had, at least once, worse download performance than that of the visited network's own SIM.

Figure 39 presents an overview of all the instances in Figure 38, showing that in 50% cases (88 of the 177 instances) a visiting SIM had worse download performance in a visited network than that of the visited network's own SIM.

Doing intersection between the set of 88 'red' cases of Figures 38 & 39 and the set of 69 'red' cases of Figures 11 & 12, a common set of 44 cases was found which represented all those roaming instances where a visiting SIM had, at least once, worse download roaming performance than at home *and* at the same time it was worse than what was technically possible[18] in the visited network.

The above results are summarised below:

(a) Of the 29 visiting SIMs, 25 SIMs had, at least once, worse download performance in roaming than at home. It accounted for 69 of the 177 roaming instances.

(b) Of the 29 visiting SIMs, 27 SIMs had, at least once, worse download performance in roaming than what was technically possible in the visited network. It accounted for 88 of the 177 roaming instances.

(c) 44 of the 177 roaming instances were common to (a) and (b), when a visiting SIM had worse download performance in roaming than at home and at the same time worse than what was technically possible in the visited network.

(d) These 44 instances occurred for 21 SIMs from 11 countries.

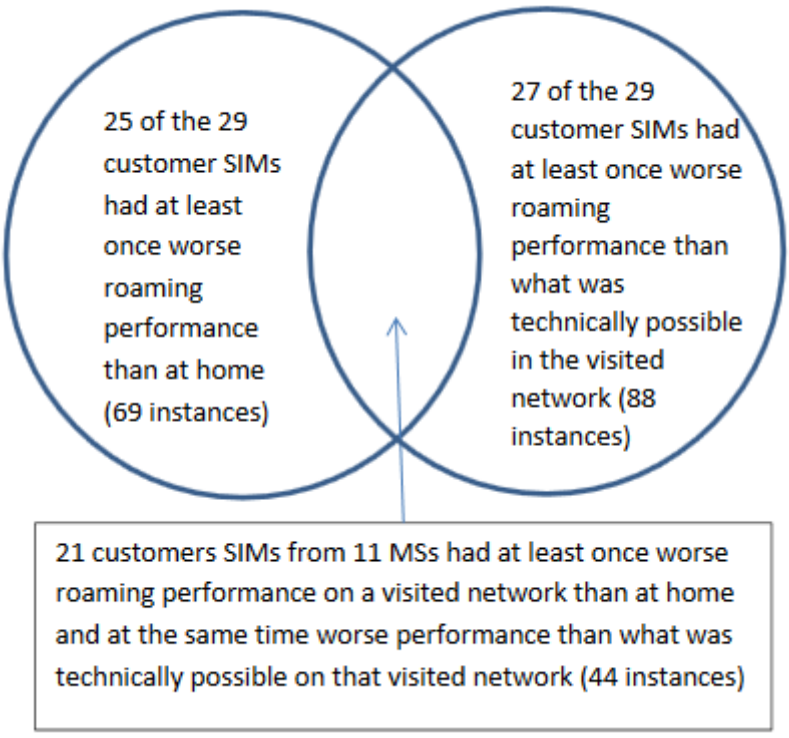


Figure 40. Problem cases identified in roaming tests

In summary on Q4: The analysis for download speeds showed that 21 customers from 11 countries had worse download speed performance in roaming than at home even when better quality was technically possible on the visited networks.

[18] By 'technically possible', it means that a higher speed on a visited network was achieved by the home customer of the visited network during the same test round.

6 Conclusions

This study concerns assessment of the quality of service in roaming in the context of the EU Roaming Regulation. The study addressed the following questions:

(1) Whether roaming customers had different quality of service when roaming compared to the performance on their own home network.
(2) Whether quality of service on visited networks differs between the customers of the visited network and the roaming users visiting the network.
(3) Whether roaming customers had different quality of service on a visited network compared to other visiting roaming customers.
(4) How often did customers have worse quality of service in roaming than at home, even when the visited network was technically and practically able to provide better quality?

