BROADBAND ACCESS VIA INTEGRATED TERRESTRIAL & SATELLITE SYSTEMS

D7.1
Trial Evaluation

Instrument	Collaborative Project
Topic	ICT-2011.1.1
Project Title	Broadband Access via Integrated Terrestrial & Satellite Systems
Project Number	317533
Project Acronym	BATS
Contractual Delivery Date	M39
Actual Delivery Date	14/01/16
Contributing WP	Work Package 7
Project Start Date	01/10/2012
Project Duration	36 months
Dissemination Level	Public
Editor	R
Contributors	AVA, UoS, GRAD, Mulsys, FhG, MAV, DLR, OPT

Document History			
Version	Date	Modifications	Source
0.1		First version of document	R
QAT	06/01/16	Ready for QA	AVA
1.0	14/01/16	Document complete	QAT

Contributors		
Name	Company	Contribution
ALL		Section 1
Barry Evans, Paul Thompson and Erhan Ekmekcioglu .	UoS, MulSys	Section 2
Johannes Dommel	FhG-HHI	Section 3.3 Section 5.1.3
Antonio Rodríguez Del Corral	R	Section 3.3 Section 4
Luis Pérez Roca	GRAD	Section 3.3
Osianoh Glenn Aliu	FhG-FOKUS	Section 3.2
Stefan Erl	DLR	Section 5.1
Rosalba Suffritti, Irene Menicagli, Massimo Neri	MAV	Section 5.2
Xose Ramon	Optare	Section 5.4
Simon Watts, Mukul Kumar	AVA	All

Table of Contents

List of Figures

List of Tables

List of Acronyms

AGC	Automatic Gain Control
AWGN	Additive White Gaussian Noise
DVB-RCS2	Digital Video Broadcasting - Return Channel Satellite v2
GbE	Gigabit Ethernet
GUI	Graphical User Interface
MODCOD	Modulation and Coding
OFDM	Orthogonal Frequency Division Multiplexing
PER	Packet Error Rate
PSD	Power Spectral Density
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
SC-FDMA	Single Carrier – Frequency Division Multiple Access
SSPA	Solid State Power Amplifier
USRP	Universal Software Radio Peripheral

Executive Summary

This document is the primary output of the WP7 *"Show Cases & Validation*".

The purpose of this deliverable is to summarize the lab and field trial results and reach a conclusion on the feasibility and applicability of all investigated techniques during the BATS concept.

Therefore, the main objectives in this deliverable are as follows;

- Describe and summarize the results of the tests conducted in the lab located at UoS facilities in UK.
- Describe and summarize the results of the Field Trial Testbed with real users carried out in Spain and Germany.
- Analysis and validation of results.
- Provide conclusions and recommendations

In the WP7 the theoretical concept of combining the terrestrial, satellite and cellular links to provide the user with an enhanced quality of experience while using various types of applications that require different levels of throughput were put to test with actual real world users in a laboratory as well as field scenario. The field test scenario offers an added advantage where the link conditions are more dynamic and the users experienced a next generation prototype system. Although the system and service being a prototype, a full scale customer support and management infrastructure was setup as the users in the real world would except from their service providers.

The subjective and objective results from the Lab trials suggest that using BAT's enhances the QoE for most of the popular and increasing activities on the internet such as streaming, video chatting, VoIP as well as web browsing. In case of streaming application there is an initial buffering period which goes away as soon as the connection is shifted to satellite where the download through put is higher. In case feature rich browsing is done the users quality of experience is highest when a good DSL link is available but due to dynamic switching of the BAT's system, the bulk of the content of the web page can be downloaded using the satellite interface and further updates to the web page are done using the lower through put links such as DSL / Cellular, thus increasing the users QoE. In case of delay sensitive applications such as Video conferencing and Online gaming, the system was able to identify the application and use the link with the least delay. Overall BAT's provided the users a higher level of satisfaction as compared to using a single link.

The field trials that were run in Germany and Spain ran in two phases where the users were requested to provide their feedback after every phase. The users experience with the system increased after the perceived issues were fixed after the first phase and the expectations were reset. In Germany 75% of the users considered BAT's quality to be superior to normal DSL connection and also 50% of the users indicated higher QoE with streaming, content rich application and normal web browsing. While in Spain 80 - 90% of the users considered BAT's system to have a higher quality as compared to previous DSL connection. Over all in both the field trials users were more satisfied with the quality provided by BAT's as compared to previous DSL only services.

Another very important aspect that should be highlighted is that users in rural areas had a positive attitude towards a system like BAT's if issues such as form factor, stability, configurability for SoHo users of the CPE were enhanced. Further it was identified that a service such as BAT's if bundled with other services like IPTV, on demand video etc. then it would provide a much enhanced commercial viability.

1. Introduction

1.1 Purpose of the Document

This document D7.1 is the only deliverable included in the WP7.

Its purpose is to collect the lab and field trial results and reach a conclusion on the feasibility and applicability of all investigated techniques during the BATS concept.

1.2 Scope of the Work

In this document, the result of both lab and field test are summarized. During the trial, the following KPIs were measured:

- Lab Trials:
  - Logs from Lab Environment
  - End-user feedback from subjective tests
- Field Trials:
  - SNMP monitoring of IUGs – 24x7
  - ING syslogs
  - End-user questionnaires (Pre-Trail + 2 x In-Trial)
  - DSL Traffic Analysis prior to IUG (Spain)
  - SAT Traffic Analysis prior to IUG (Spain and Germany)

1.3 Objectives

The following objectives were identified:

- Reproduction of show cases in the lab to validate the concept with a variety of applications, collection of statistically meaningful data on user experience, and act as a show case for key stakeholders in government and industry. The laboratory test site is planned to be located at UoS facilities in UK.
- Reproduction of show cases in the field with the Field Trial Testbed and with real users and current technology / applications involving a relevant government municipality. Two test sites are planned. One in Spain and Germany.
- Collection, analysis and validation of results and impressions from final users during the performance of the show cases
- Collection of technical performance logs for further analysis and evaluation
- Recommendation derivation on the suitability of the system following the results analysis

1.4 Structure of the Document

This document contains three Chapters:

Chapter 2 describes the lab tests;

Chapter 3 describes the field tests;

Chapter 4 presents analyses, results, conclusions and recommendations;

Chapter 5 describes the proofs of concept demonstrations.

2 Lab Trials

2.1 Scope of lab trials

Lab trials were conducted to provide a high degree of confidence that the BATS concept using an IUG/ING combination is valid. The trials comprised two parts. The first was to ensure that the IUG and ING were functioning as expected according to the design parameters developed in the project. This was done by a set of tests using pre-determined objective measurements. These were conducted to provide a statistically sound technical set of results that will verify the accuracy of the IUG/ING performance under agreed conditions. For such tests a range of transmission path parameters were used to provide realistic emulation of the individual paths.

Subjective tests were then conducted in the lab test campaign in order to assess the perceived impact of using such devices in a user environment via real users. These tests were designed to provide confidence in the results which employ the well-known 'Mean Opinion Score' methodology. The subjective test campaigns were designed to avoid bias and to be statistically meaningful. The campaign was carefully planned to accomplish its goals without undue repetitions as such tests are complex to run and assess as well as time consuming. For details of the planning approach see D6.1.1.

Design and validation of the Lab Trial emulation facility was addressed in D6.3 and the results presented therein covered the end to end emulation with the IuG/InG bypassed as the prototype units were not available at that time. A number of challenges and outstanding issues were identified in D6.3 section 6 and these have been addressed as indicated in following material.

Subsequent to the provision of the appropriate IUG/ING units the tests were repeated. During this time the lab trial objective tests proved to be an invaluable asset in validating the performance of the IUG and ING and to provide early feedback to the designers to permit early resolution of problems so that the devices used in both the lab and field trials were performing as expected.

The test bed was Show Cased at a BATS 'Open Day' on 10th June 2015 (attended by 40 people representing stakeholders in the BB industry) and also demonstrated to the BATS General Assembly on 8th and 9th June 2015 at the University of Surrey with a reduced range of features prior to the delivery in July of a new revision of the IUG/ING software.

By early July 2015 the test bed (including IUG/ING) had been sufficiently refined to enable formal objective and subjective tests to be performed. These were completed in September 2015 and reported in this deliverable.

2.2 Lab Trial Description

The Integrated Test Bed outlined in D6.1.1 and more definitively described in D6.3 is depicted in Figure 2-1. The figure shows the various servers and switches that together make up the Test Bed. Several LANS were employed which enabled suitable interfacing of the units as well as providing monitoring points created by appropriate port mirroring in the switches.

The letters in red circles indicate key interface points used during the testing.

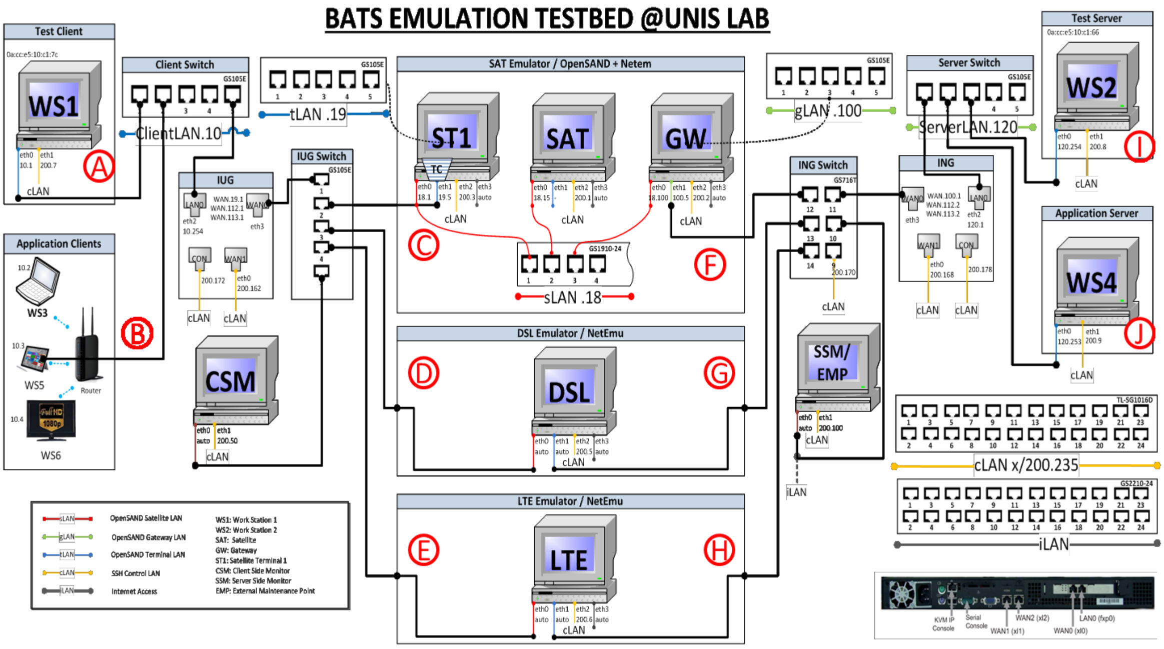


Figure 2-1 Schematic of UoS BATS Emulation Test bed

Various aspects of the lab trials were detailed in earlier deliverables. In particular see Table 2-1

Table 2-1 Aspects of the Lab Trial

ASPECT	DELIVERABLE	SECTION No.
Lab Trials setup and prior expectations	D6.1.1, {D6.3}	4.1, 4.6 {3, 4}
Traditional terrestrial network comparison	D6.3	4.3
Scenarios and technologies combination	D6.3	3.2
Transmission Path Emulation Parameters (see Note below from D6.3)	D6.3	4.1 Repeated in Table 2-2 Agreed Emulator Parameter Settings below

NOTE FROM D6.3

During the discussions of appropriate parameters to be used in describing the transmission path emulator characteristics it became evident that there were two different philosophies for setting the parameters and characteristics. The first one was to set baseline parameters and then to allow them to degrade by operating with differing contention ratios through the incorporation of additional artificial traffic. The second one was to incorporate the contention ratio effects within the table of parameters. If this philosophy is adopted then additional artificial traffic would not be required and the lab trial system would be simplified.

Eventually, the second alternative was chosen due to its lower physical complexity.

Table 2-2 Agreed Emulator Parameter Settings

Parameter Settings					
	DL Bandwidth	UL Bandwidth	Latency (one way)	Jitter	PLR
SAT-G	15 Mbps	2 Mbps	260 ms	50 ms	1.2×10^{-6}
SAT-M	12 Mbps	1 Mbps	300 ms	80 ms	1.2×10^{-5}
SAT-P	6 Mbps	0.5 Mbps	300 ms	100 ms	1.2×10^{-3}
DSL-G	8 Mbps	1 Mbps	20 ms	2 ms	1.2×10^{-6}
DSL-M	2 Mbps	0.5 Mbps	40 ms	30 ms	1.2×10^{-5}
DSL-P	0.5 Mbps	0.25 Mbps	100 ms	50 ms	1.2×10^{-3}
LTE-G	6 Mbps	2 Mbps	100 ms	20 ms	1.2×10^{-5}
LTE-M	2 Mbps	1 Mbps	100 ms	50 ms	1.2×10^{-5}
LTE-P	0.3 Mbps	0.1 Mbps	100 ms	50 ms	1.2×10^{-3}

2.2.1 Test Bed Development Timelines

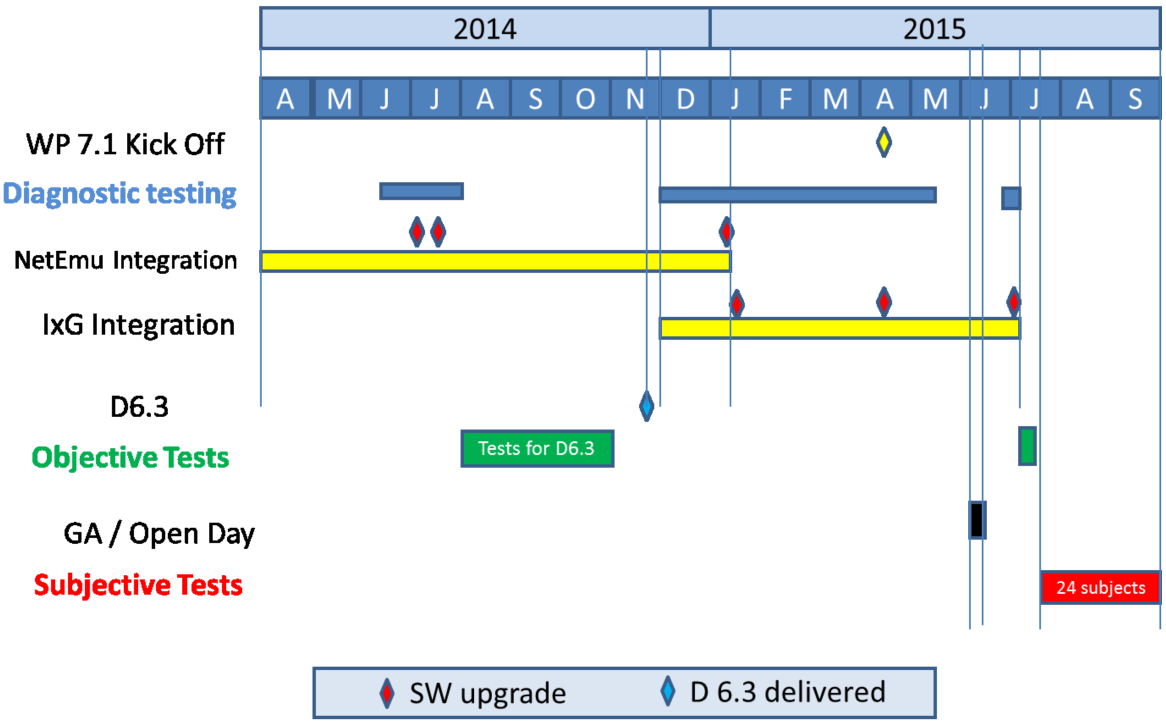


Figure 2-2 Integrated Test Bed Development TimeLine

Work was reported in D6.3 regarding the development of the Lab Trial Test Bed prior to the integration of the IUG and ING. The first element of this work was the establishment of the satellite path emulator using OpenSAND Version 2. This was followed by integration of the

DSL path emulator and LTE path emulator. Table 2-2 presents the timeline from the point at which the two latter path emulators were integrated.

As with most test beds such as this a number if integration anomalies occurred that required diagnosis and rectification. Hence, figure 2-2 includes elements for diagnosis and software upgrades. The figure also depicts the periods when more formal objective and subjective campaigns were conducted.

NetEmu Integration: The integration of NetEmu went quite well on 1 April 2014 with interactive sessions between the developer and the test bed integration team. Two software updates related to changing configuration files and were readily handled. A third software update was more extensive as the underlying Linux platform was changed from Debian to Ubuntu in order to exploit the enhanced control plane features such that fast re-configuration could take place. This was completed on 14th January 2015.

OpenSAND Integration: OpenSAND version 2 was integrated very early in the programme by the integration team. This was upgraded to Version 3 when that version became available in April 2014. This became the key satellite emulator in the test bed. When the version 3.1 release of OpenSAND became available in late December 2014 an implementation of it was undertaken on 'mock' servers in order to assess its potential prior to full integration. It was found that the key SSH features that were being exploited in the test bed control plane were not compatible with the new version. It was agreed that for this project the version 3 software would be retained as all other key characteristics were the same as far as the test bed is concerned.

For some time the OpenSAND system had been anonymously shutting down. A special interactive diagnostic session was conducted in order to try and understand this. Examination of Wireshark files taken for diagnostic purposes on the control plane showed very occasional SSH activity from the OpenSAND sub network. This was unexpected and was traced to a misunderstanding by the platform integrator regarding the Ethernet port configuration of the OpenSAND servers. This was rectified on 27th May 2015 and from there on the platform was very much more stable.

IUG/ING Integration: A basic 'dumb' IUG/ING configuration was added to the test bed on 28th November 2014. Some problems were experienced with configuring this to the appropriate level 2 and level 3 interfaces to the path emulators. Various VLAN switch configurations had to be tried before a suitable arrangement was found.

Various diagnostic exercises were then conducted to evaluate the influence the IxGs were having on the test bed. These ranged from repeat objective tests as conducted in tests without the IxGs to new bespoke tests to diagnose unexpected performance.

During the period when diagnostic tests were being conducted some fine tuning of the individual transmission paths was undertaken to enable them to better match the required performance characteristics (Table 2-2) to within a few percent. This was undertaken by changing the individual path emulator configuration files or by changing parameters in the host Linux kernel. The areas addressed in this activity were detailed in section 6 of deliverable D6.3 where a number of challenges and items for further consideration were detailed.

As software upgrades took place key sets of tests (using Iperf and ICMP) related to the objective performance of the total integrated test bed (with the IxGs installed and a single transmission path emulator active) were performed. The results were compared to the results presented in D6.3 without the IxGs. Such tests indicate the ability of the IxGs to handle that specific transmission modes as well as any impact from them on the overall test bed performance. The comparison was favourable and an example set of results is presented in Table 2-3. The values in square brackets are those measured with the IxGs in place.

Table 2-3 Example comparison of single path operation with and without the IxGs

	DL Bandwidth		UL Bandwidth		Latency		PLR	
	UDP	TCP	UDP	TCP	DL	UL	DL	UL
CORE-SAT G Settings	15Mbps		2Mbps		250ms		1.2x10-6	
CORE-SAT G Measured, [with IxG]	15.0Mbps [14.7]	13.2Mbps [8.4]	1.8Mbps [1.55]	1.7Mbps [1.63]	273.65ms [277]	274.45ms [278]	0% [0 to 2.0]	9.5% 0 to [9.6]
CORE-LTE G Settings	6Mbps		2Mbps		100ms		1.2x10-6	
CORE-LTE G Measured [with IxG]	6.0Mbps [5.8]	5.1Mbps [4.7]	2.0Mbps [1.9]	1.8Mbps [1.45]	100.75ms [102]	97.85ms [104]	0.6% [0 to 4.5]	0.5% [0 to 5.5]
CORE-DSL G Settings	8Mbps		1Mbps		20ms		1.2x10-6	
CORE-DSL G Measured [with IxG]	7.9Mbps [7.8]	7.3Mbps [7.4]	1.0Mbps [0.94]	1.0Mbps [0.92]	20.25ms [22.5]	20.25ms [23]	1.8% [0 to 5.2]	1.9% [0 to 5.6]

Following such tests and resolution of any issues, a further set of tests were conducted to identify how the IxGs handled different types of traffic. Some of these were objective whilst others may be considered as 'Observational Tests' where an application would be run and the actions of the IxGs observed. Thus, these are not strictly objective or subjective in nature but could best be classified as observations.

Observational Tests were conducted with a range of applications. These led to a number of unexpected results that required resolution. Such resolutions were either to control applications so as to avoid such problems or to upgrade the software in the IxGs to eradicate the problems.

Software upgrades were undertaken by the IxG supplier on 16th January, 16th April and 10th July 2015.

The interaction that took place and the power of being able to precisely configure the test bed as required led to a very significant level of improvement in the functioning of the IxGs with known applications and transmission paths.

Photographs of the developed physical test bed are shown in Figure 2-3 to Figure 2-8 Demonstration of the lab trials to the BATS General Assembly Figure 2-8. Please note that the subjective testing suite is situated in the adjacent room, visible through the glass separating window.

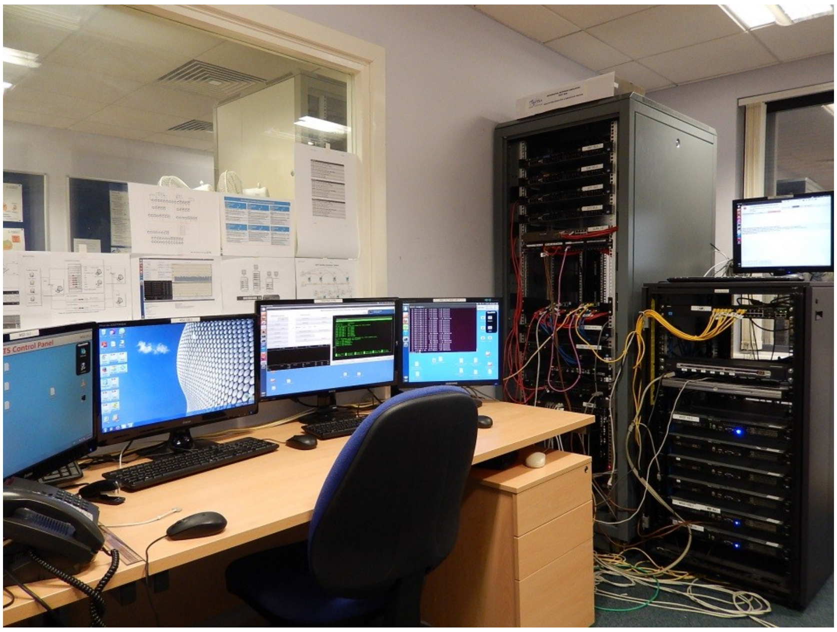


Figure 2-3 An overview of the Integrated Test Bed

Figure 2-4 The Left hand section of the Test Bed is the subjective test control station

Figure 2-5 The OpenSAND and DSL transmission path emulators

Figure 2-6 The IUG, ING and associated VLAN switch

Figure 2-7 The Objective testing and overall test bed control station

Figure 2-8 Demonstration of the lab trials to the BATS General Assembly

2.3 BATS IxG objective tests

2.3.1 Description

As indicated earlier with regard to the objective testing, the key goal was to validate that the IUG and ING perform as expected in a lab environment with the three emulated transmission paths. These paths were operated under a range of conditions. The first set was to validate that the IUG/ING performed as expected under good operating conditions on the transmission paths. Such tests should result in a performance that reflects what is expected of the IUG/ING and what was achieved during in-plant testing of the units prior to them being shipped to the University of Surrey.