The methodology of the study was based on field measurements by 29 SIMs from 12 countries, roaming in 13 countries, on 37 mobile networks. Altogether SIMs from 40 MNOs were involved. The tests produced 177 roaming instances of *(visiting SIM, visited network)* pairs. The field tests were carried out during October 2017 – October 2019. The JRC mobile app netBravo designed for the measurement of quality in mobile and broadband networks was used to measure and record the mobile network performance (download speed, upload speed and latency) by various SIMs both in their home network and in visited networks.

The following are the **main findings** of the study:

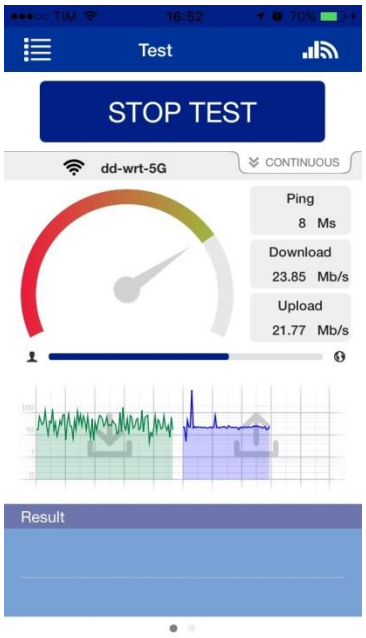
(1) Out of the 177 roaming instances, the download performance of customer SIMs was worse than in their respective home network on 39% occasions (69 instances) whereas the upload performance was worse in roaming than at home on 59% occasions. The latency was worse in roaming than at home on 62% occasions.
(2) The download performance of visiting SIMs (roaming customers) was worse than the home SIM (home customer) of the visited network in 50% cases (88 of the 177 roaming instances). The upload performance of the visiting SIMs was worse than the home SIM in 72% of the roaming instances. The latency of the visiting SIMs was worse than the home SIM in 73% of the roaming instances.
(3) In relation to the roaming peers (other roaming users in the same visited network, at the same location and at the same time), there was even distribution of instances of roaming with below average and above average download performance. The same was true for the distribution of upload performance and latency. It shows that the test results were overall statistically valid. However, it was found that some customer SIMs were generally more likely to have below average performance than others, pointing towards possibly QoS in roaming being offered to them at unfavourable level.
(4) Six Customer SIMs (20%) had generally worse speed in roaming than at home and also in relation to other roaming customers in the visited networks.
(5) In 25% cases (44 instances out of 177 roaming instances), a visiting SIM had, at least once, worse download performance in roaming than in its home network even when better quality was technically possible in the visited network. These cases occurred for 21 Customer SIMs from 11 countries.

The study shows that taking into account the number of analysed networks and MSs in this analysis, roaming customers (in 25% of all roaming instances) had worse download speed in roaming than at home even when technical conditions on the visited network existed for them to achieve better quality of service.

Annexes

Annex 1. netBravo

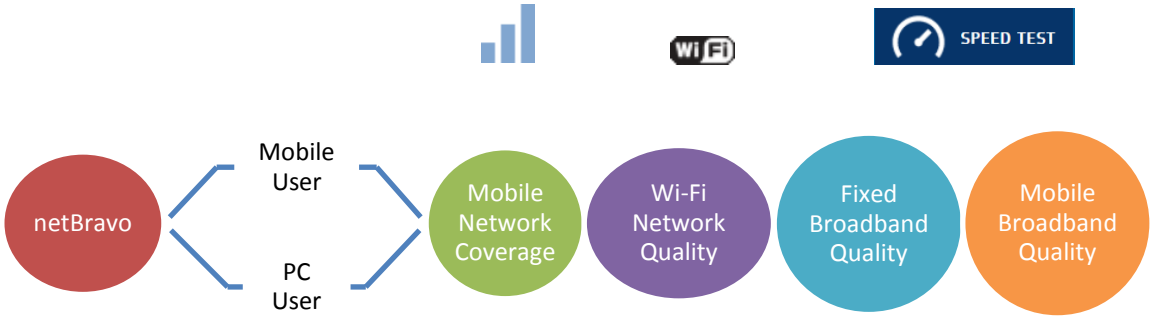
NETBRAVO - AN APP TO MAP MOBILE NETWORK COVERAGE AND MEASURE QUALITY OF SERVICE



http://netbravo.eu
http://netbravo.jrc.ec.europa.eu

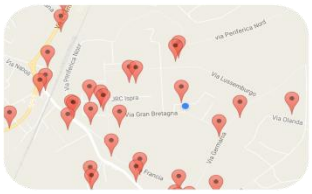
What is netBravo?

netBravo is a mobile app developed by the Joint Research Centre of the European Commission for smart phones and tablets to help measure the quality of mobile and broadband connections as experienced by users anywhere in the world.



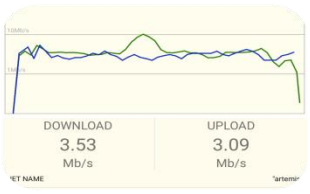
Why should I use netBravo?

By using netBravo, you get real evidence of the quality of your internet connection and the quality of signals of your mobile network in your area. By sharing your mobile network measurements with other users, in other areas and even other networks, together you all get a big picture to help you choose a network based on cost, quality and coverage.

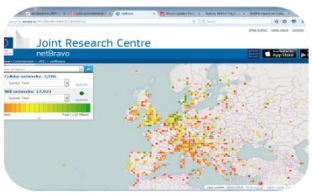


Local Wi-Fi map

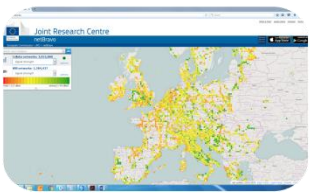
Nearest Wi-Fi stations



Speed test – mobile networks



Quality of broadband experience



Quality of mobile network coverage

Speed Test – fixed networks

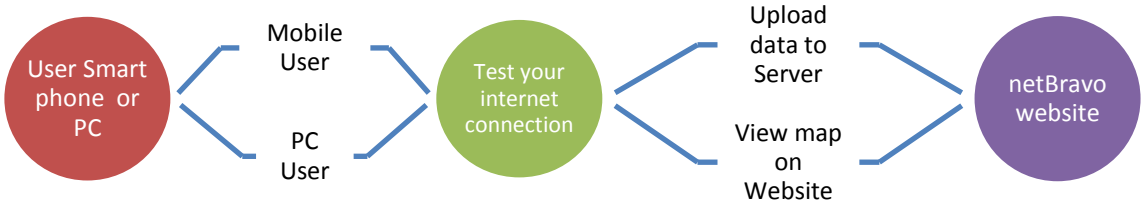
How do I use netBravo?

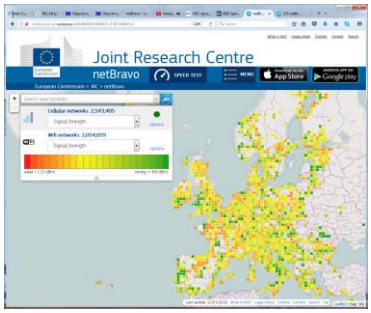
As a mobile user, you need a smartphone or tablet running Android® or iOS®. These cover a large majority of smartphone users worldwide. You will need to download the netBravo app from AppStore® or GooglePlay®. Once you have installed the app, you can start looking at the signal quality of your local Wi-Fi® Access Points and run speed test and quality of your internet connection whether connected through Wi-Fi® or a mobile data network (3G/4G).

As a PC user, you can access netBravo directly from your web browser by accessing http://netbravo.eu where you can browse the quality data on the map. You can also run a speed test on your internet connection.

How does it work?

netBravo works on the principle of crowd sourcing. It collects measurements made voluntarily by end users on their mobiles, providing aggregate data for locations covered by any network. Whereas netBravo continuously samples the signal strength of mobile signals and Wi-Fi® connections at its user's location, it also allows the user to run speed and quality tests on their internet connection. All data collected by netBravo is anonymous, respecting the principles of privacy. The measurements are uploaded to the netBravo server and aggregated with other measurements to become visible on the netBravo site on an interactive map.