The units were then tested to validate their performance under marginal transmission path parameters which are set to be at the limit of acceptable performance.

A third set of tests validated the performance of the IUG/ING when one or more of the paths degrade beyond an acceptable quality.

This was done by a set of pre-determined objective tests. These were conducted to provide a statistically sound technical set of results that verified the accuracy of the IUG/ING performance under agreed conditions. For such tests a range of transmission path parameters were used to provide realistic emulation of the individual paths.

TCP and UDP tests were conducted based on the predefined transmission path parameter settings using Iperf, ICMP and other test facilities. The measured UDP values represent performance relating to delay variance and packet loss, using synthetic UDP traffic generated by Iperf. The measured ICMP values represent features such as latency, jitter and packet loss by sending ICMP Timestamp streams to the destination. Various scenarios were tested separately in satellite, LTE as well as DSL transmission paths, and then in the integrated core network environment where the switching elements in the test bed transmission chain are included.

It is important to note that for the IxG configuration tested only applications/traffic with a session originated at the user (client) having an IuG will be processed by the IuG/InG system for access to the Internet (in our case servers).

2.3.2 Technical performance Results

Iperf and ICMP tests related to the objective performance of the total integrated test bed (with the IxGs installed and a single transmission path emulator active) were performed. The results were compared to the results presented in D6.3 without the IxGs. Such tests indicate the ability of the IxGs to handle that specific transmission modes as well as any impact from them on the overall test bed performance. The comparison was very favourable and within the bounds of expected performance. See Table 2-4 for the required and measured G and M values.

Following these tests a further set of tests were conducted to identify how the IxGs handled different types of traffic. A few issues were experienced as discussed below.

UDP traffic suffered higher than expect PLR values. This could be rectified by limiting the MTU size to 1400 which matches the configuration of the IxGs. In addition, UDP, was run at 10% lower speed than the bandwidth to avoid excessive packet loss ratio.

Use of VLC as a video streaming server resulted in incorrect operation of the IxG routing algorithm (see Figure 2-9 IxG routing Algorithm), this was resolved in a new issue of the IxG software.

Certain applications had longer than expected inter-packet periods that fell outside of the algorithm range; this was resolved in a new issue of the IxG software.

Some restriction of average TCP ftp rate to 8.4 Mbps over satellite path by using WGET or other FTP server whilst http goes to 14.6 Mbps. This was believed to be a problem in interaction between OpenSAND and the IxGs. This is not an impairment that will affect the subjective testing.

Handover between paths were found to be seamless due to the use of appropriate buffers and logic in the IxG implementation and no lost packets due to this were identified.

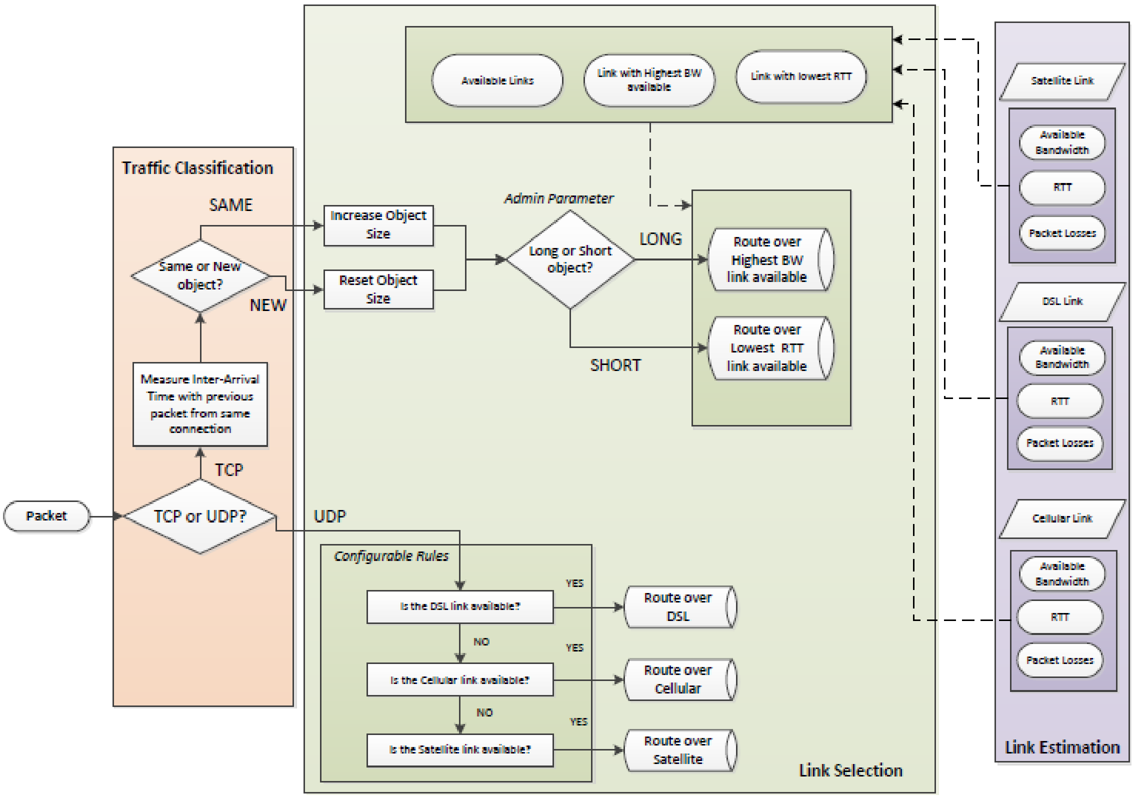


Figure 2-9 IxG routing Algorithm

Table 2-4 Measured Values of single path DL Bandwidth, UL Bandwidth and Latency

	DL Bandwidth		UL Bandwidth		Latency	
	UDP	TCP	UDP	TCP	DL	UL
SAT-G Settings	15Mbps		2Mbps		250ms	
SAT-G Measured	14.7Mbps	13.2Mbps[8.4]	1.55Mbps	1.63Mbps	277ms	278ms
SAT-M Settings	12Mbps		1Mbps		300ms	
SAT-M Measured	11.8Mbps	9.5Mbps[8.4]	0.98Mbps	0.9Mbps	328ms	325ms
LTE-G Settings	6Mbps		2Mbps		100ms	
LTE-G Measured	5.8Mbps	5.1Mbps	1.9Mbps	1.45Mbps	102ms	104ms
LTE-M Settings	2Mbps		2Mbps		100ms	
LTE-M Measured	1.96Mbps	1.68Mbps	1.9Mbps	1.52Mbps	104ms	108ms
DSL-G Settings	8Mbps		1Mbps		20ms	
DSL-G Measured	7.8Mbps	7.4Mbps	0.94Mbps	0.92Mbps	22.5ms	235ms
DSL-M Settings	2Mbps		0.5Mbps		40ms	
DSL-M Measured	1.96Mbps	1.8Mbps	0.49Mbps	0.48Mbps	43ms	44ms

2.3.3 Objective tests key findings

During the diagnostic test periods and the more formal objective tests a number of issues were identified and the partners cooperated to resolve these such that the test bed could be declare fit for purpose with the IxG units performing as expected with a few minor constraints on the tests being conducted.

The integrated test bed was then found to comply with the requirements stated in section 2 of D6.3.

The transmission paths replicated quite accurately the required performance characteristics adopted for the trials.

A number of adaptations were made based upon the objective and observational tests in order to ensure that the test bed was suitable for the planned subjective test trials.

Observational, and to a lesser extent objective, tests indicate that the IxGs performed as expected with regard to multipath operation and its in-built algorithms following the previously mentioned software updates.

In Mid July 2015 the completed test bed with integrated IxGs was declared to be in a suitable state to perform the formal subjective test campaign. The status is summarised below in Table 2-5

Table 2-5: Test Bed Status

Item	Status	Comments
Individual transmission Emulators	Meets required performance characteristics	Fine tuning conducted since D6.3
Single path characteristics with IxG integrated	Acceptable in all three states	Objective test based
Multipath characteristics with IxG integrated	Several issues were found and addressed with suitable resolutions to permit subjective tests to progress. Issues were:	Objective and Observational tests
	1) UDP, run at 10% lower speed than bandwidth to avoid excessive packet loss ratio	Adhered to during subjective testing
	2) Certain applications had longer than expected inter packet periods that fell outside of the algorithm range	Algorithm adjusted on software upgrade
	3) Problems with specific server – application compatibilities	Sever package changed
	4) MTU issues with a maximum of 1400 affecting UDP	MTU in the subjective tests were restricted
	5) Some restriction of average TCP rate to 8.5 mbps over satellite path	Data rate in the subjective tests were restricted
Overall Test bed	Meets requirements stated in D6.3 section 2.	

2.4 BATS IxG subjective tests

2.4.1 Description

The description of the subjective tests had previously been outlined in detail in Deliverable 6.1.1[1]. This subsection summarises the key points in the design of the subjective tests in the lab environment.

Four different applications have been deployed to measure the Quality of Experience (QoE) of subjects in the presence of IxG. These applications are: HD multimedia streaming, web browsing, video conferencing, and online gaming. The former two applications consist of TCP data traffic; whereas the latter two involve UDP data traffic, since they are relatively more delay-sensitive. The tests have been completely isolated from the Internet, in order to prevent any random impact of the Internet-associated issues. Therefore, all applications are hosted by the test application server, as shown in Figure 2-10. For the HD multimedia streaming scenario, several test videos are prepared at an average bit-rate of 8 Mbps (using H.264/AVC) accompanied by 5.1 audio encoded at 0.5 Mbps (using AAC) and stored in an Apache web server. The subject is situated in front of a For web browsing, the contents of ten different web sites have been copied into the same web server using the website copier tool called HTTrack [3]. The web server is accessible by the test clients through the network emulators. The Mozilla Firefox browser set up in the test clients have been pre-configured to bookmark these web pages and to delete all cookies and cache after each test. Cookies and cache are cleared deliberately after each test to prevent the browser to use them next time, which will otherwise impact the web browsing experience despite the changes in the network condition. For the video conferencing scenario, an application called Ekiga [4] is installed on both the test client and the test application server. During the tests, subjects talk to the test coordinator who sits in front of the test application server that is also equipped with a web-cam and microphone. In order to facilitate the talks, several short conversational scenarios have been created in line with the ITU-T recommendation P.920 [5]. For the online gaming scenario, the server for the game called Counter Strike, which is a First-Person-Shooter type game, has been pre-installed into the test application server. The game server is accessed through the dedicated application installed on the test client. The game involves directing the game character through an artificial battle platform and target and shoot any enemies seen using the mouse and the key board buttons, which is shown in Figure 2-11 Online gaming scenario screen-shot and controls

.

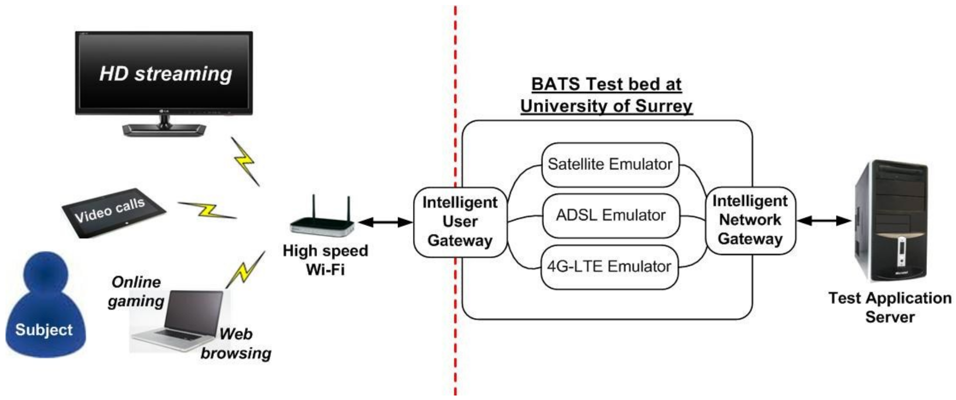


Figure 2-10 Overview of the lab trials test bed used for the subjective experiments

Figure 2-11 Online gaming scenario screen-shot and controls

As previously outlined in Deliverable 6.1.1 [1], the subjective tests consisted in two groups. The first group involves a single application accessed at a time by a subject through the emulated networks, whereas the second group involves two applications accessed at the same time by different subjects.

The Intelligent User and Network Gateways are expected to analyse the application traffic, measure the link conditions, and optimally route through the most suitable link based on the application requirements. In order to measure the QoE gain obtained by the IxG devices, each test application has also been accessed through individual network emulators with their specific settings (i.e., without the IxG in Figure 2-10). The purpose in doing so is to measure the maximum and minimum levels of achievable QoE associated with each test application. Hence, it is possible to judge whether integrating the IxG leads to an improvement in the quality or not. To be more specific, Table 2-6, depicts these test categories and the associated attributes.

The subjective test room is adjacent to the room where the network emulators and the test application server reside. The test operator is located in the server room, changing the network emulator settings in between each test, where each test is an instance of an application use. Besides, the test operator also helps in person during the video conferencing application by talking to the test subject who sits in the subjective test room and uses the test client. The test subject is accompanied by another person in the same room, who introduces the subject to the test, instructs how to use the score sheet and tells when he/she should start with the next test. A couple of pictures from the subjective tests are shown in Figure 2-11. These pictures are taken during the second part of the tests, where a couple of subjects attend and use different applications simultaneously.

Table 2-6 Subjective test categories and the associated attributes.

Test category	Attributes
Experiment I, Part 1	Single subject, single application over a single network (IxG inactive)
Experiment I, Part 2	Single subject, single application over a combination of three networks (IxG active)
Experiment II, Part 1	Two subjects, two applications over a single network (IxG inactive)
Experiment II, Part 2	Two subjects, two applications over a combination of three networks (IxG active)

Figure 2-12 Sample pictures taken during the subjective tests (top figure: one subject uses web browsing and the other subject uses online gaming, bottom figure: one subject watches an HD stream and the other subject makes a video chat with the test operator)

2.4.2 User statistics

Twenty four users have participated in the subjective tests during July-September 2015. Attention has been paid to invite subjects from a diverse age range and Internet usage background. The statistics that are outlined in Figure 2-13 to Figure 2-20 indicate that the vast majority of the users have an ADSL connection at home and about 45% of all users have an average download speed of 10 – 25 Mbps. The reported average download speeds are generally high and it may be expected that participating users have initially high expectations in terms of the bandwidth offered and it might be difficult to highlight potential gains in terms of QoE by the deployment of IxG. However, the QoE comparisons are done against the benchmark results obtained in *Part 1* of the first experiment (please see Table 2-6). Therefore the perceived quality improvements are judged by the users against the experience during the first part, where the IxG is inactive and a variety of network conditions (for Satellite, DSL and LTE) are used. Besides, the application usage statistics also reveal that web browsing is the most widely used application by all users, followed by video streaming, video calls and finally online gaming. It should be noted that half of the users have reported that they never play online games and have almost no acquaintance with online games. Therefore, in order to make the QoE results associated with the online gaming scenario more reliable, only the opinion scores of those who play online games very often, often or sometimes are taken into account.

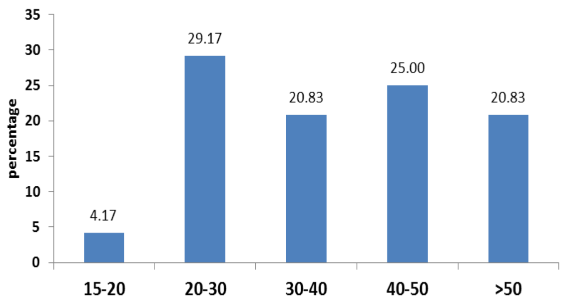


Figure 2-13 Age group distribution

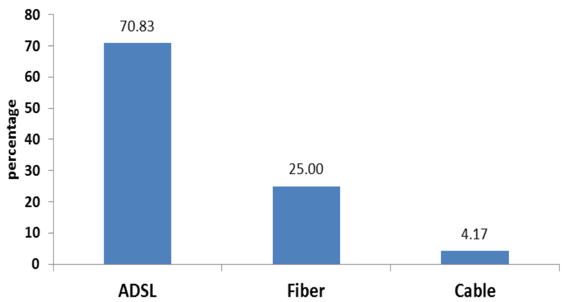


Figure 2-14 Broadband connection type

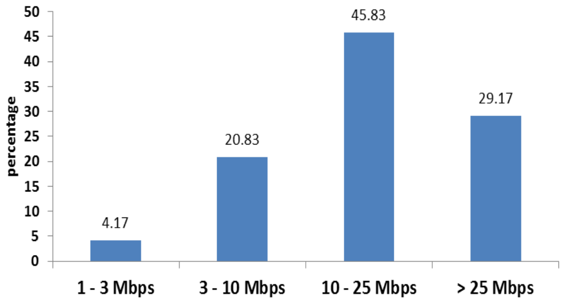


Figure 2-15 Average download speed

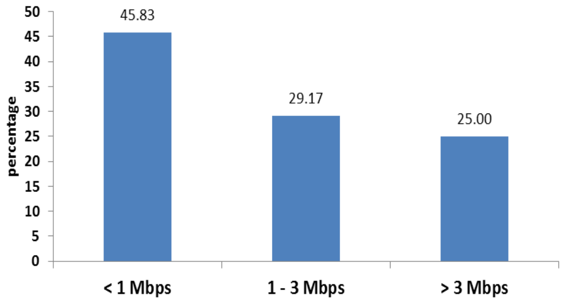


Figure 2-16 : Average upload speed

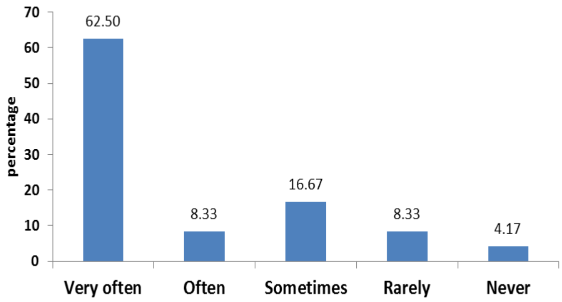


Figure 2-17 Video streaming experience

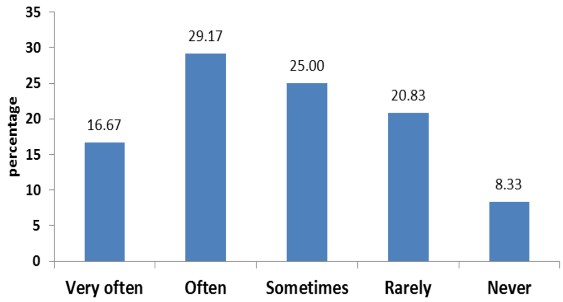


Figure 2-18 Video calling experience

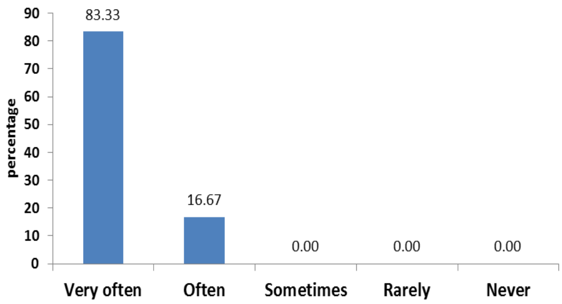


Figure 2-19 Web browsing experience

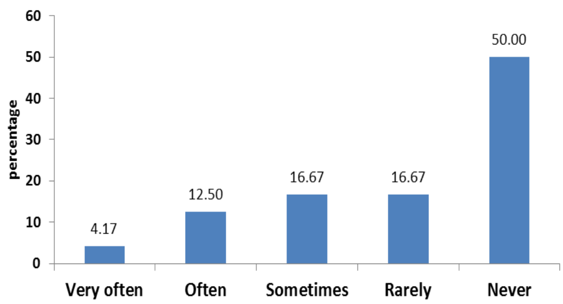


Figure 2-20 Online gaming experience

Besides writing down their opinion score on a scale of 0 to 100 for each test they have taken (please refer to [1] for more details), the users have also been asked to answer several question associated with each type of application. The possible answers to these questions are "*never*" (i.e., 0), "*rarely*" (i.e., 1), and "*frequently*" (i.e., 2), for each application. Answering these questions also facilitates the judgement of the perceived quality of the used application. Table 2-7 summarises these questions. The statistics associated with these questions are outlined along with the Mean Opinion Score (MOS) results in Section 4.

Table 2-7 Questions asked to the users during the tests

HD multimedia streaming	
Question 1	How often did the video freeze during the test?
Question 2	How often was the video distorted during the test?
Question 3	How often was the synchronisation between the video and the audio lost?
Video call	
Question 1	How often were there noticeable delays affecting communication?
Question 2	Was the audio/video quality poor?
Question 3	How often was the lip synchronisation lost during the conversation?
Online gaming	
Question 1	Was the animation choppy/jittery?
Question 2	Was the targeting rate low?
Question 3	How often was the character not responsive to your commands?
Web browsing	
Question 1	How often was the page response time excessively longer than usual?
Question 2	How often did the pages load very slowly?

2.4.3 Subjective tests key findings

- The detailed bar charts outlining the MOS results for each application under different network conditions or combinations are provided in Section 4. Taking those into account, the key findings of the lab trials – subjective tests can be summarised as below:
  - In the absence of the IxG, where the applications were routed individually on different network emulators with different conditions, it was seen that the average user experiences changes on a sufficiently large scale. Therefore, the positive gain of inserting the IxG in to the system was noticeable.
  - Except for the HD media streaming, where the Satellite network was the best choice due to the large bandwidth requirement, the high speed DSL link with sufficiently large bandwidth was the best choice for the other applications.
- When the IxG was in place, in general, the variations in the calculated Mean Opinion Score (MOS) across different network combinations were limited. On average the MOS was close to the upper limit, where the upper limit denotes the maximum achieved MOS for that particular application when the best choice network was active.
  - This shows that the application traffic routing is done correctly by the installed IxG.
  - It is observed that for the video conferencing and online gaming applications, where the network latency has the utmost importance, the link with the lowest delay was chosen for routing the traffic.
  - For web browsing, unless pages with large size were loaded, the link that provides the lowest delay was chosen for better page response. However, to improve the experience, as soon as the downloaded object size exceeded a certain limit, the traffic was routed to the satellite network that provides a larger bandwidth, hence, reduced download time.
  - The only poor results despite the presence of IxG are observed when the Satellite network doesn't have sufficient capacity to carry the HD stream.

- When more than one application was used simultaneously (i.e., Experiment II), the results have indicated that similar to Experiment I, the MOS of both applications were consistently close to their upper limits. The only exception to this was HD multimedia streaming, as in the case of Experiment I. When the satellite network is not in 'Good' state, even if the IxG chooses the best available network with the highest bandwidth, the perceived quality of the video is not good. However, this didn't affect the quality of the other application.
  - This shows that the IxG can also correctly classify different traffic sources and treat them differently.
  - For example, while the video streaming is loaded on the satellite network, the web http traffic is mostly routed through the DSL due to the low latency requirement. Nevertheless, when web pages with large pictorial content were loaded, the IxG adaptively reacted by routing the traffic to the satellite network.
  - It is seen that the average of the users' responses to the questions asked during the trials (please see Table 2-7) are in line with the calculated MOS. This is as expected. These responses, ranging between 0 (never observed) to 2 (frequently observed) refer to several application-specific quality degrading factors. The higher the observation frequency of such factors, the lower the MOS.

2.5 Lab trials results (subjective tests)

This section provides the statistical results obtained from the lab trials, namely Experiment I (single application) and Experiment II (two applications). The findings from the graphs outlined in this section were summarised in Section 2.4.3. The statistical results are presented in terms of the Mean Opinion Score (MOS), which is the average of all users' opinions on a particular test application and test condition. Parts 1 and 2 of both Experiment-I and Experiment-II are as previously explained in Table 2-6. The graphs also contain the standard deviation from the calculated MOS. The MOS graphs are accompanied by the graphs, which outline the average score given to the questions asked during the user trials. These questions are presented in Table 2-7. A different set of questions is applicable to each application that is tested. The vertical axis on these graphs represents the severity of various factors asked in the questions, such that 0: *never observed*, 1: *rarely observed*, and 2: *frequently observed*.

Experiment I – Part 1

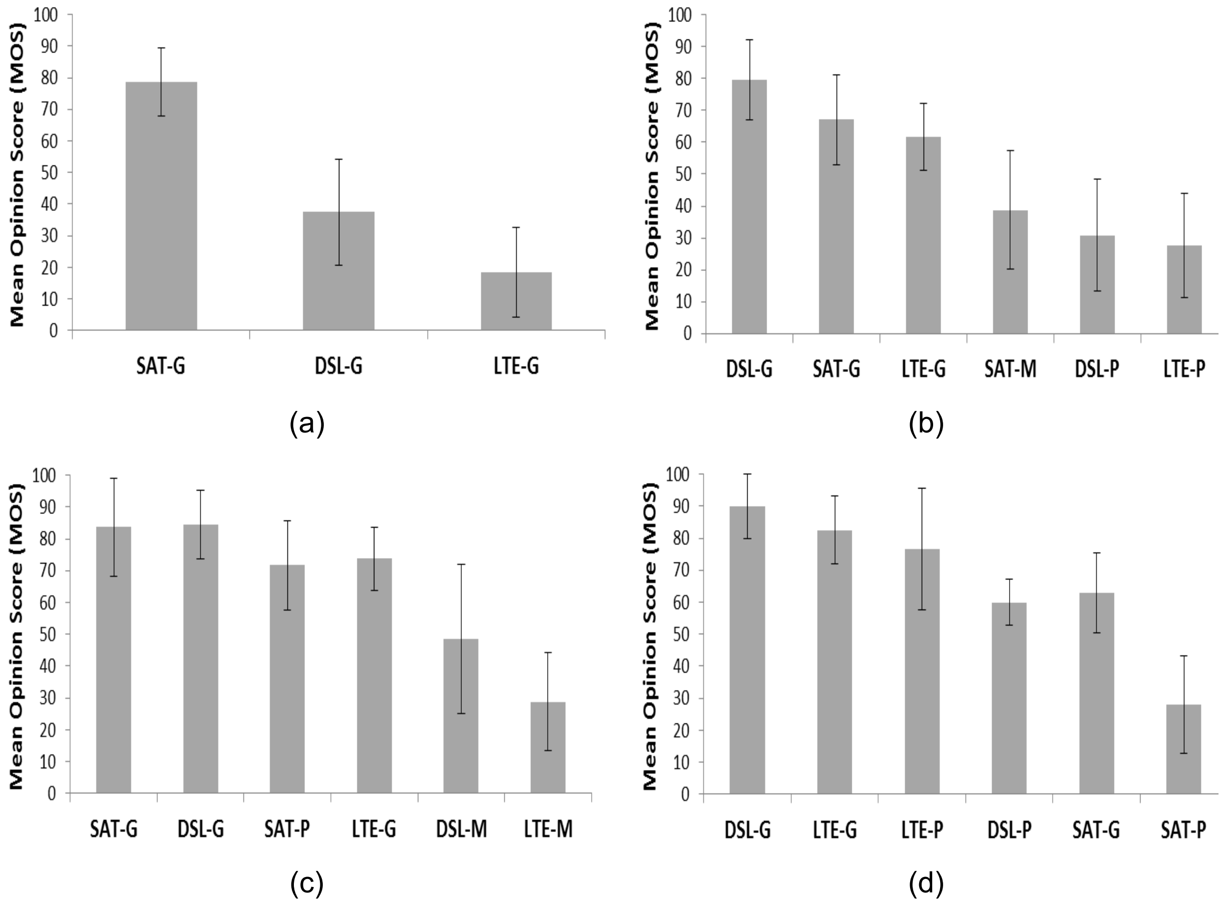


Figure 2-21: MOS results in Experiment I – Part 1, (a) HD streaming, (b) Web browsing, (c) Video conferencing, (d) Online gaming

Experiment I – Part 2

The results in Figure 4-2 show the MOS of users under different network conditions with the presence of the IxG. On the graphs presented in Figure 2-22, the dashed horizontal lines represent the achieved MOS levels in Part 1. These are shown on the graphs for quick comparison between the experience with and without the IxG. The emulator configurations are presented in the format of [*Satellite condition*, *DSL condition*, *LTE condition*] (e.g., GMM, PMG, MGG, etc.). Besides, Figure 2-23 shows the users' average responses to the questions asked during each test. The questions are presented in Table 2-7.

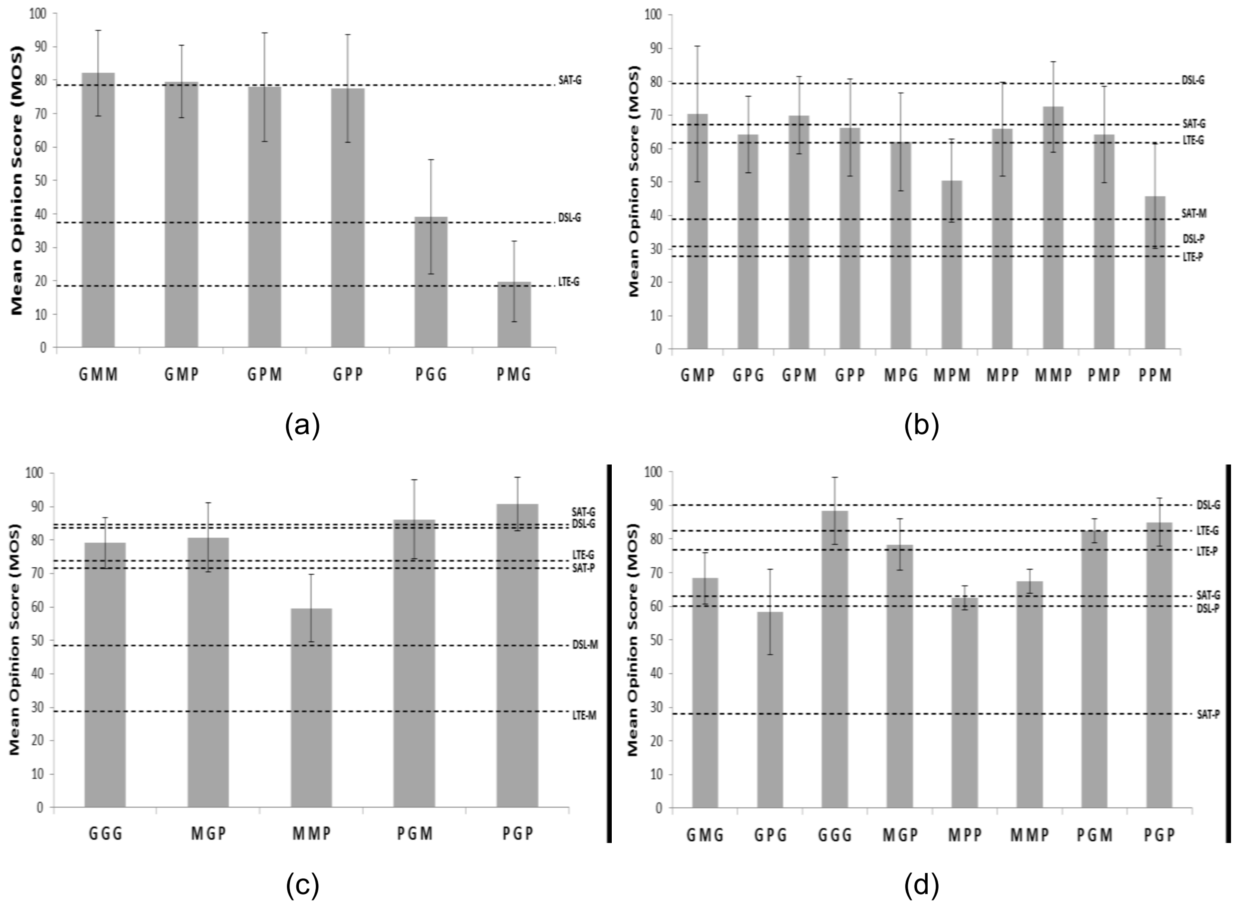


Figure 2-22: MOS results in Experiment I – Part 2, (a) HD streaming, (b) Web browsing, (c) Video conferencing, (d) Online gaming

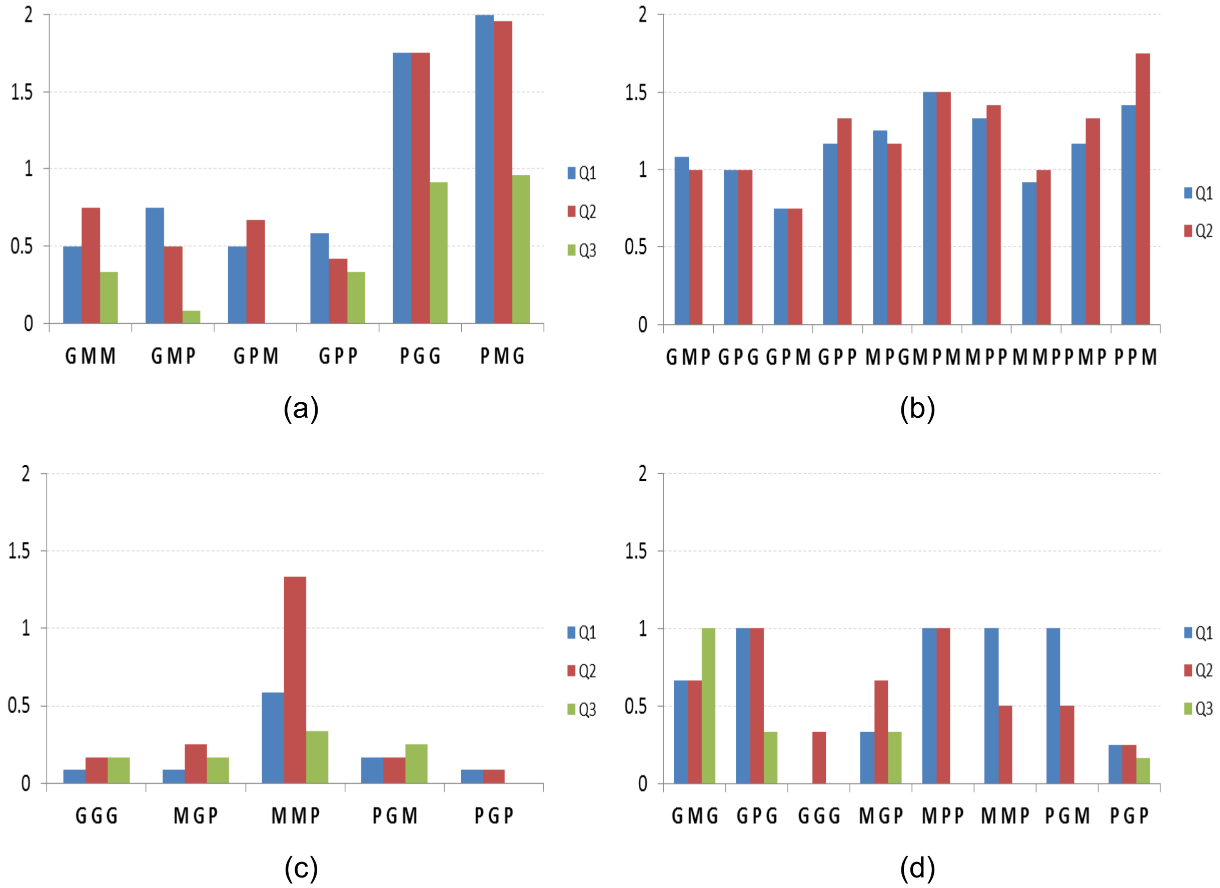
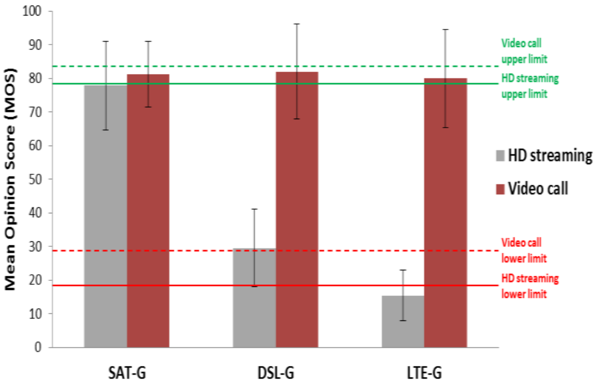


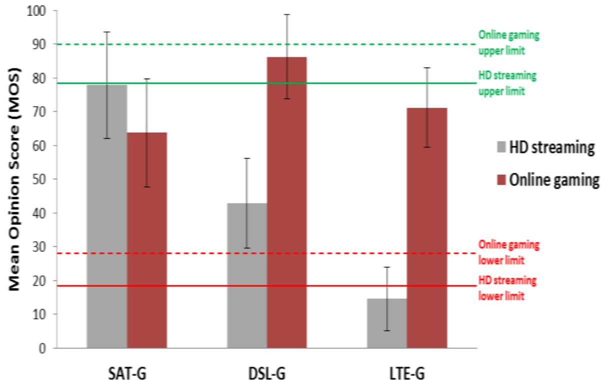
Figure 2-23: Users' average responses to the questions asked in Experiment I – Part 2, (a) HD streaming, (b) Web browsing, (c) Video conferencing, (d) Online gaming
Vertical axis: *0: never observed*, *1: rarely observed*, *2: frequently observed*

Experiment II – Part 1

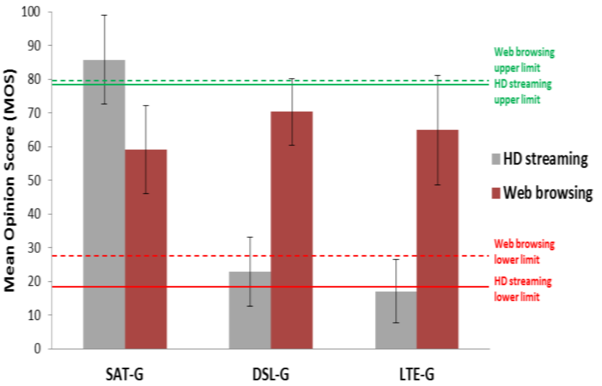
The horizontal lines in Figure 2-24 depict the maximum and minimum observed MOS values for the particular application in Experiment I (upper and lower limits). These lines are displayed for reference and comparison in the existence of two applications on the same network.



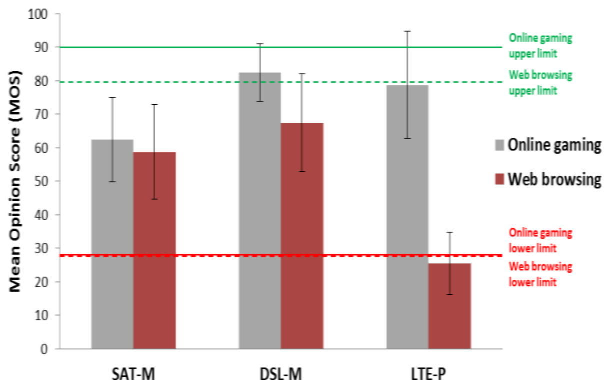
(a)



(b)



(c)



(d)

Figure 2-24: MOS results in Experiment II – Part 1, (a) HD streaming & Video conferencing, (b) HD streaming & Online gaming, (c) HD streaming & Web browsing, (d) Online gaming & Web browsing

Experiment II – Part 2

Figure 2-25 depicts the MOS results for both applications used during each test under different network conditions in the presence of IxG. These graphs are accompanied by the graphs in Figure 2-26 representing the users' average responses to the questions asked during the tests.

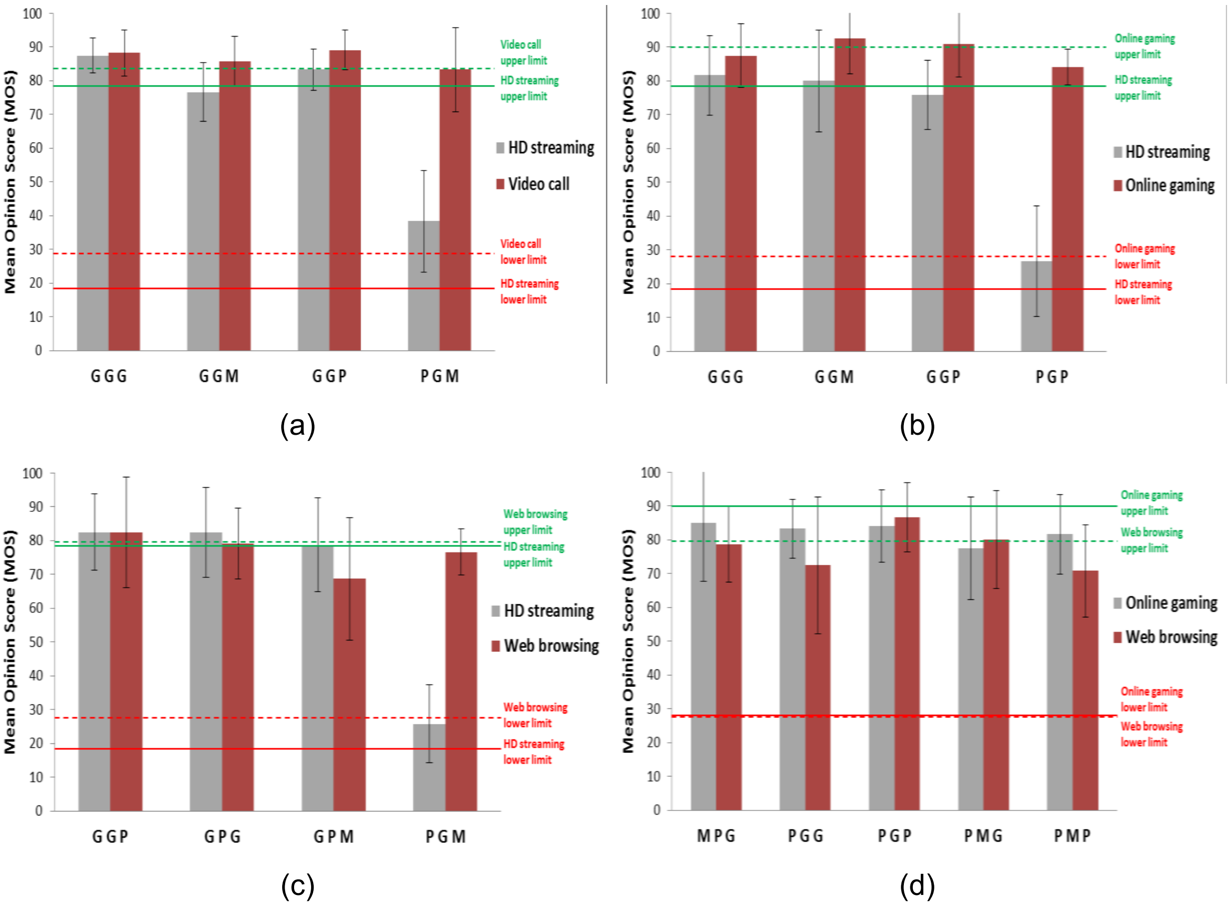


Figure 2-25: MOS results in Experiment II – Part 2, (a) HD streaming & Video conferencing, (b) HD streaming & Online gaming, (c) HD streaming & Web browsing, (d) Online gaming & Web browsing

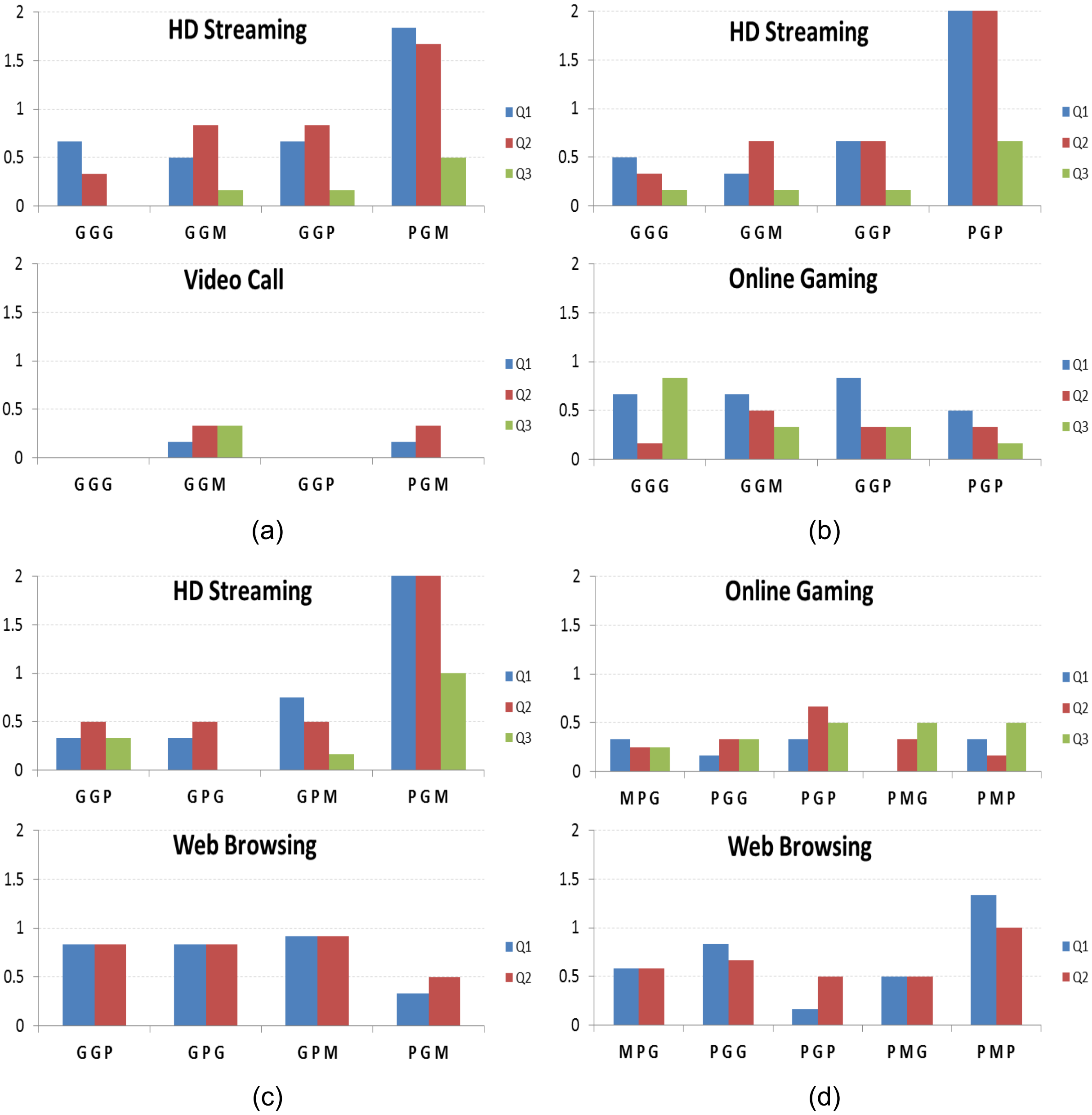


Figure 2-26: Users' average responses to the questions asked in Experiment II – Part 2, (a) HD streaming & Video conferencing, (b) HD streaming & Online gaming, (c) HD streaming & Web browsing, (d) Online gaming & Web browsing

Vertical axis: *0: never observed*, *1: rarely observed*, *2: frequently observed*

2.6 Analysis of lab trials user assessment

Analysing the mean opinion scores obtained from the lab trials, the following observations are made:

Video streaming:

The availability of bandwidth is the most crucial criterion for the tested video streaming application, where the users' quality of experience varies significantly over different channel conditions.