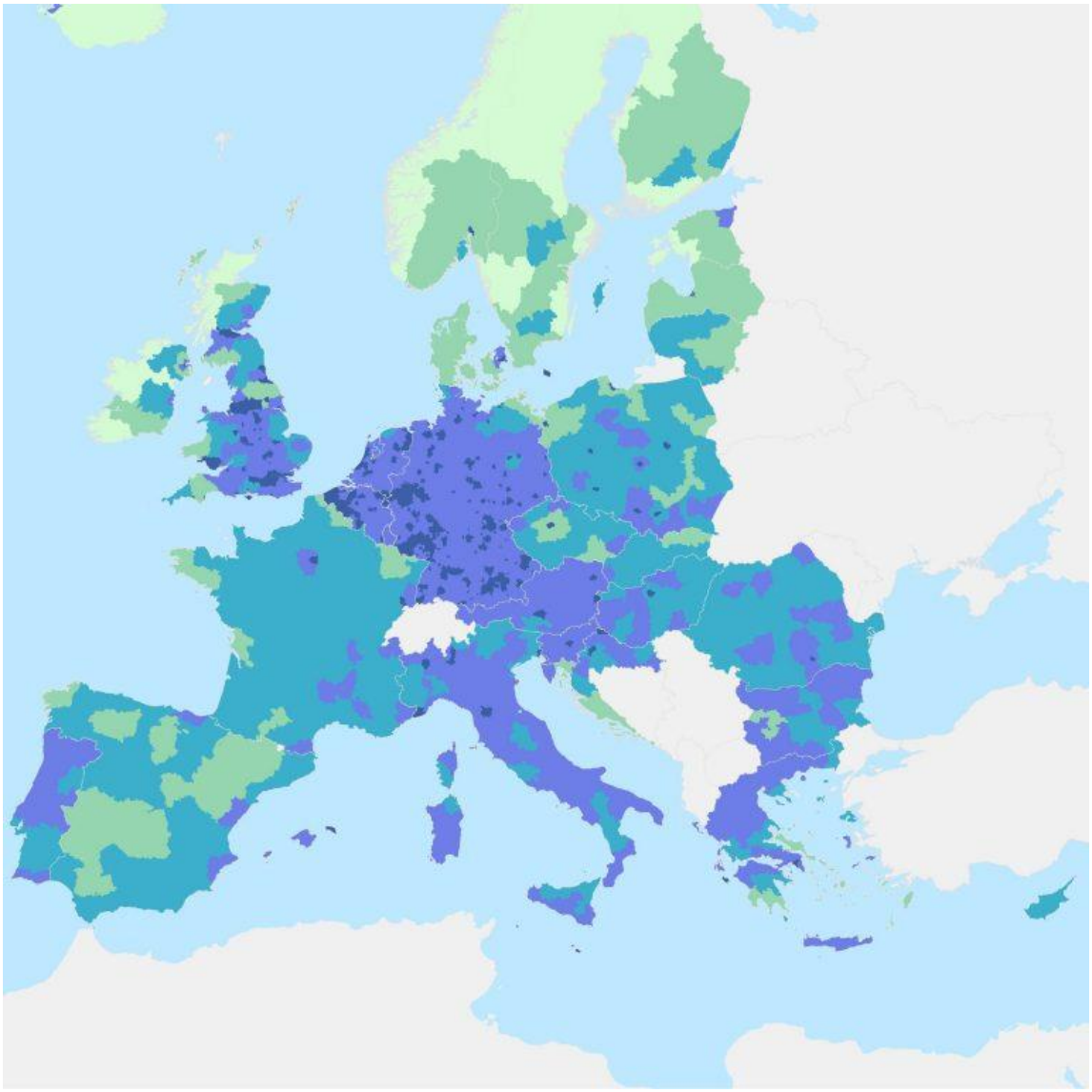
Current Status of use

netBravo is already being used widely in Europe, as evident from the map data. It has been downloaded by users worldwide in more than 70 countries. As on 1 January 2021, there were over 7 million measurements on the quality of cellular networks and over 19 million on Wi-Fi® networks.

How does netBravo help policy makers?

netBravo is one of the few independent apps that contribute data to the European Broadband Mapping Portal. The portal maps the progress in MSs on the broadband infrastructure and the quality of service of high-speed broadband in the context of Europe2020 goals. netBravo also tests and validates the emerging rules of Open Internet (net neutrality) and their technical implementation. This allows you to check if an internet service provider routinely blocks or slows down some internet applications (such as internet telephony or VOIP).