Despite providing inferior latency performance compared to the DSL network, the high throughput Satellite network improves the video streaming experience significantly, while the DSL channel can barely provide an acceptable level of service.

Still, the bandwidth of the emulated good condition of the DSL channel matches the average bit-rate of the compressed HD multimedia streams. However, the intermittent service as a result of the need for occasional re-buffering influences the quality of experience.

The impact of the latency at the beginning of video streaming in the Satellite link is negligible.

The IxG function of routing the bandwidth-demanding streaming services to high-throughput links is quite useful.

Web browsing:

The quality of experience in the case of web browsing is not solely dependent on the latency of the network or on the throughput. It is affected by both, depending on the web browsing activity.

Page response time is an important factor, which is accommodated with the availability of the low-delay terrestrial link that is the DSL channel. Monitoring the traffic over each link throughout the web browsing tests, it was observed that the DSL link is always active at the beginning.

Depending on the size of the page that is loaded (e.g., number and size of the included multimedia elements, such as pictures), the traffic is dynamically routed over the Satellite link to facilitate fast content loading.

The best quality of experience can be observed when the user has a decent DSL connection with sufficiently high throughput. However, when this is not the case, the bulk of the page content can be retrieved through the Satellite network, which still leads to comparable quality of experience. This can be observed in Figure 2-21(b) especially when the DSL emulator is set to ‘Poor’ (P).

This proves that the dynamic traffic routing performed by IxG is a useful feature to maximise the quality of experience for HTTP based applications, such as web browsing.

Video conferencing:

In the lab based subjective tests, it has been observed that the perceived video conferencing quality is high as long as the network provides sufficient bandwidth for the transport of the video and audio.

Even in the satellite network, which has inferior latency performance than DSL and LTE, the video conferencing application is used successfully without noticeable problems. Based on the subjects’ responses after each test, the most notable issue with the video conferencing application was the degrading audio and video quality that is linked with the channel throughput.

IxG is able to classify the type of the traffic and video conferencing data is regarded as latency-sensitive. Therefore it is treated in a way to route it through the link with the lowest delay, which is the right process. Nevertheless, it should also closely monitor the bandwidth requirement of the real-time audio and video traffic to make routing decisions accordingly. If this was already incorporated, the mean opinion score, when the DSL network was in ‘Marginal’ (M) condition, would have been higher (please see Figure 2-21 (c)).

Online gaming:

Similar to the video conferencing application, the tested online gaming application is also latency-sensitive, but doesn’t demand much bandwidth as the video conferencing application.

The impact of the latency on the online gaming quality of experience is more visible, especially when the traffic is carried over the Satellite network (note that in Figure 2-21, the quality is comparable between the cases where the DSL network is in ‘Poor’ condition and the Satellite network is in ‘Good’ condition).

The measured quality of experience is mostly in and above the good range (i.e., above 60/100) in the existence of the IxG, which doesn’t necessarily route the gaming traffic through the network that provides the maximum bandwidth.

3 Field Trials

Field trials in the BATS project have been introduced and designed for validating the concept of BATS with actual real world users, dynamic network settings, and a variety of applications in order to act as a show case for the key stakeholders in government and industry. They are also used as validation for the BAT's concept and moving from theory and hypothetical situations to prototypes which can help in the development of business cases for commercial partners and ISP operators.

3.1 Field trials description

3.1.1 Field Trials setup and prior expectations

The field trials were setup as follows:

- Users were selected from Spain and Germany.
- In Spain R was the BATS operator and the performance analysis carried out by Gradient. System installation was also carried out by R.
- In Germany FhG-Focus was the BATS operator and the performance analysis was carried out by FhG-HHI. Initial system installation was carried out by an Avanti partner.

Initial expectation from the field trials was that the users would utilize the service available to them during the trial period and in return would provide the feedback on the system, which would act as a valuable resource in order to evaluate the user acceptability of the BATS System, while the system logs would provide indications to overall system performance..

3.1.2 Spain Field Trial detailed description

This section gathers the most relevant information related to the Field Trials in Spain, comprising aspects such as the network architecture from the point of view of the operator, the installation of equipment in the customers' premises, the end-user feedback collection process and the mechanisms employed for performance monitoring. It should be noted that a large part of this information has already been included in section 4 of D6.1.2 and section 3 of D6.4, so these documents will be taken as a reference.

Several of R's departments have been involved in the course of the trials, each one being responsible of a particular role:

- *Data Networking* and *Customer's Equipment*: network performance monitoring and IUG behaviour testing.
- *Installers Team*: equipment installation, incident resolution and maintenance.
- *Marketing*: sending the online questionnaires and collecting the resulting data.
- *Communication*: elaboration, dissemination and coordination of the external communications related to the project and the field trials (press releases, blog content, etc.).
- *Customer's BackOffice*: direct communication with the customers, coordination of the installation, etc.
- *TAS* (Technical Attention Service): solve any doubt or incident related to the IUG or the SAT connection and report these issues to OneAcces when necessary.

On the other hand, Gradiant has carried out the preparation and evaluation of the end-user questionnaires and the analysis of the technical performance logs.

3.1.2.1 Network Architecture for Field Trials

The final network architecture employed for the field trials in Spain is detailed in section 3.1 of D6.4.

3.1.2.2 Installation of the BATS equipment

The installation of the equipment in the customers' premises, carried out by a team of R installers, was divided into two phases:

- The installation of the satellite equipment, whose initial stages are described in section 3.2 of D6.4, was conducted between March and June 2015. 33 successful installations were completed, since 2 of the 35 initially selected users did not accept the characteristics of the installation (due to the antenna size and location). These set of users enjoyed several months of satellite service, during which some complaints regarding the latency of the satellite connection and a few problems related to proxy configurations were minor incidences. A high level of expectancy regarding the IUG and the BATS system performance was perceived among the users, causing a clear impact on their final impressions regarding the system.
- The installation of the IUGs was carried out between July and September 2015. 29 successful installations were completed, since 4 of the previous 33 users, most of them SoHo users, abandoned the trials due to two main issues found in this process:
    - VoIP. The automatic QoS control currently implemented was not sufficient for the VoIP service offered by R.
    - LAN configuration. The available configuration options of the IUG are limited and too rigid for SoHo users (port redirections, etc.).

Figure 3-1 Installed satellite dish

Figure 3-2 End User Equipment

3.1.2.3 Users Profile

As described in section 3.3.1 of D6.4, the process of selection of the final users took into account the user profile of the candidates assuring that a broad scope of scenarios (type of household, activities on the Internet, employed devices, etc.) were covered in the trials. Although some issues found that during the installation of the equipment it caused the loss of part of the initial set of selected trialists, as exposed in section 3.1.2.2 of this document, a check was conducted to ensure that the final set of users met the defined criteria.

Additionally, some of the information collected through the online questionnaires, presented in section 3.3.1.1, was employed to update the data regarding the activities on the Internet (frequency of use of Internet, type of applications and services used).

Figure 3.3 shows the geographical distribution of the final trialists.

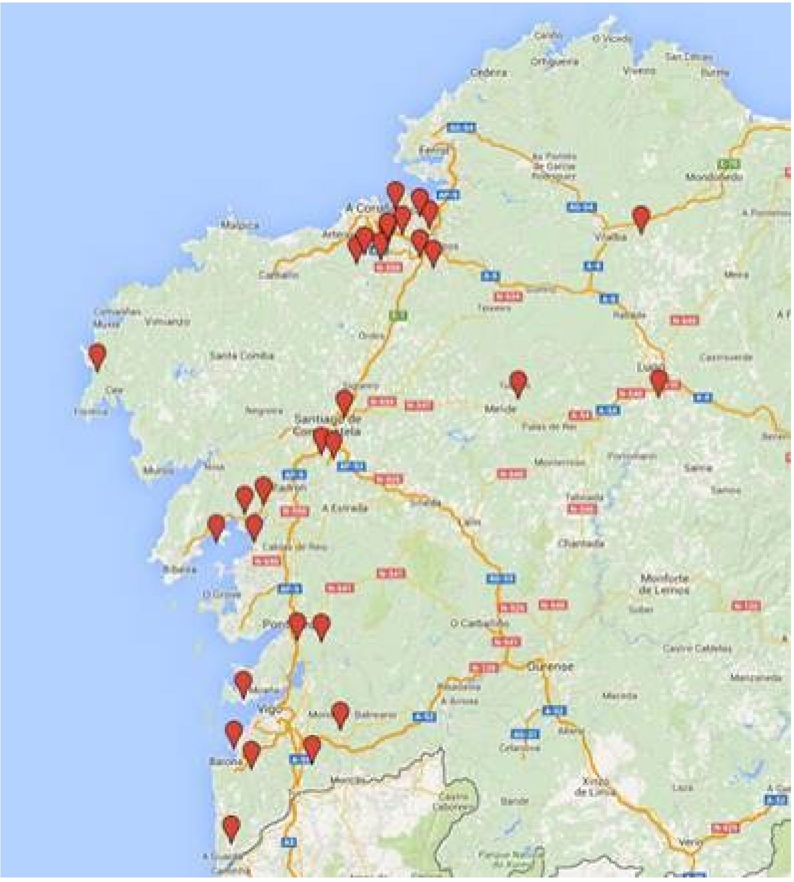


Figure 3-3 Geographical distribution of the final trialists

3.1.2.4 **Users Feedback**

The users' feedback has been an extremely important element in the course of the trials and in their evaluation phase. As described in D6.1.2 and D6.4, the feedback gathering process has been based on telephone and online communication with the participants. The following mechanisms has been employed for this purpose:

- Two online questionnaires (an intermediate and a final one), designed to address issues as:
    - the level of satisfaction regarding different aspects of the BATS system installation and the BATS service performance,
    - the perceived QoE for different Internet applications and services,
    - the nature of the problems encountered by the users,
    - the level of interest of the users in a commercial service.

  The first of these questionnaires, the intermediate one, was sent in September 2015, one month after the end of the IUG installation phase. It was mainly focused on obtaining an early feedback from the users, allowing us to identify possible issues occurring during the initial stages of the trials.

  The final questionnaire, shown in 0, was sent in November 2015. Its main purpose was to provide the final opinion of the participants, serving as the main reference for the trials evaluation process.

- A dedicated thread in R's technical support forum, aimed mainly at allowing users to share their doubts and opinions about the service. It has been used as an additional channel of communication with the end-users.

3.1.2.5 Technical performance logs

As detailed in section 2.5 of D6.4, one of the features of the ING is the capacity of storing and automatically reporting different computed statistics of the traffic per IUG. These statistics include, among others, bandwidth, RTT, total amount of traffic, number of connections and size of objects for each one of the links (satellite, cellular and terrestrial).

During the Field Trials period, two CSV[1] file (one per ING) containing these traffic statistics for the previous 24-hour period was sent daily as attachment in an email.

In order to provide a more useful and graphical way to analyse these data, a specific script was implemented. The output of this script (as shown in Figure 3-4) consists on a periodic report, in an excel file, summarizing the most relevant information per IUG and some average statistics for the period under consideration.

Figure 3-4 Screenshot of a Periodic Report

In order to gather and analyse other statistics and alarms from the IUGs/INGs (SNMP objects), R has employed the commercial tool Zabbix. As an example, the following figure shows the amount of traffic sent/received each 5 minutes through the cellular interface.

[1] Comma-Separated Values

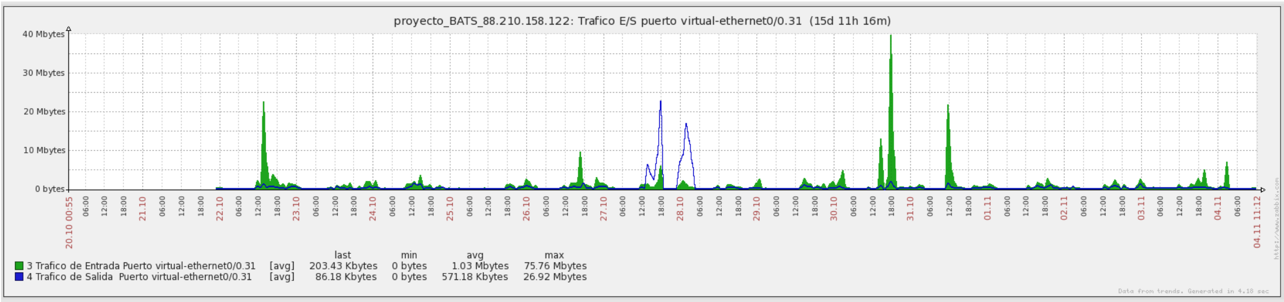


Figure 3-5 Zabbix Screenshot

3.1.3 Germany Field Trial detailed description (FH-FK)

Deliverable D6.4 details the architecture setup for the field trials. However modifications were made for some end users due to the peculiar nature of their building, number of devices and internal LAN configurations. These modifications were mainly adding switches and routers to the single LAN port of the IUG and creating another virtual network within the BATS network. In some cases the router also served as a DSL modem with its own DHCP settings. This led to IP conflict issues and routing loop.

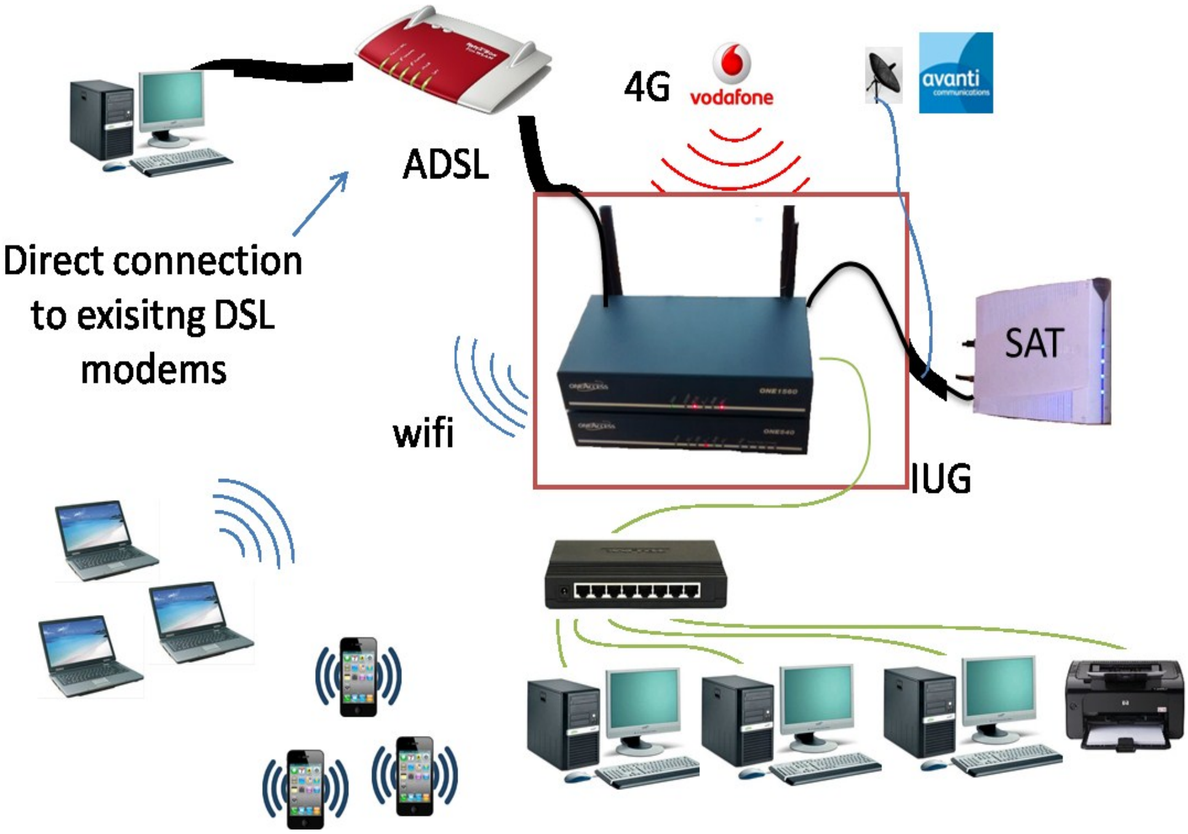


Figure 3-6 Setup for home office user

The German field trials were conducted in two phases. This is based on the known issues faced by end users and familiarization with a new device. It also created an avenue to address any technical challenges not envisaged.

Phase I: August – October 2015

- IxG Software version 7.1.2
- satellite latency ~3000 ms at some sites
- 15 active End users
- Frequent reconfiguration at some sites due to ip conflict.

Phase II: October – November 2015

- IxG Software version 7.1.5
- Issues with satellite latency resolved.
- 11 active End users
- Stable LAN configuration

As noted above, there was a continued development of the IUG prototype to address some of the issues observed in the lab trials and by the end users. In Phase II, we thus used an updated SW version 7.1.5 which included the following features:

- Fix link estimation when peer reduces the advertised window size. When DSL or LTE has very low bandwidth, the IUG may announce very small window to ING that reduces TCP bandwidth and causes wrong link estimation. This specific case is now handled correctly.
- Fix Inter Arrival Time (IAT) issue when uploading from IUG.
- Added MCTCP statistics collection & storage;
  - Add In/Out statistics,
  - Add GUI in monitoring tools (new package on admin) and export in csv format,
  - Send daily summary with attached statistics in csv format using cron,
  - Add 2 new scripts that create, mount and configure disk partition on ING to be used for handling the mctcp stats database;
- Implemented mechanisms for SW upgrade ING to IUG (scripts to upload SW, upgrade IUG, configure IUG, check).

3.1.3.1 End User Profiles

In D6.4, we had based our assumptions (verified with the end users) of having DSL and cellular coverage. In practice a number of users had only GSM coverage. This was only realized due to poor QoE in phase I for these users. The link selection algorithm favored sending flows (with short object lengths) via the poor cellular link. In order to correct this anomaly, the cellular link for 2 end users (IUG36 and IUG48) were administratively shutdown.

Another unique user was IUG44 (a technical user) which had a special load balancing solution over his DSL and cellular links. He was thus only able to combine his satellite link and a second cellular link. All other users had 3 links UP.

3.2 *Field trial results – Germany (FH-HHI)*

3.2.1 Internet usage, QoE of the regular connection and setup of the BATS system

In both questionnaires, the test-users were asked about their internet usage as well about their subjective performance evaluation of their regular internet connection. In the follownig we present the results from the first questionnaire since these effects are general and do not relate to the reduced performance of the system during the first trial.

First, the users were asked about the amount of time spend on the internet during a regular week. In Figure 3-7, the results are summarized. Thus, around 75% of the users spend between 4 and 30 hours online which is between half an hour – to 4 hours per day.

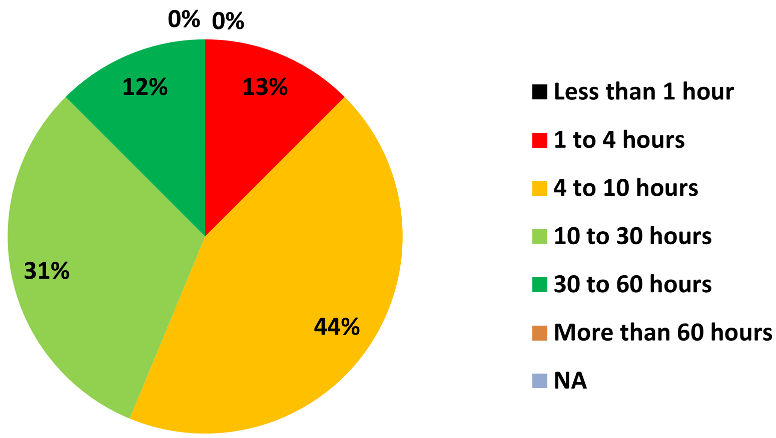


Figure 3-7 Internet usage per week in hours

Regarding their regular internet connection, test-user in the majority rate their subjective application specific quality of experience (QoE) as poor and fair, as depicted in the chart in Figure 3-8.

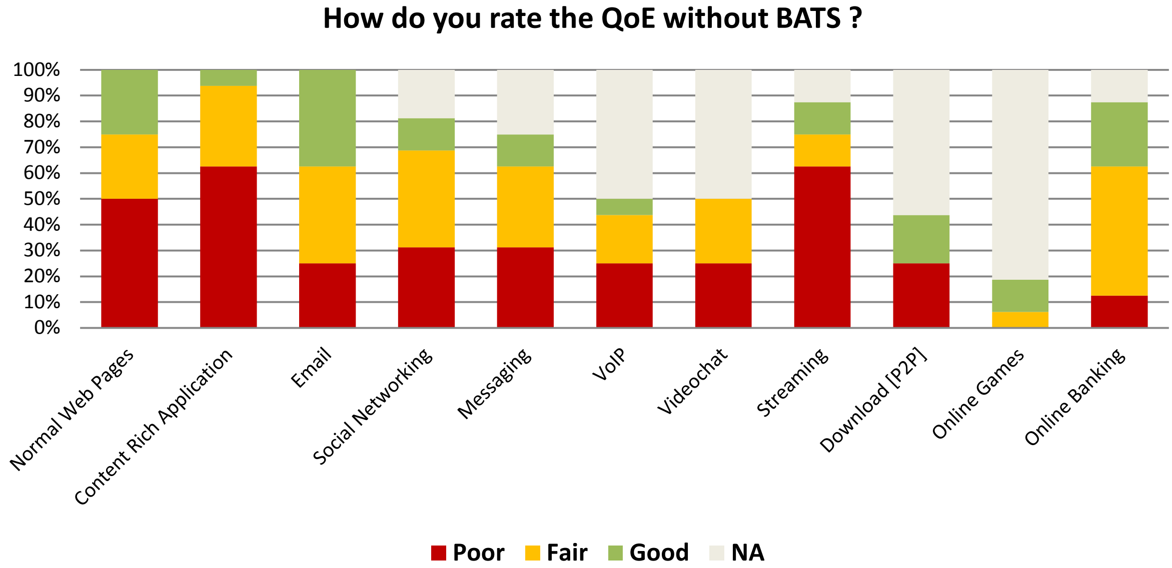


Figure 3-8 Evaluation of the application specific QoE before installing the BATS System

3.2.2 Application specific performance assessment of the BATS system

In the following the results of the application specific performance assessment is summarized. The results from the first and second questionnaire are separated separately.

3.2.2.1 Phase I

The application specific QoE assessment for the first phase is depicted in Figure 3-9.

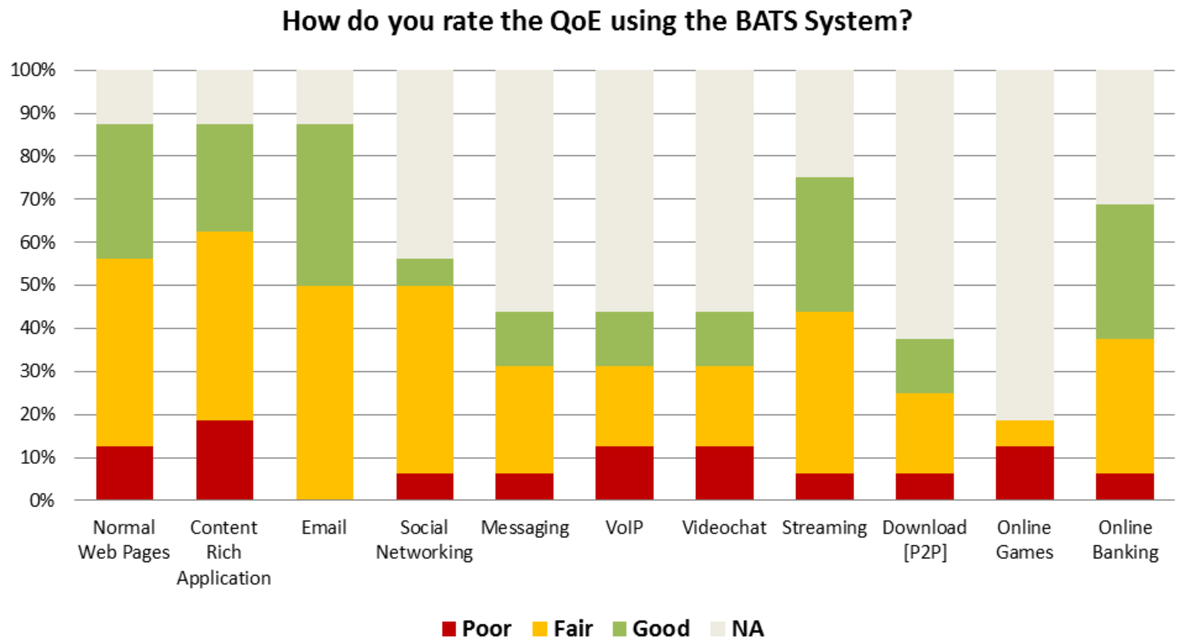


Figure 3-9 Evaluation of the application specific QoE using the BATS System [First Phase]

3.2.2.2 Phase II

The application specific QoE assessment for the first phase is depicted in Figure 3-10

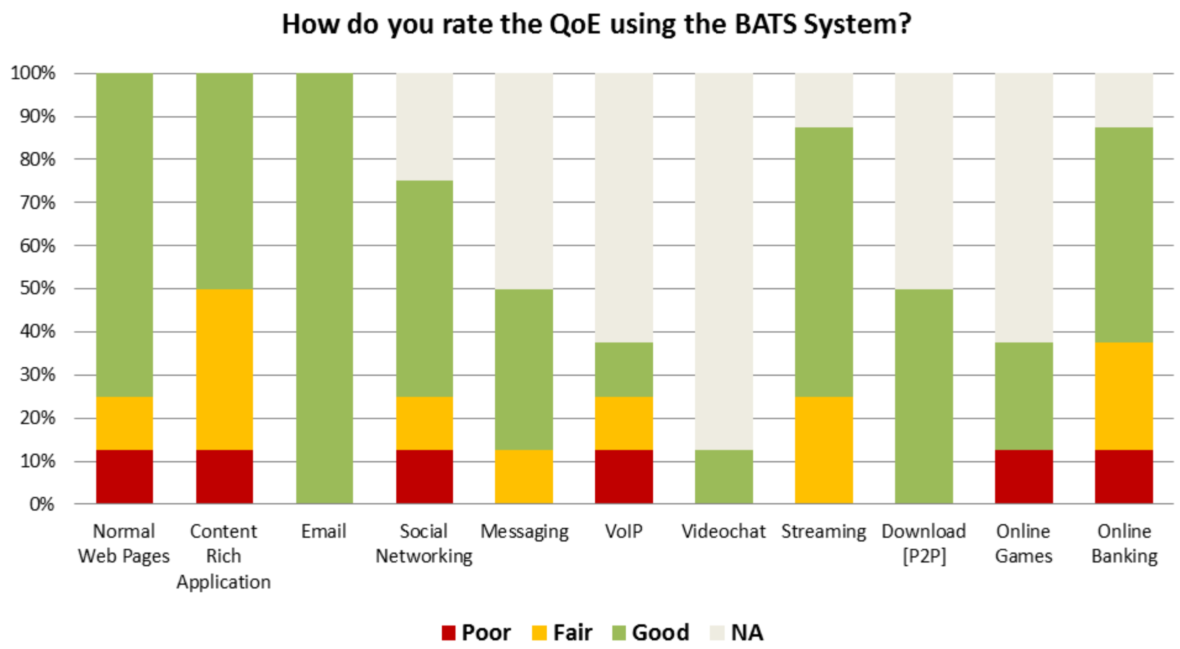


Figure 3-10 Evaluation of the application specific QoE using the BATS System [Second Phase]

3.2.3 General performance aspects of the BATS system

In the following, the users were asked how they rate specific aspects of the BATS system in general, i.e. download speed, upload speed, response time and stability.

3.2.3.1 **First Phase**

The general performance evaluation for the first trial is depicted in Figure 3-11.

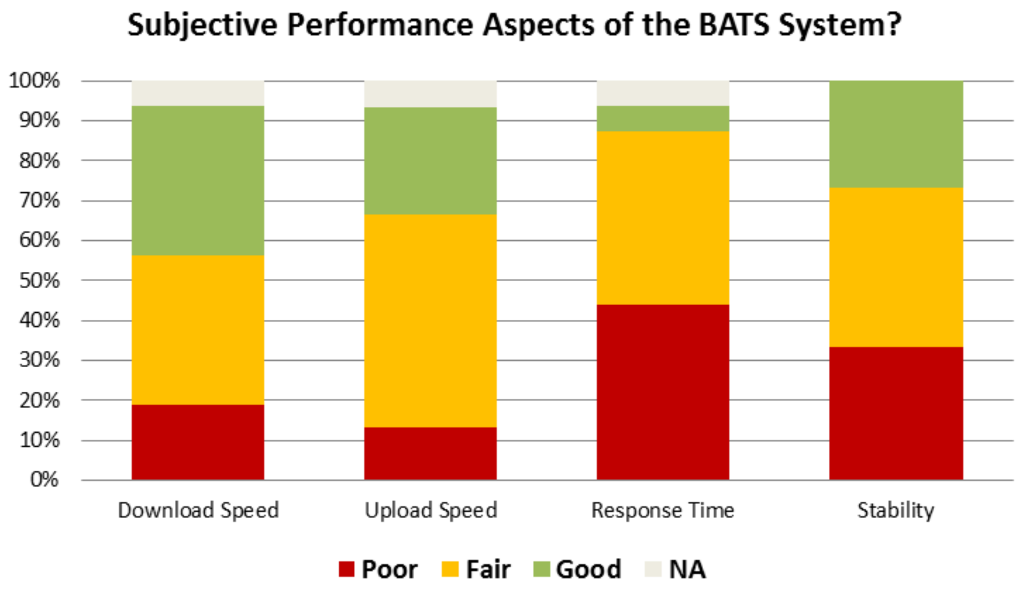


Figure 3-11 General performance evaluation of BATS [First Phase]

3.2.3.2 Second Phase

The general performance evaluation for the second phase is depicted in Figure 3-12.

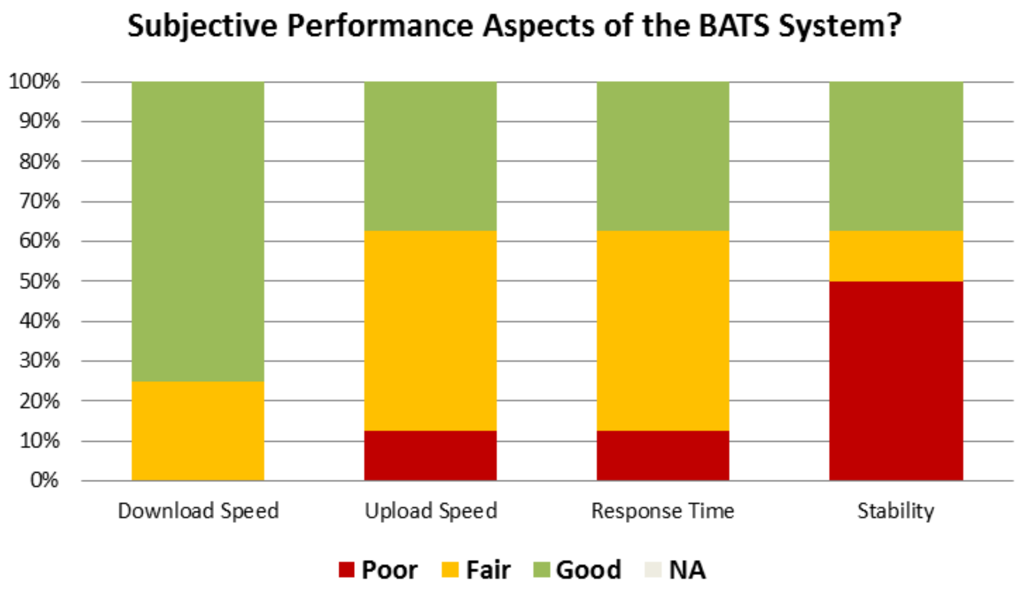


Figure 3-12 General performance evaluation of BATS [Second Phase]

3.2.4 Satisfaction Level and Expectations

In the following, the users were asked to quantify the level of satisfaction and if the expectations were fulfilled.

3.2.4.1 First Phase

The outcome on the question regarding the satisfaction level and expectations for the first field trial is depicted in Figure 3-13.

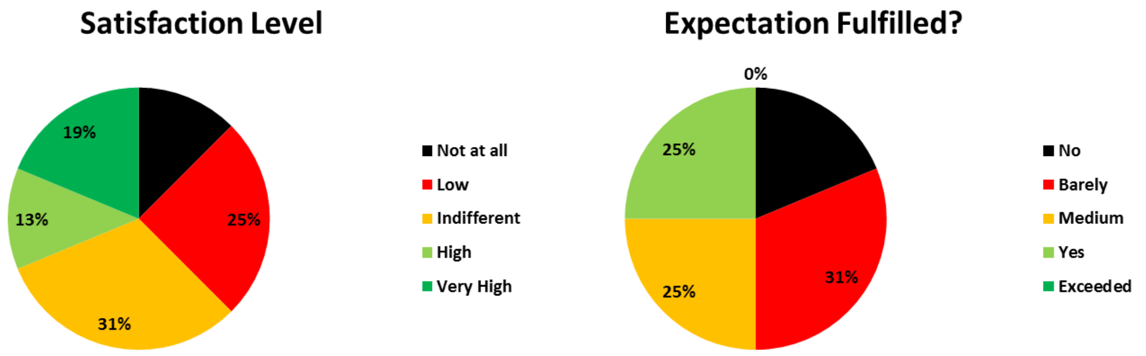


Figure 3-13 Satisfaction level and expectations on the BATS system [First Phase]

3.2.4.2 Second Phase

The outcome on the question regarding the satisfaction level and expectations for the second field phase is depicted in Figure 3-14.

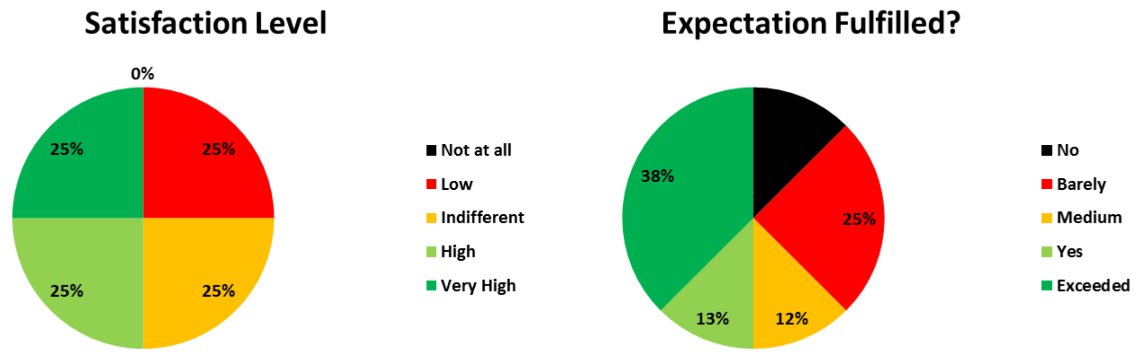


Figure 3-14 Satisfaction level and expectations on the BATS system [Second Phase]

3.2.5 BATS System Setup

The installation of the system is rated positive regarding the satellite setup, i.e. the antenna installation, etc. The level of satisfaction regarding the IUG size / location is positive/neutral, as depicted in Figure 3-15.

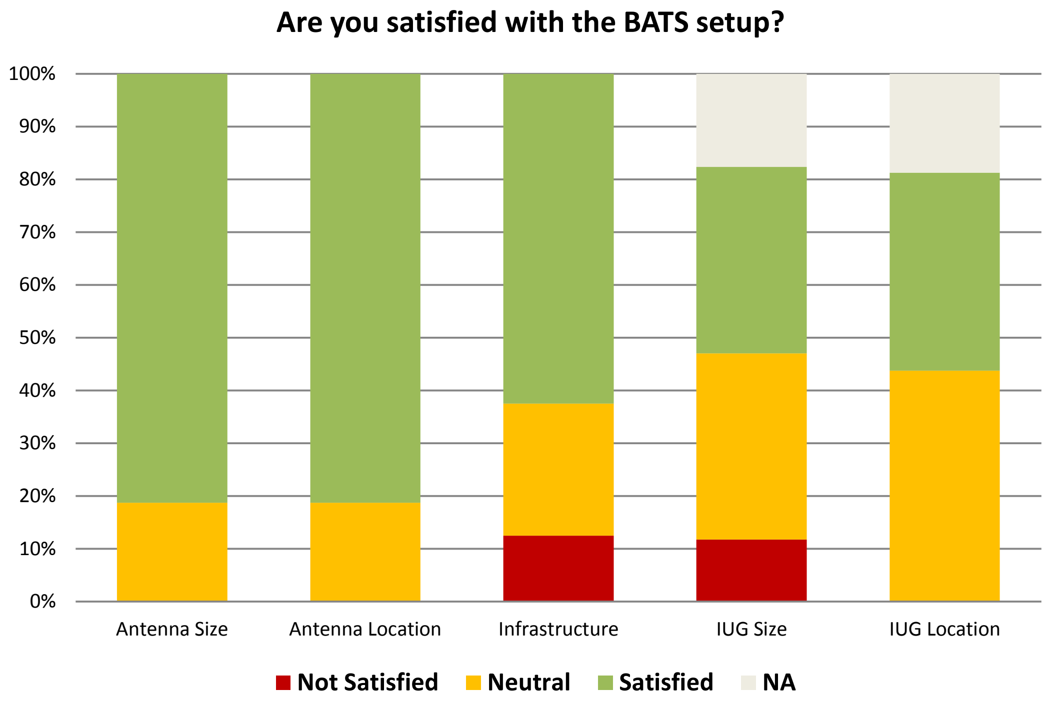


Figure 3-15 Assessment of the BATS installation and setup [First Phase]

Note: since the setup was not changed during both phases of the between the first and the field second trials, assessment of the installation setup was only requested once.

3.2.6 QoE using BATS compared to previous System

In the second phase of the field trial, specific questions were asked how the performance of the BATS system is evaluated compared to the previous system.

In Figure 3-16, the application specific performance improvement is depicted based on the answers of the second field trial questionnaire. It can be seen, that depending on the application >50% of the users experience performance improvements using the BATS system, for example normal web browsing, streaming as well as content rich application.

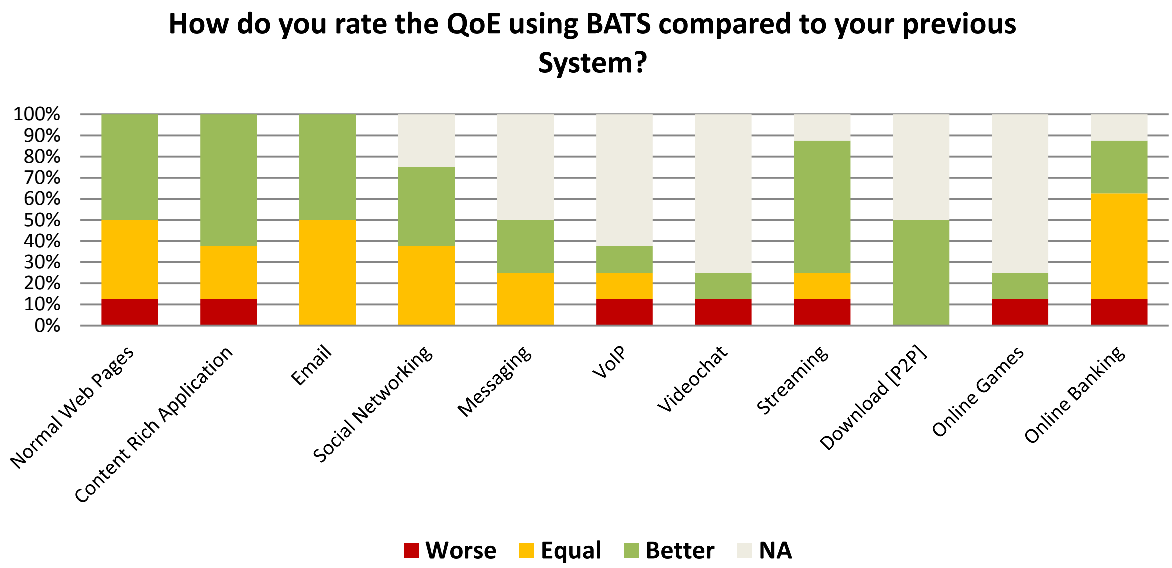


Figure 3-16 Performance improvements by using the BATS system [second Phase]

The test-users were asked how the BATS system affects the internet usage. In Figure 3-17 the application specific change in the internet usage is depicted.

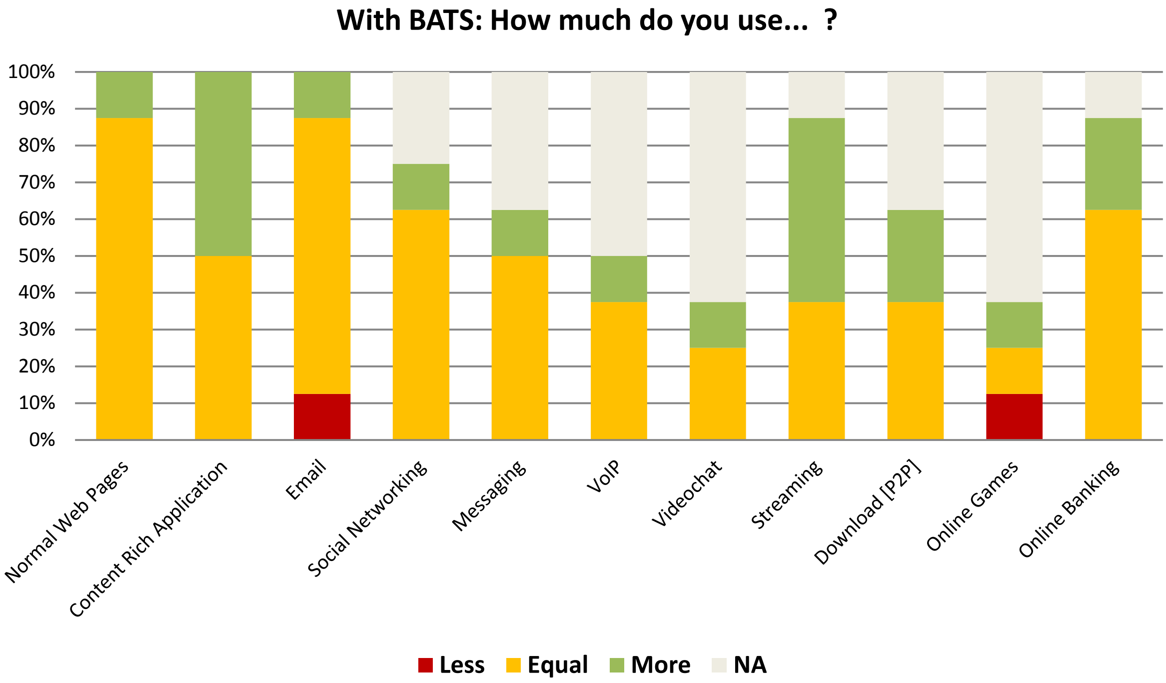


Figure 3-17 Application specific change in the internet usage by using the BATS system

3.2.7 Summary and comparison for the German field trials

In Figure 3-18, a comparison on the general quality assessment of the BATS system for both trials is depicted.

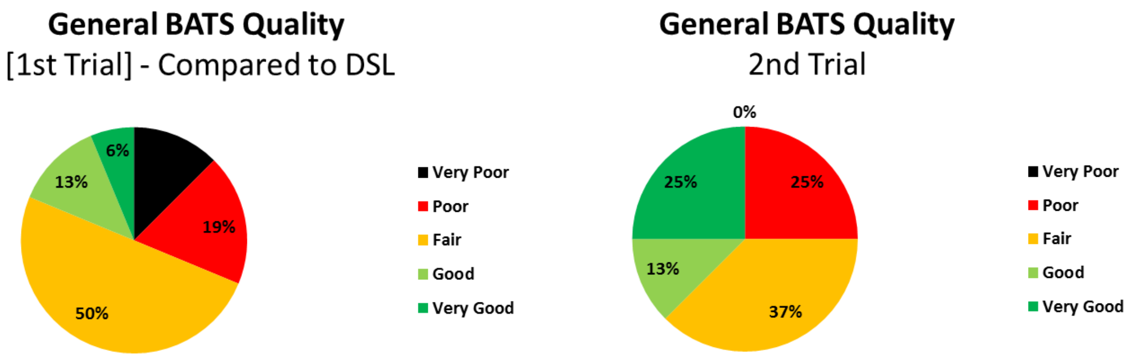


Figure 3-18 General BATS Quality: Comparison between the two German field trials.

The second field trial shows a much more positive outcome regarding the performance of the BATS system. When comparing the subjective QoE for specific applications before and after installing the BATS system (see Figure 3-19) we observe a 40% to 50% improved positive feedback while a -25% to -50% reduced negative feedback for three major applications.