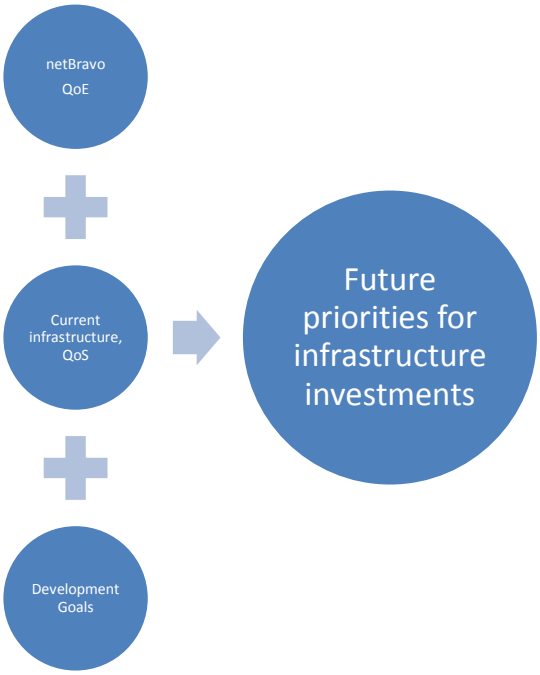
https://www.broadbandmapping.eu/



How can netBravo help non-EU countries?

Any country in the world can benefit from mapping the coverage and quality of ICT infrastructure in various regions – cities, rural areas, mountains, tourist spots etc.

The evidence from netBravo on the quality of service can help them in refining their policies for communications infrastructure, strategic investment and further development: education, tourism, businesses and e-Government services.



How can a country use netBravo to map its infrastructure?

Pilot phase – Getting Started

On the user side, the administration would need to promote the use of netBravo among the population.

Because netBravo is a crowd-source application, its impact depends on the depth and breadth of its use by the general public. The more people use it, the more shared information will become available about the coverage and quality of mobile and broadband networks in their community and country.

On the policy side, the administration will need access to the aggregated data collected by netBravo. This is already provided to Open Data Portal and on the netBravo website.

Adoption phase - Lots of users, lots of data

Once the policy makers have ascertained the value of QoS data to promote their development goals, they can move towards full adoption of netBravo as a system. This means owning or co-sharing the host infrastructure and service in their own environment. For this, one or more netBravo servers could be installed, nearer the users, in each country to allow acquisition of network quality data and its processing better tailored to their needs.

Such servers can be installed in one or more large cities. The options are:

- at a national university with good access to the internet backbone and back-up power;
- in a government ministry or agency with good access to the internet backbone and back-up power;
- at an internet service provider with web hosting service.

The economics and options for installing local servers would vary in each country. An economic analysis can be carried out on a case-by-case basis.

How much does netBravo cost the end user?

The netBravo app and website access are free of charge.

The automatic sampling of signal quality of mobile and Wi-Fi® networks by your smart phone does not cost you anything. It consumes a little amount of battery power when the app is running.

Whenever you decide to run a speed test on your internet connection, netBravo will do some data transfer (both upload and download) to test the quality of connection. In this case, your internet data plan will be used (i.e. your active Wi-Fi® or mobile connection at the time of running the test).

When you are on a Wi-Fi® connection, netBravo app automatically uploads sampled measurements to the netBravo server which will merge your samples with those from all the other netBravo users.

Can a user see the quality measurements on the map?

Users can see measurements only as part of all the other samples by all the other users. All the measurements are anonymous so it is not possible to tell who took which measurements. We are not interested to know your SIM number or your mobile phone number since these have no link to the quality of your internet connection. Instead, we collect the name of the network service provider and the type of mobile device you use because these affect your quality of service

In which languages is the netBravo app available?

To involve a maximum breadth of citizens, netBravo has been designed in a multi-lingual framework. Currently, it is available in English, French, Italian, Portuguese and Arabic. To add a new language to the user interface is a simple process.

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