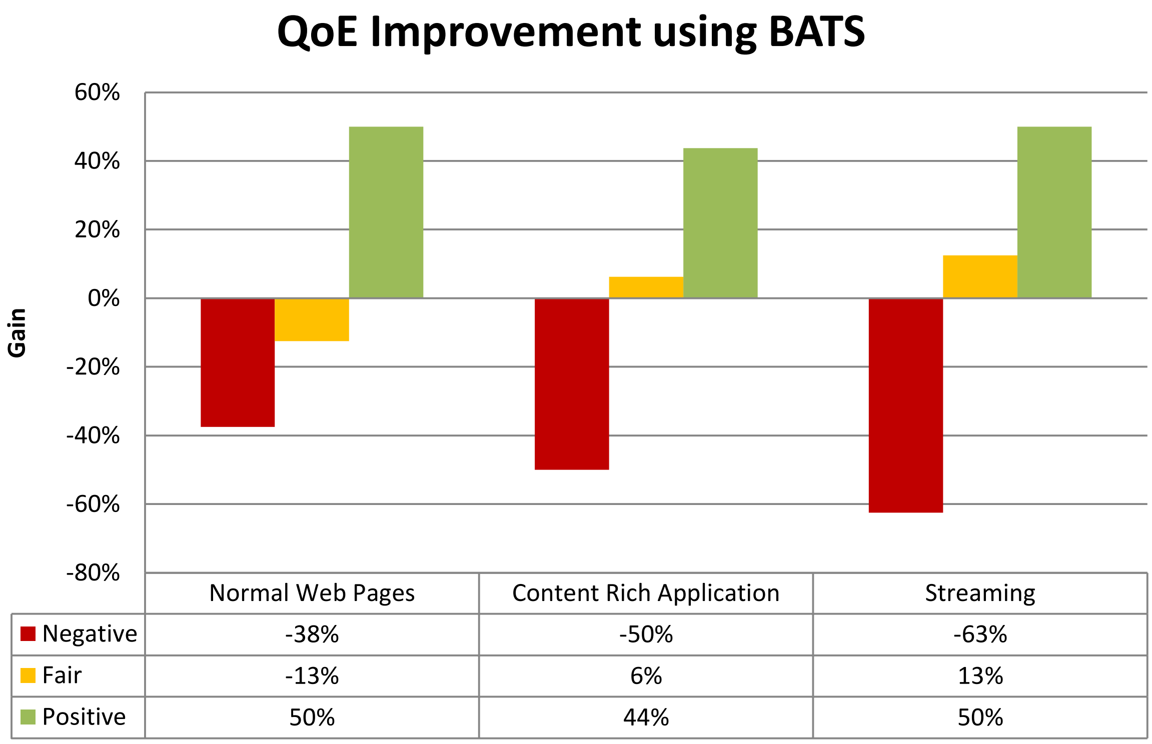
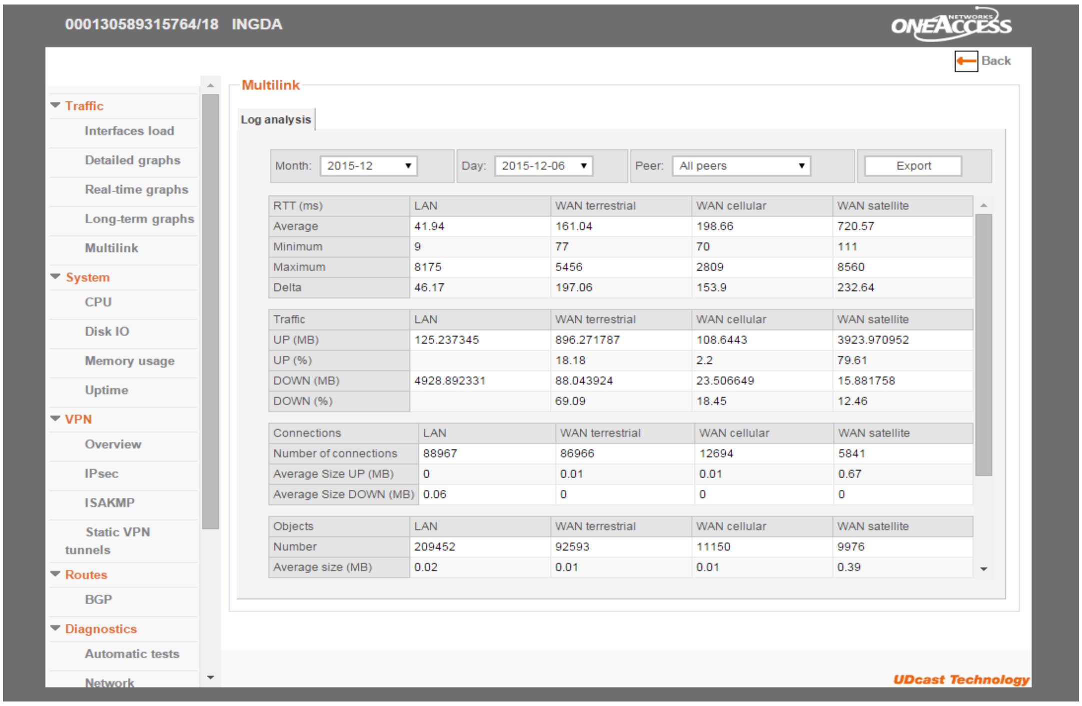


Figure 3-19 Improved QoE performance using BATS for 3 major applications.

As a result, the German field trial shows that the BATS system can improve the subjective performance significantly but the acceptance remains low due to instability.

3.2.8 Technical performance logs

Technical performance logs analysis



RTT (ms)	LAN	WAN terrestrial	WAN cellular	WAN satellite
Average	41.94	161.04	198.66	720.57
Minimum	9	77	70	111
Maximum	8175	5456	2809	8560
Delta	46.17	197.06	153.9	232.64

Traffic	LAN	WAN terrestrial	WAN cellular	WAN satellite
UP (MB)	125.237345	896.271787	108.6443	3923.970952
UP (%)		18.18	2.2	79.61
DOWN (MB)	4928.892331	88.043924	23.506649	15.881758
DOWN (%)		69.09	18.45	12.46

Connections	LAN	WAN terrestrial	WAN cellular	WAN satellite
Number of connections	88967	86966	12694	5841
Average Size UP (MB)	0	0.01	0.01	0.67
Average Size DOWN (MB)	0.06	0	0	0

Objects	LAN	WAN terrestrial	WAN cellular	WAN satellite
Number	209452	92593	11150	9976
Average size (MB)	0.02	0.01	0.01	0.39

Figure 3-20: Snapshot of ING log dashboard

This feature enables monitoring of the three WAN link interfaces and LAN interface per IUG. This provides granular details of typical KPIs to characterise the link based on the IXG link estimation module and well as accurate traffic statistics such as number and size of connections per links. A total of 62 unique parameters (per IUG) are monitored and stored in the ING. These logs are exported in CSV format for further analysis and were also useful in troubleshooting during the course of the trials.

To gain an insight into the type of logs stored, we have randomly chosen an iug who had an above average utilisation of the three links. We consider the BytesIn% and BytesOut%.

Xyz_BytesIn = xyz_conn_sizeIn * xyz_connections (where xyz = TER, SAT or CEL and connection refers to a TCP connection).

'BytesIn' refers to the total traffic (in MBytes) coming in to the ING from a particular IUG. This translate to be the **uplink** of the IUG. Similarly BytesOut refers to the end user's **downlink**.

Detailed logs for each IUG over the entire duration of the trails can be provided upon request. More insights will continue to be gained from this data for future EU projects and serves as input for the business analysis in WP8.

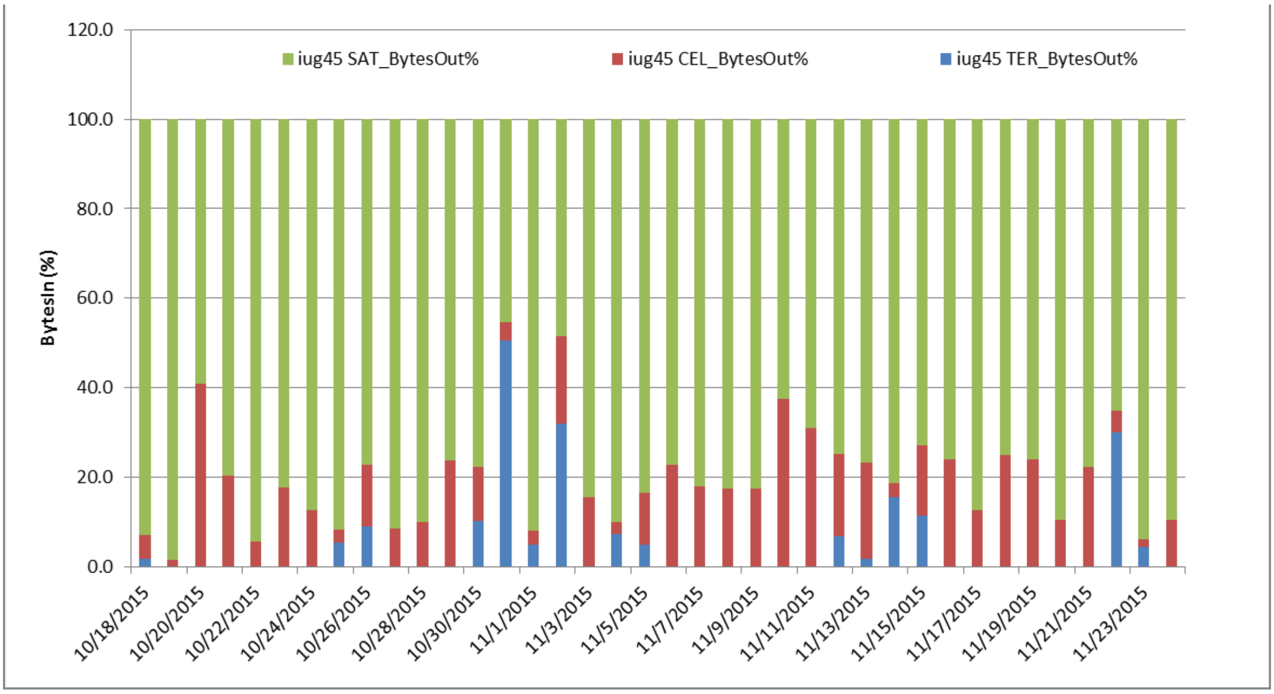


Figure 3-21 Analysis for iug45 showing percentage of downlink traffic (BytesOut) over the three links

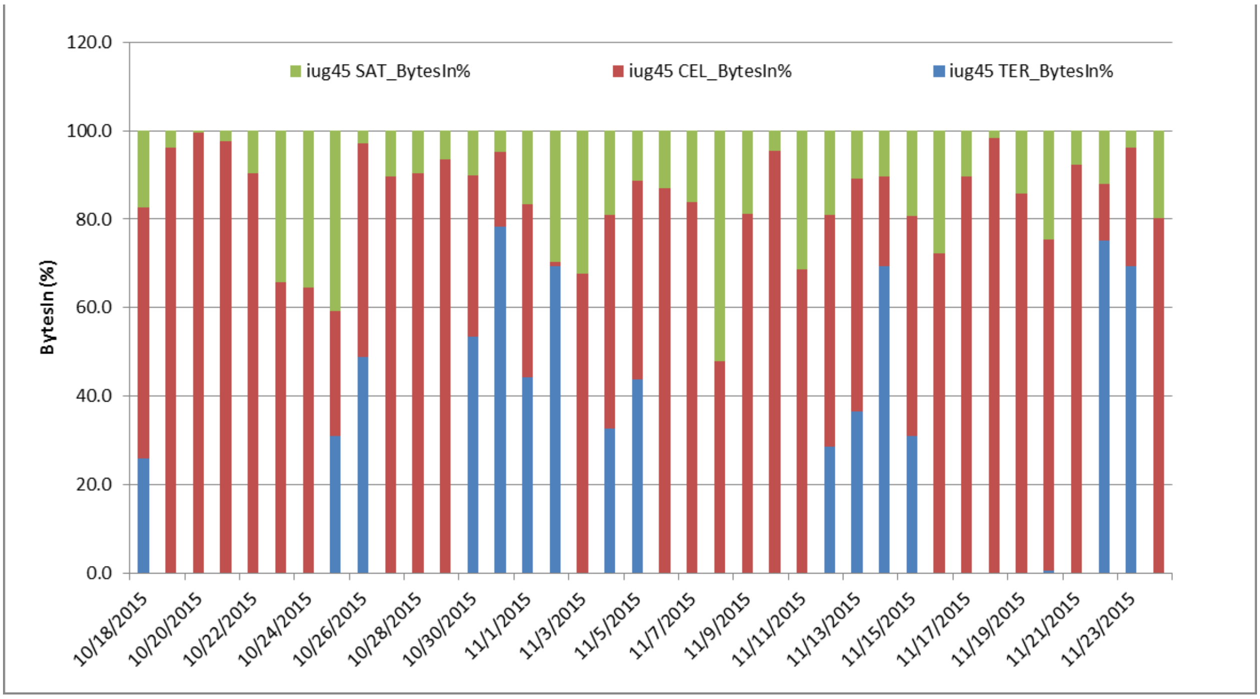


Figure 3-22 Analysis for iug45 showing percentage of uplink traffic (ByteIn) over the three links

In the example shown above (Figure 3-21), the overall average resulted in 84.2% of the downlink traffic were routed via the satellite link (5.5% over DSL and 10.3% over Cellular). In the uplink the overall average resulted in just 19.6% of the uplink traffic routed via satellite with 27.7% via DSL and 52.7% via Cellular.

One of the numerous insights we can draw from Figure 3-21 and Figure 3-22 is that traffic on the downlink typically has larger object sizes than on the uplink in most cases. Thus asymetric system architectures should be considered in future multilink network architectures.

3.2.9 Technical issues found, system failures and support experience

Technical issues, system failures and support experience)

An 'Open Technology Real Service' (OTRS) system was used for managing issues raised during the trials. A snapshot of the online ticket managing platform is shown below.

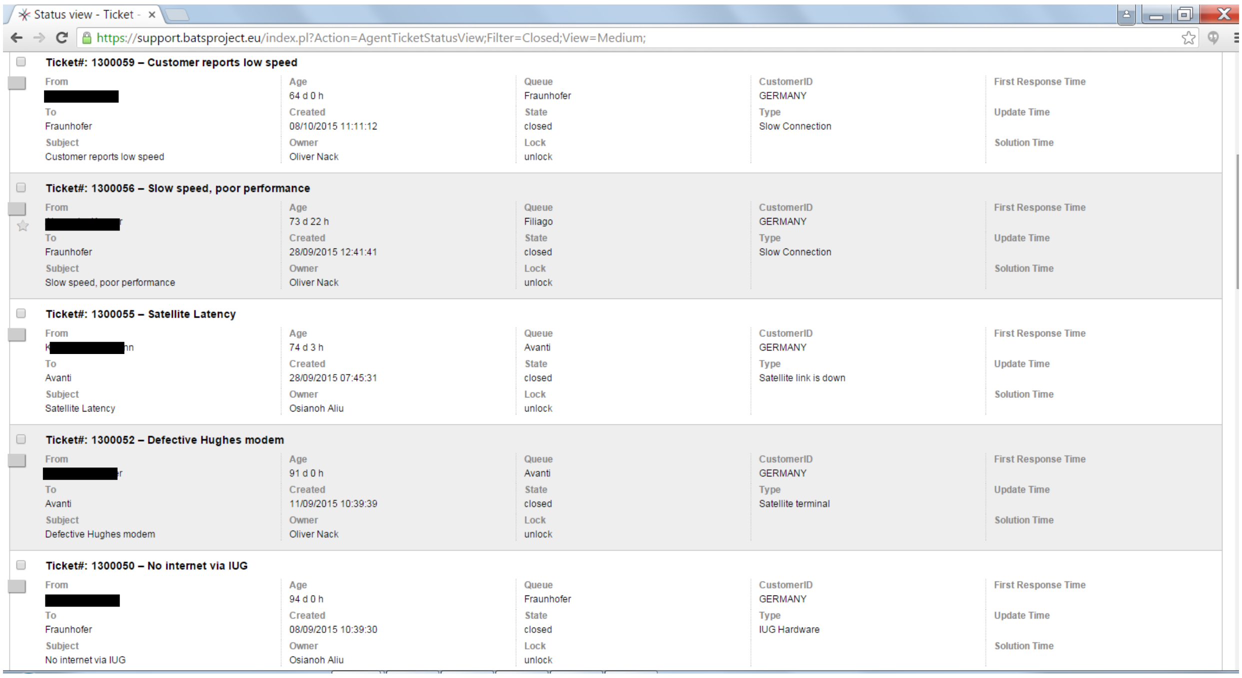


Figure 3-23 Online OTRS Ticketing System

The technical issues faced during the trials include the following:

- <u>Limited 3G/4G coverage</u>: 13% of the users had no 3G/4G coverage in their homes despite the coverage survey indicated otherwise. The location of the IUG in the user's premises may have led to this. The effect of this was that some flows with short objects were routed via the cellular link leading to dropped packets or very slow connection. To resolve this, the cellular link was deactivated.
- <u>Data caps on the cellular link</u>: Using our monitoring tool, we observed some users had data caps on their cellular link. Such users were upgraded from 1GB to 2GB monthly allocation at an extra cost.
- <u>User LAN setup</u>: We had envisioned a simple network setup. However, a number of the users who volunteered for the trials had more complex LAN configurations with a lot more devices than were described in the pre-selection questionnaire.
- <u>Satellite latency</u>: For a major part of the trials, we observed that the RTT of the satellite link was very high (approximately 3s) for some users some of the time. It took a while to trace the source of the problem as other users under the same beam coverage had normal RTT values. The Tech support at Avanti detected a problem with the bandwidth allocation low level configutation on the satellite link return channel resulting in high latency for a number of end users. This was resolved in October.
- <u>Disconnected DSL modem</u>: Due to the issues faced during the first phase of the trials, a couple of users stopped using the BATS solution. After necessary software updates, we convinced then to participate in the 2nd phase but they still left their DSL modems disconnected.
- <u>Poor first level support</u>: A third party company was commissioned to do installations of satellite terminals, IUGs and provide first level support. It was later realised they were not able to provide round the clock support and were not very responsive in duties delegated to them. We also believe the number of layers in the support chain

led to slower response time in resolving technical issues. This was unacceptable for end users who were actively using the BATS system when the ticket was opened and thought a solution would be provided within minutes. In future field trials SLAs should be included.

- Stability of the network: The BATS solution was at certain times providing maximum performance (up to 11 Mbps on the downlink) but this changes to 1 Mbps in a couple of hours. This was a source of frustration to some end users. For example this is a comment received on stability:

  "*The Connection was quite fast but ever since the rest of the hardware was installed, it became very unstable which was pretty annoying. If it is possible to get it stabilized we would love to keep using it.*"

  The quality of the individual links had direct impact on the QoE for the end users. In future development, an active link estimation approach will be considered which will have a direct weighting on the 'object size' based path selection.

- UDP based applications: Since the BATS solution addressed TCP traffic a slight degrade in performance was observed for such applications such as VoIP and online gaming.

It should be noted that not all users provided us with their subjective feedback despite numerous reminders.

3.2.10 Field trials in Germany key findings

All the technical issues described in the preceding section resulted in important findings during and after the trials. This wealth of experience will be applied in future applied research projects. We would like to emphasize some of these.

Based on the feedback received, 43.8% of the users spend 4 to 10 hours per week using the internet while another 31.3% spend 10 to 30 hours per week. This shows the importance of broadband service in daily activities. It has grown from being a service to a necessity. The implication of these figures stresses the point that the EC digital agenda for universal availability of broadband internet access is transforming from a being a target to an important requirement to ensure equality the daily life of citizens.

A large number of users indicated interest in participating in the trials as most of them were not satisfied with their current internet connection service. At the end of the trials, a few users noted they would like to have a more compact IUG with lower energy consumption if/when a commercial product is launched. We have no data on ideal costs the users will be will to pay monthly for a typical BATS solution.

In summary, the expectations of about 50% of the participants were met and even exceeded. The BATS concept is a viable solution worth further investigation towards improving the prototype towards a commercial product.

3.3 Field trial results – Spain

3.3.1 Users surveys

This section summarizes some of the results obtained through the two online questionnaires designed to gather the user feedback, as described in section 3.1.2.4.

3.3.1.1 **Internet usage**

The users were asked about their use of the Internet during the trials. The following figures show an increase in this usage for the second period of the trials. About 60% of the users spent from 10 to 60 hours online per week in both periods.

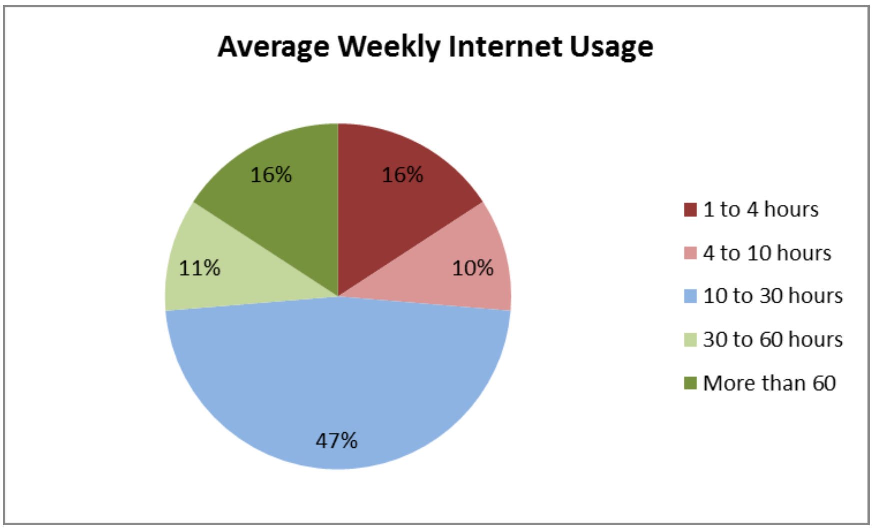


Figure 3-24 Internet Usage per Week [First Period]

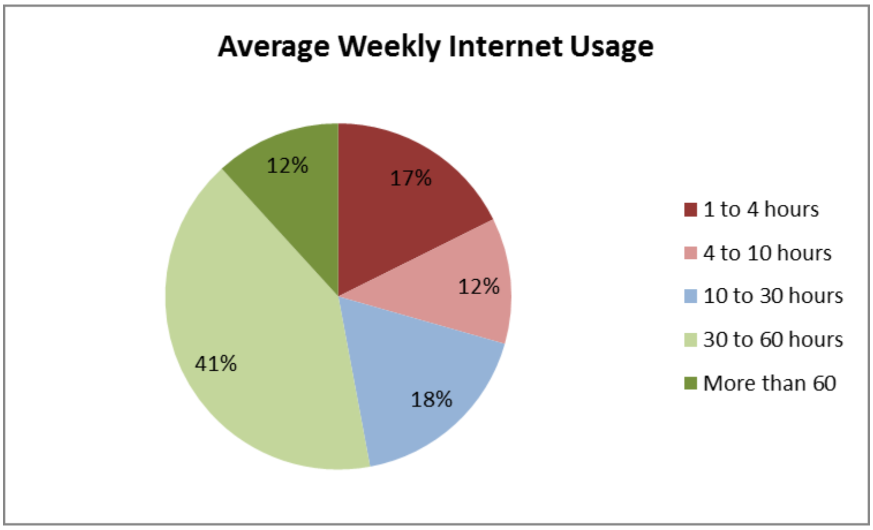


Figure 3-25 Internet Usage per Week [Second Period]

The following graphs show other aspects such as the usage of different categories of Internet services and applications and which is the most important of these categories for the user. In both cases Normal Web Pages, E-mail and Streaming services stand out among the other ones.

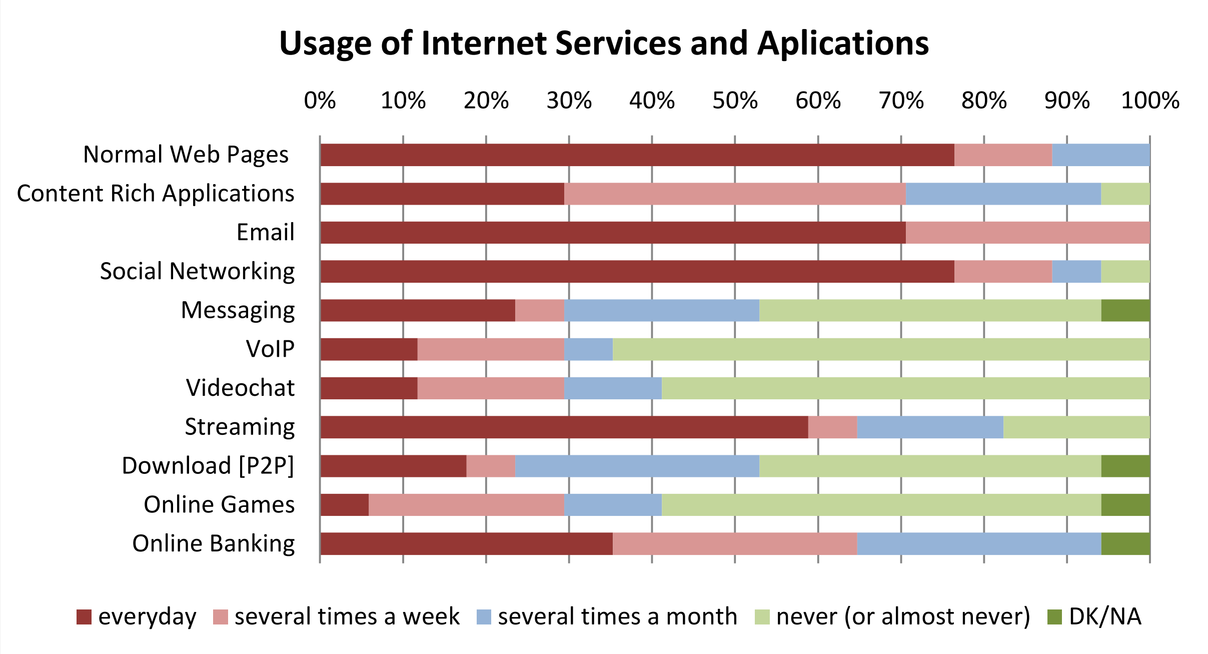


Figure 3-26 Usage of Different categories of Internet Services and Applications

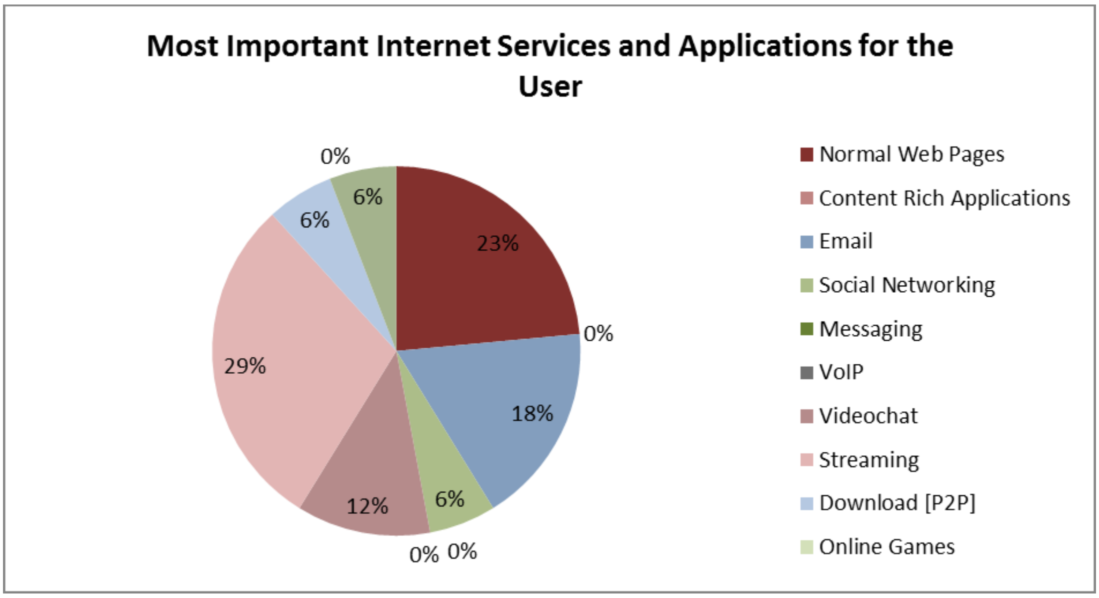


Figure 3-27 Most Important Internet Services for the User

3.3.1.2 QoE of the Previous DSL Connection

When asked about the quality of their previous Internet connection (DSL), most of the users (70%) rated it as “poor” or “very poor”, as shown in **Figure 3-28**. **Figure 3-29** shows that Streaming and Download (P2P) were the categories with lower QoE.

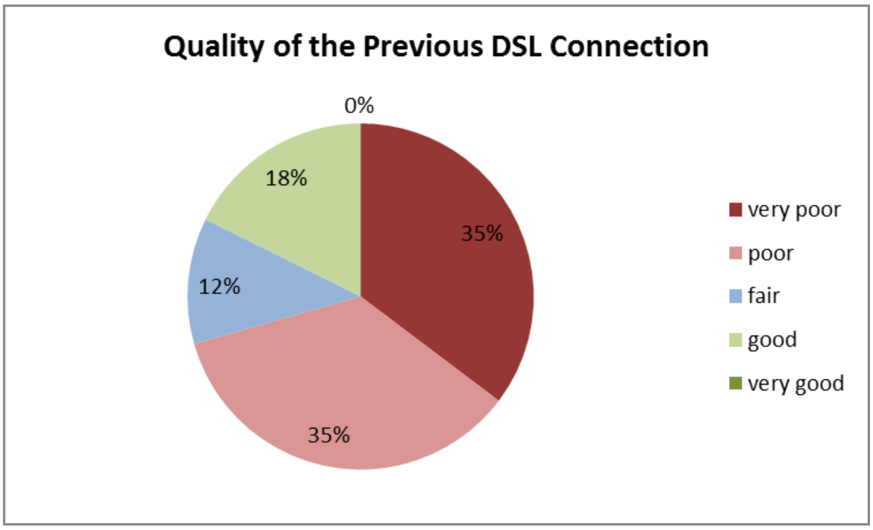


Figure 3-28 Overall Quality of the Previous DSL Connection

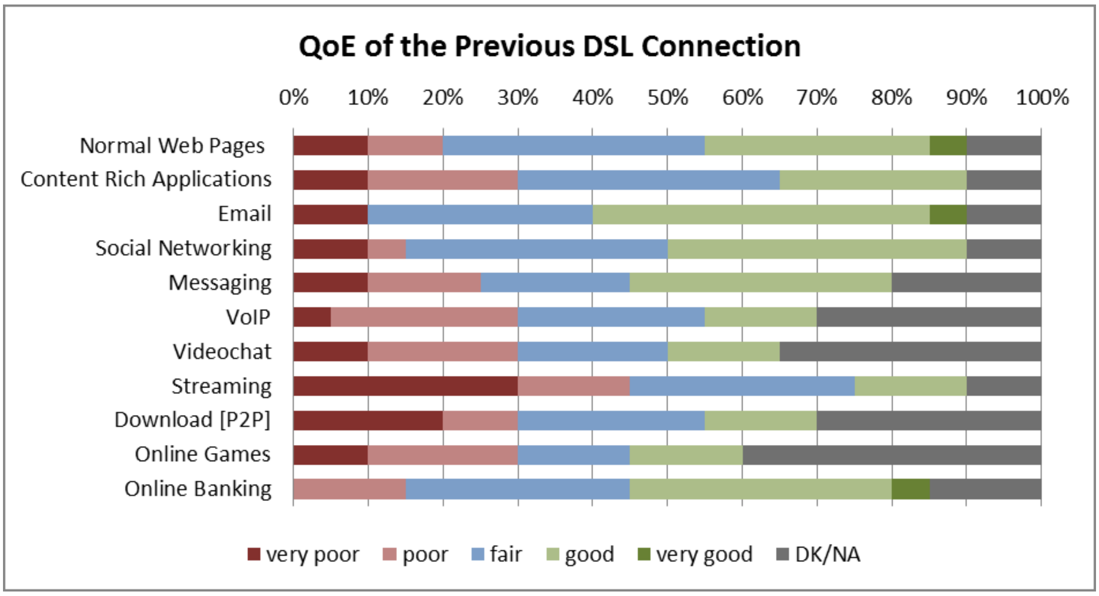


Figure 3-29 QoE for Different Internet Applications and Services with the Previous DSL Connection

3.3.1.3 BATS System Installation

The following graph shows the level of satisfaction regarding different aspects of the BATS system installation. As can be seen, the most negative outcome is related to the size of the IUG (however, it must be noted that the installed device is a prototype).

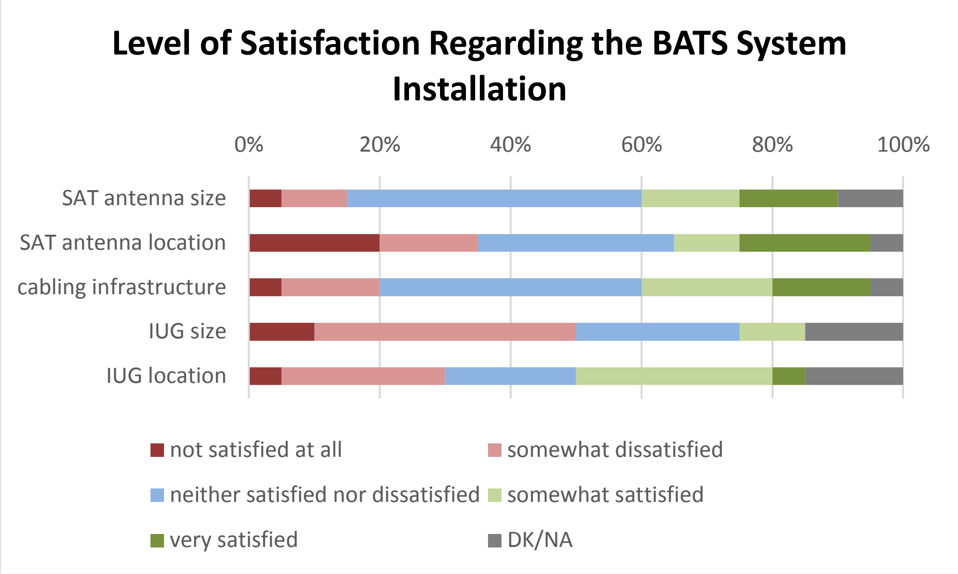


Figure 3-30 Level of Satisfaction Regarding the BATS System Installation

3.3.1.4 QoE of the BATS system

In both questionnaires, users were asked about different aspects regarding the quality of the BATS service besides a comparison between this service and their previous DSL connection.

Although the outcome for the first period of the trials was worse than expected, the results obtained for the second period are more positive for almost all the questioned aspects.

Regarding the QoE of the different categories of Internet services and applications with the BATS system, the results obtained for the second period of the trials show a slight improvement in the perceived QoE for almost all of these categories.

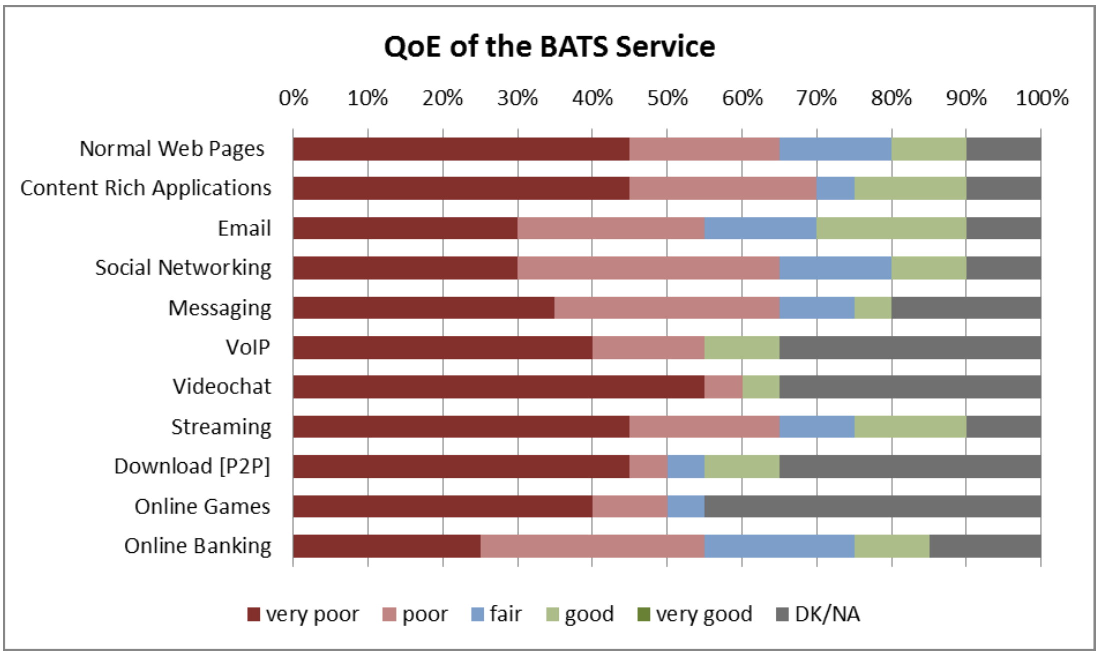


Figure 3-31 QoE for different Internet applications and services with the BATS service [First Period]

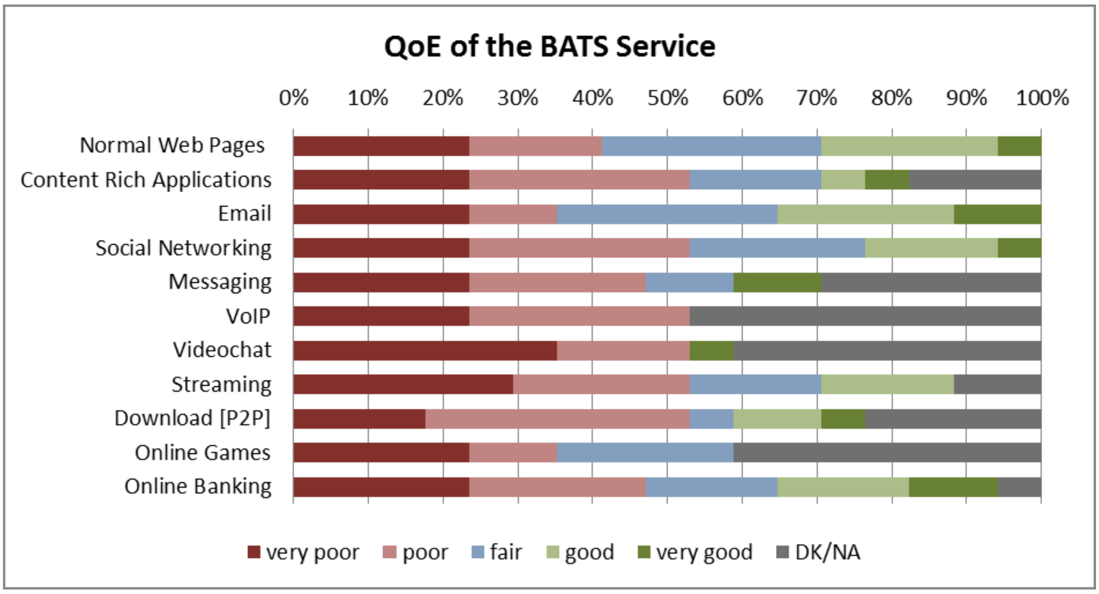


Figure 3-32 QoE for different Internet applications and services with the BATS service [Second Period]

Users were also asked to rate the QoE of these services and applications when employing the BATS service as compared to their previous DSL connection.

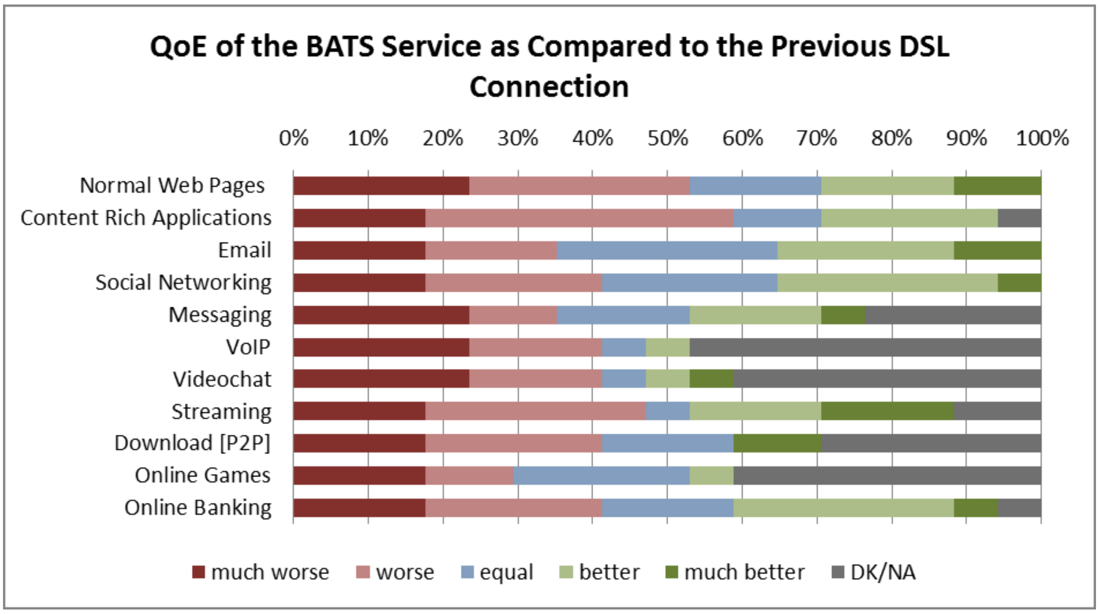


Figure 3-33 QoE for different Internet applications and services with the BATS service

Most of the user's complaints, in both periods of the trials, have been mainly related to the system stability and the response time. However, an improvement in the feedback regarding the download/upload speed for the second period can be perceived in the following figures.

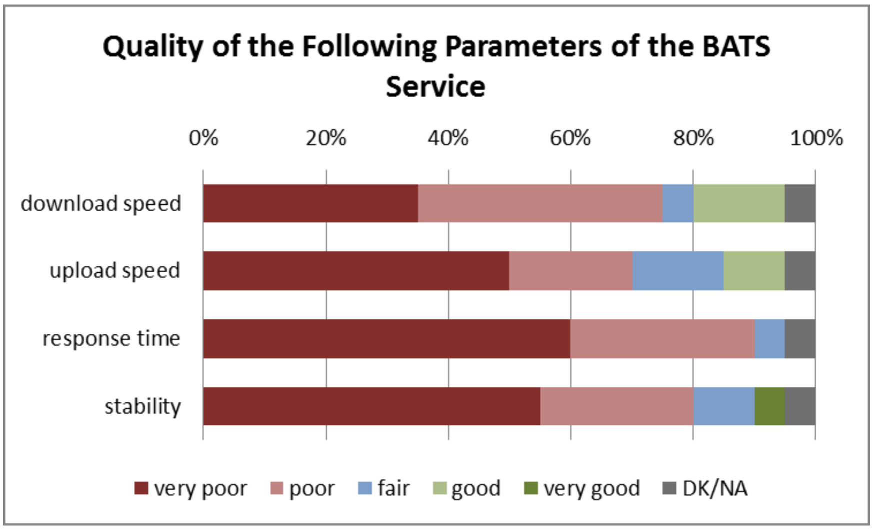


Figure 3-34 Quality of Different Parameters of the BATS Service [First Period]

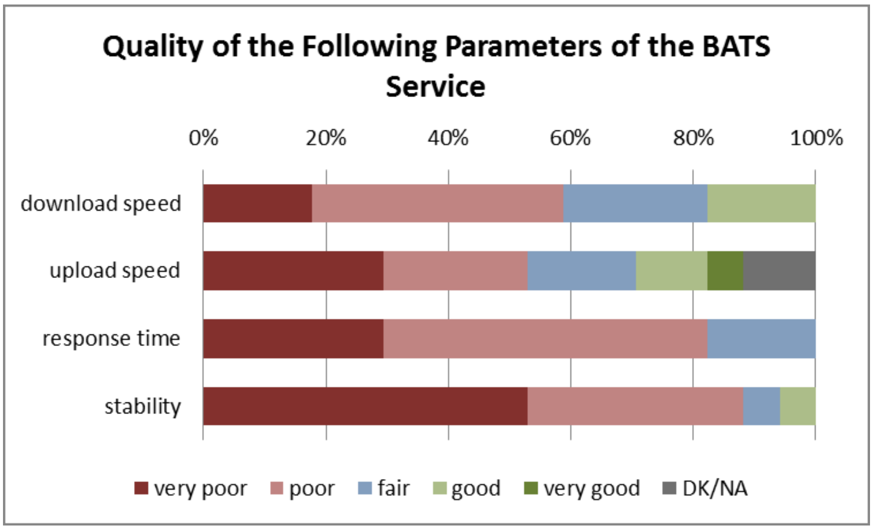


Figure 3-35 Quality of Different Parameters of the BATS Service [Second Period]

In this sense, more than 60% of the users perceived an improvement in the download speed when using the BATS service as compared to their previous DSL connection.

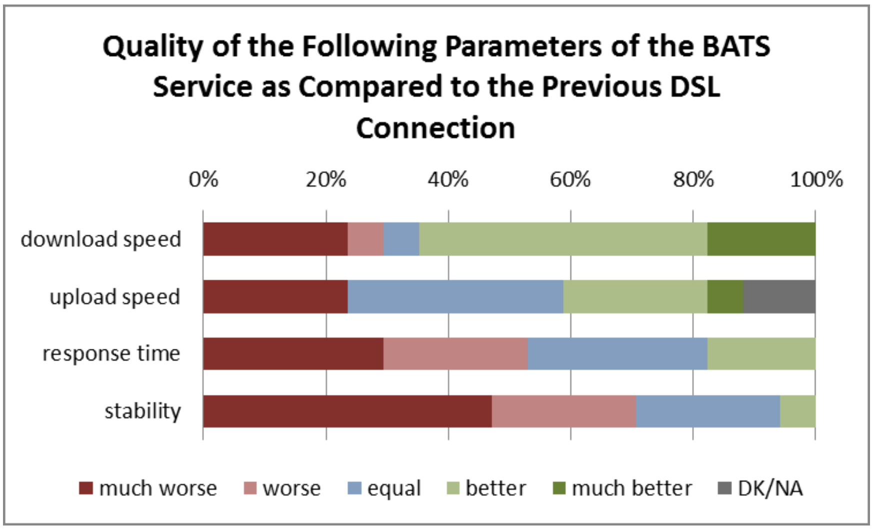


Figure 3-36 Quality of different parameters of the BATS Service as Compared to the Previous DSL Connection [Second Period]

The perception of the overall quality of the BATS system, as compared to the previous DSL connection, also shows a more positive outcome for the second period of the trials.

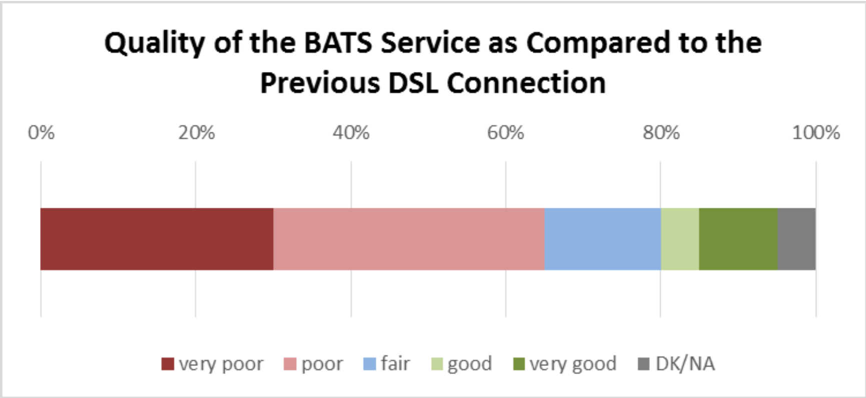


Figure 3-37 Quality of the BATS Service as Compared to the Previous DSL Connection [First Period]

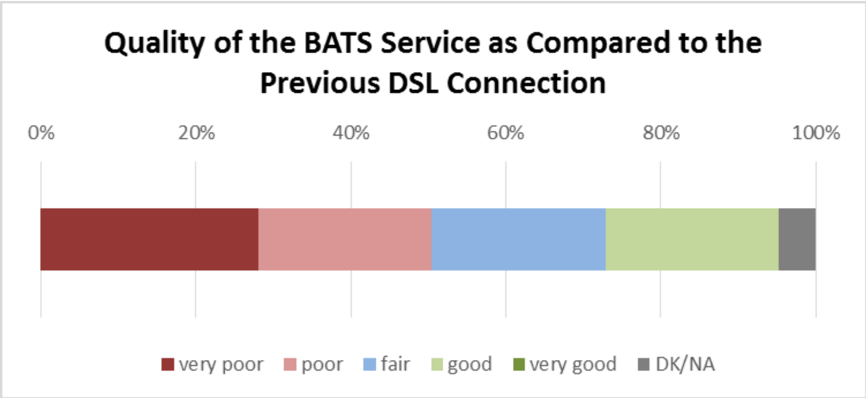


Figure 3-38 Quality of the BATS Service as Compared to the Previous DSL Connection [Second Period]

Finally, all these aspects can be summarized in the level of satisfaction regarding the BATS service.

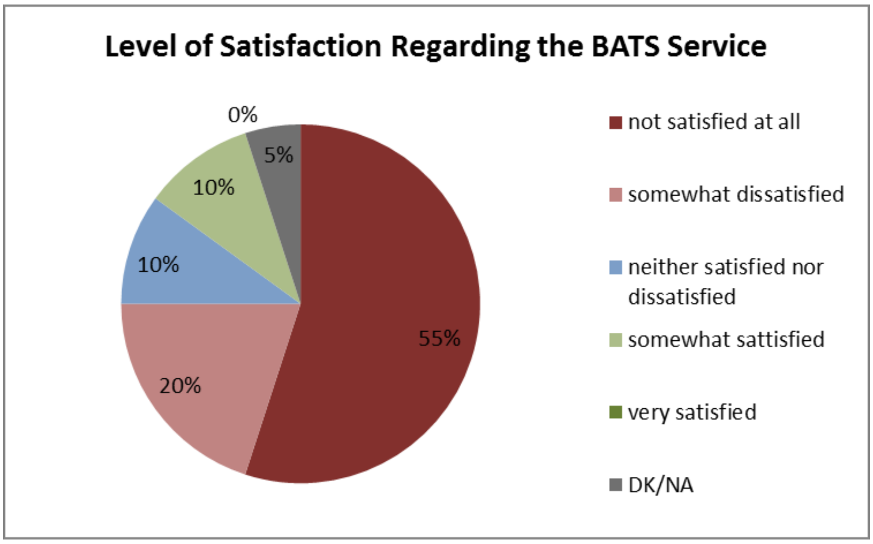


Figure 3-39 Level of Satisfaction Regarding the BATS Service [First Period]

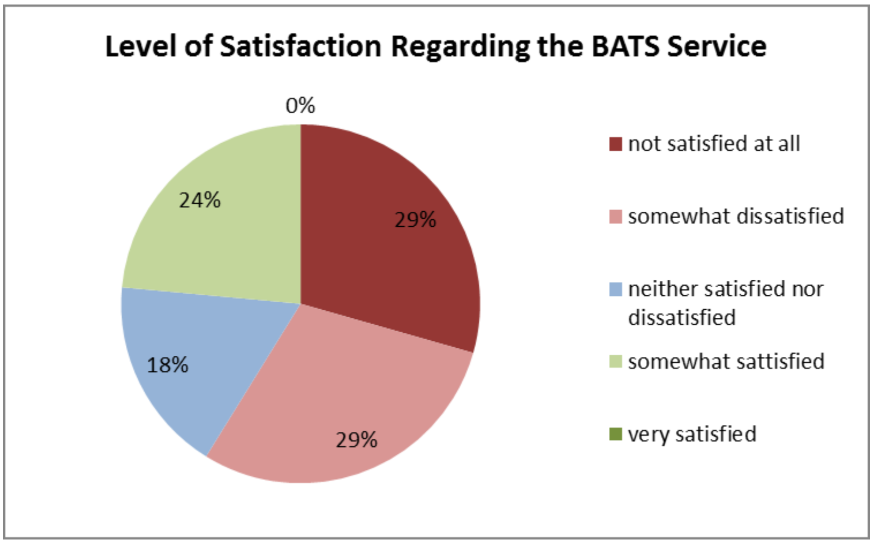


Figure 3-40 Level of Satisfaction Regarding the BATS Service [Second Period]

3.3.1.5 Level of interest in a commercial service

In order to assess the viability of the business plan, users were asked the following three questions in the final questionnaire:

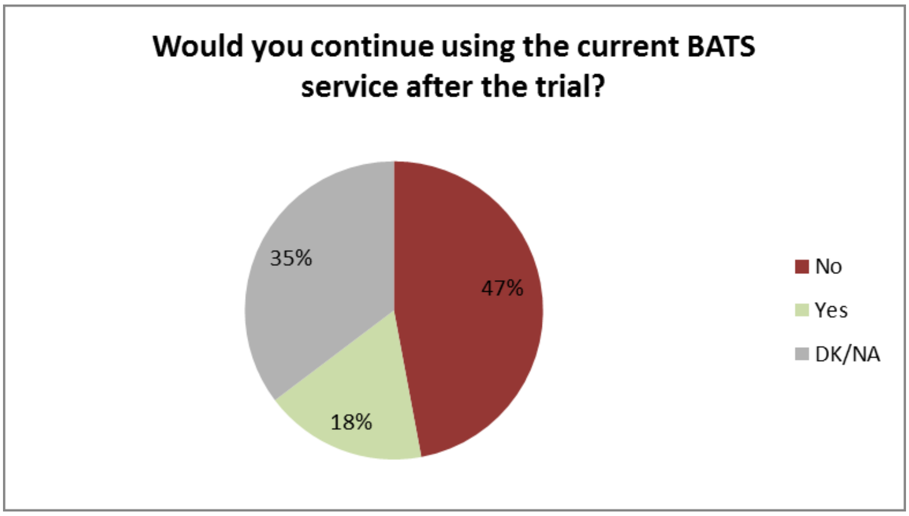


Figure 3-41 Level of interest in a commercial service (1)

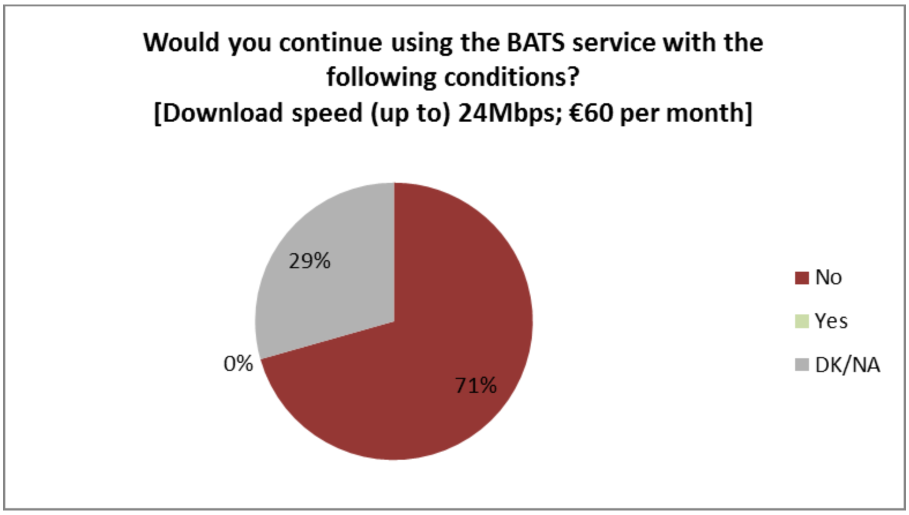


Figure 3-42 Level of interest in a commercial service (2)

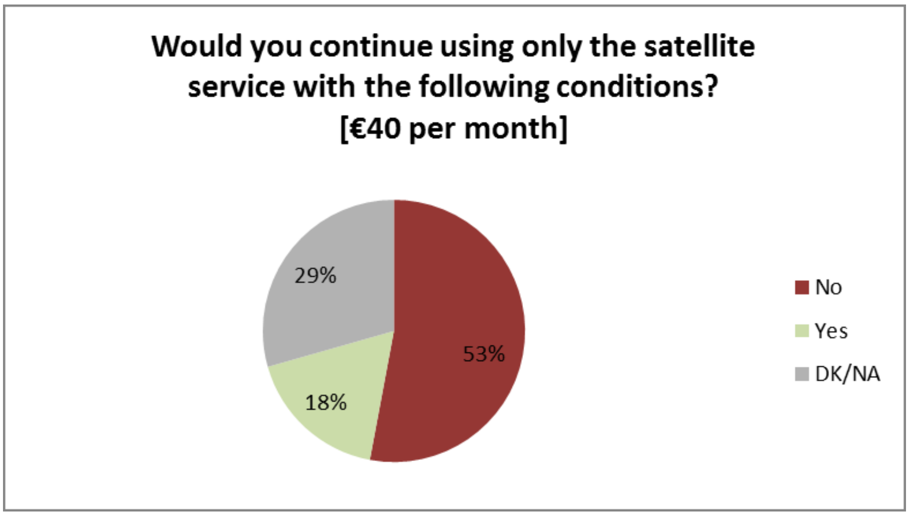


Figure 3-43 Level of interest in a commercial service (3)

3.3.1.6 Other users' feedback

As commented in section 3.1.2.4, the dedicated thread in R's technical support forum has been used as an additional channel of communication with the end-users, providing some relevant conclusions summarized in the following.

Main complaints:

- **Stability.** One of the most common reasons for dissatisfaction has been the system instability, where considerable fluctuations in download and upload rates were reported. However, some of the same users appreciate the achieved rates when the system is stable.
- **Time of response.** Some of the users have reported extremely high latencies that affect the QoE of some specific services such as videoconferencing.
- **Lack of configurability.** The available configuration options of the IUG are limited and too rigid (it does not allow port redirection, etc.).
- **WiFi router performance.** Some users perceived worse WiFi coverage than with their previous router. This fact has affected the reported QoE.

Main compliments:

- **Download and upload speed.** Some users appreciate the achieved speeds when the system is stable.
- **Improvement in the QoE** for some Internet services and applications. Most of the compliments are related to Streaming and Content Download [P2P] services.
- **Improvement in rural Internet access.** Some of the comments highlighted the importance of the system in rural areas, where a need for broadband access solutions is expressed.

3.3.2 Technical performance logs

A summary of different statistics of the traffic reported by the INGs, as commented in 3.1.2.5, is presented in this section. These statistics are shown separately for each one of the periods in which the trials have been divided. However, as can be seen in the following subsections, the obtained results, and thus the extracted conclusions, are very similar.

3.3.2.1 Daily Traffic per site

The downlink traffic is over 600MB per day in about 65% of the sites.

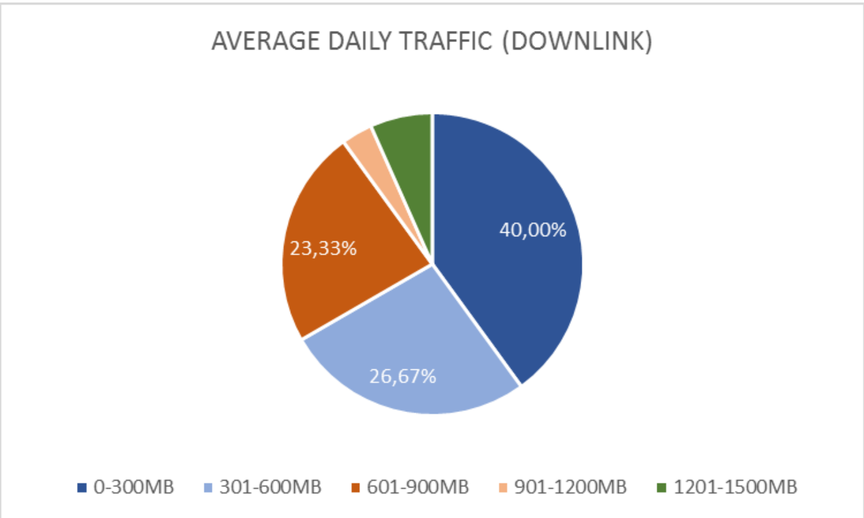


Figure 3-44 Average Daily Traffic (Downlink) [First Period]

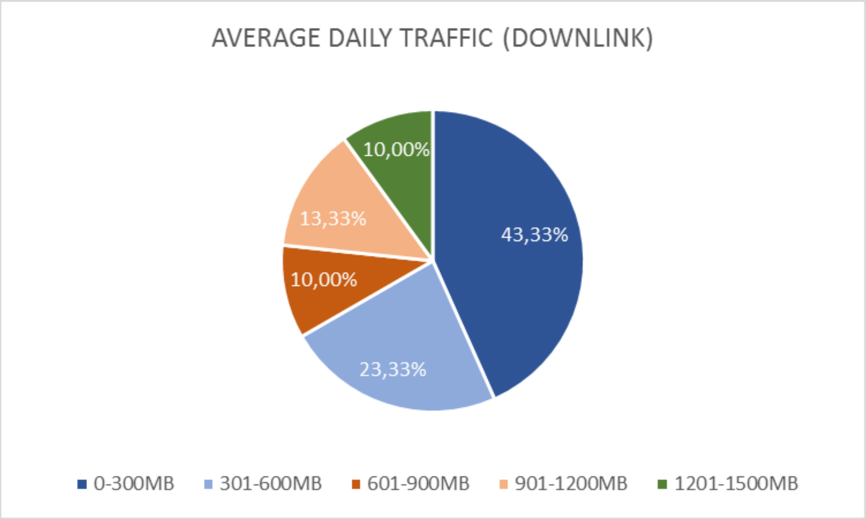


Figure 3-45 Average Daily Traffic (Downlink) [Second Period]

The uplink traffic is below 100 MB per day in about 90% of the sites.

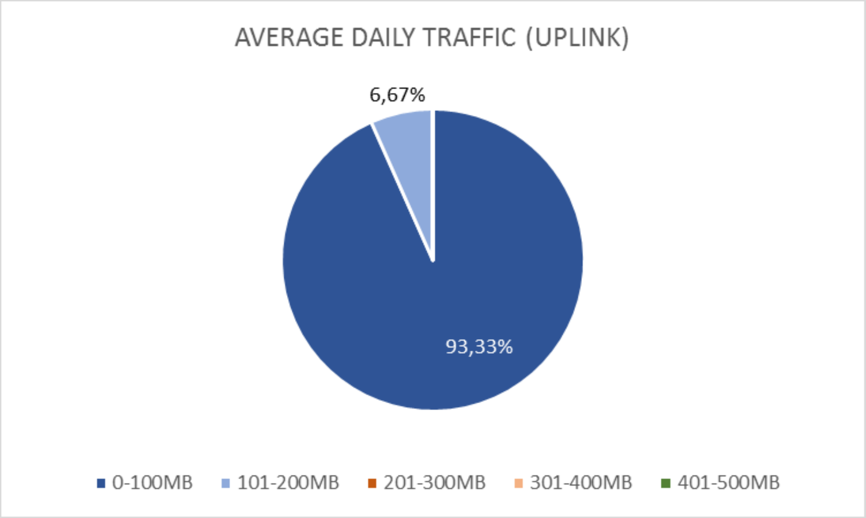


Figure 3-46 Average Daily Traffic (Uplink) [First Period]

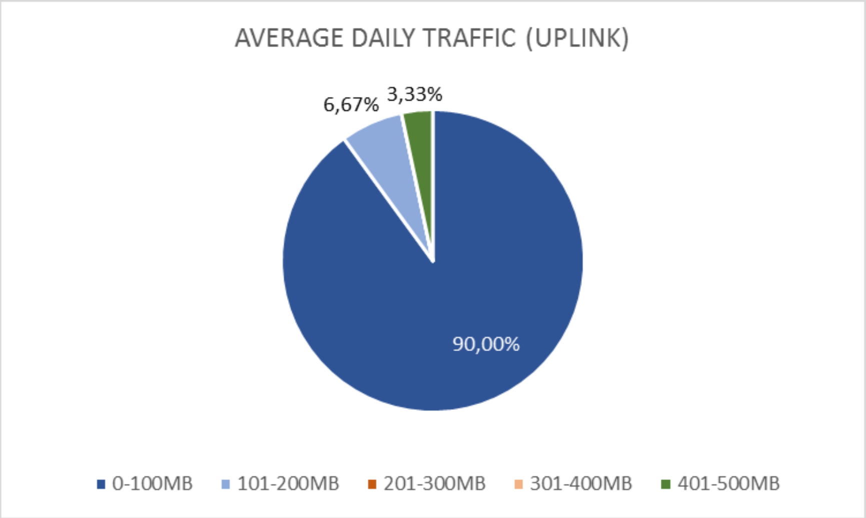


Figure 3-47 Average Daily Traffic (Uplink) [Second Period]

3.3.2.2 Percentage of traffic per link (downlink)

Satellite traffic dominates the total amount of downlink traffic (about 60%).

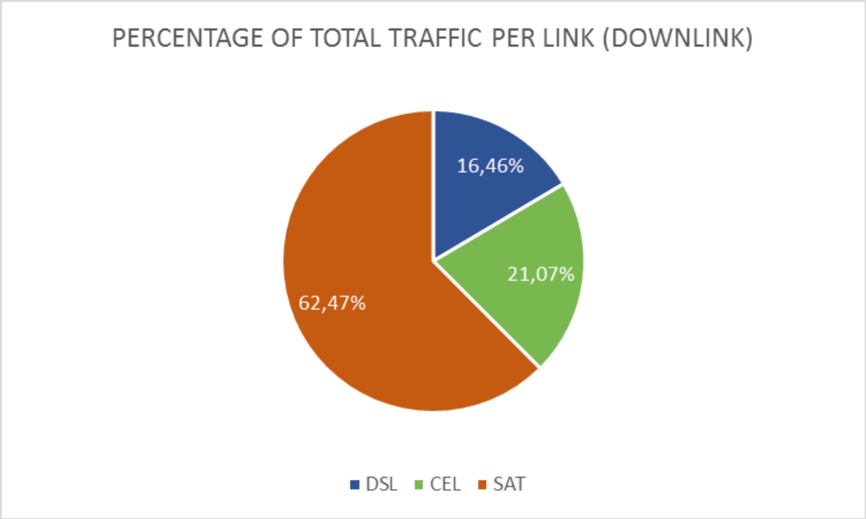


Figure 3-48 Percentage of traffic per link (Downlink) [First Period]

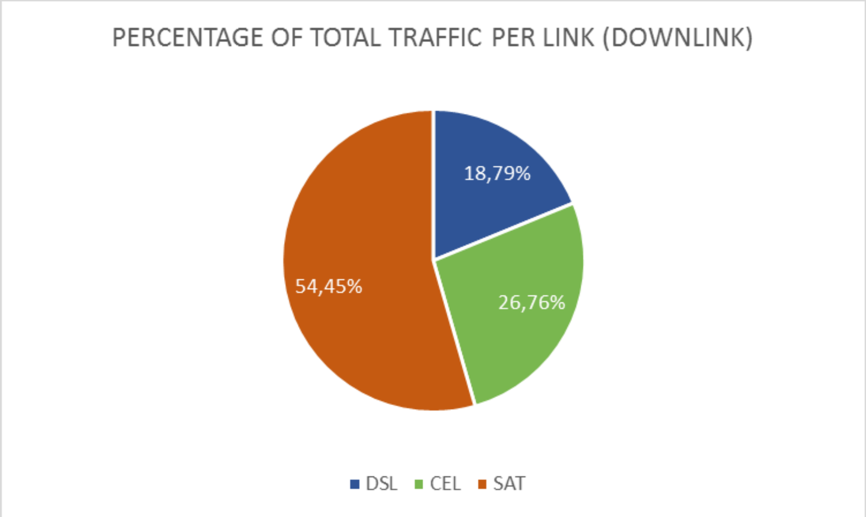


Figure 3-49 Percentage of traffic per link (Downlink) [Second Period]

The following histograms show that, in about 50% of the sites, the satellite downlink traffic is over the 60% of the total downlink traffic.

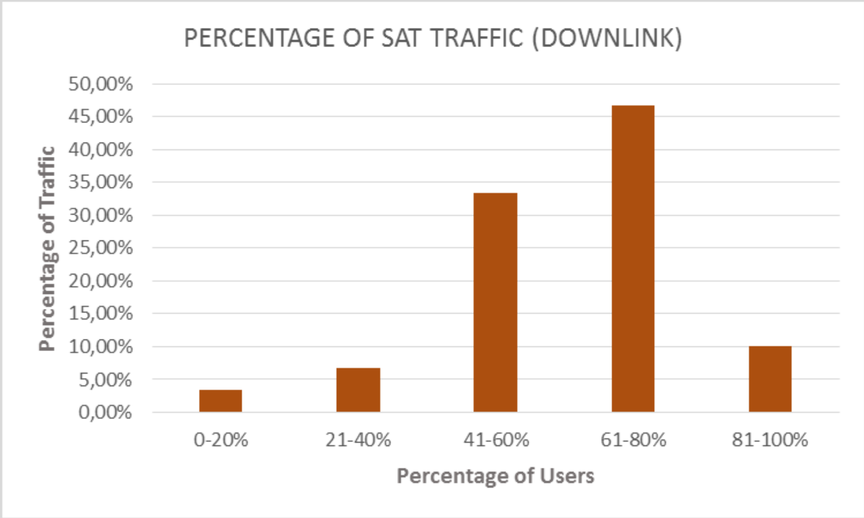


Figure 3-50 Percentage of SAT traffic (Downlink) [First Period]

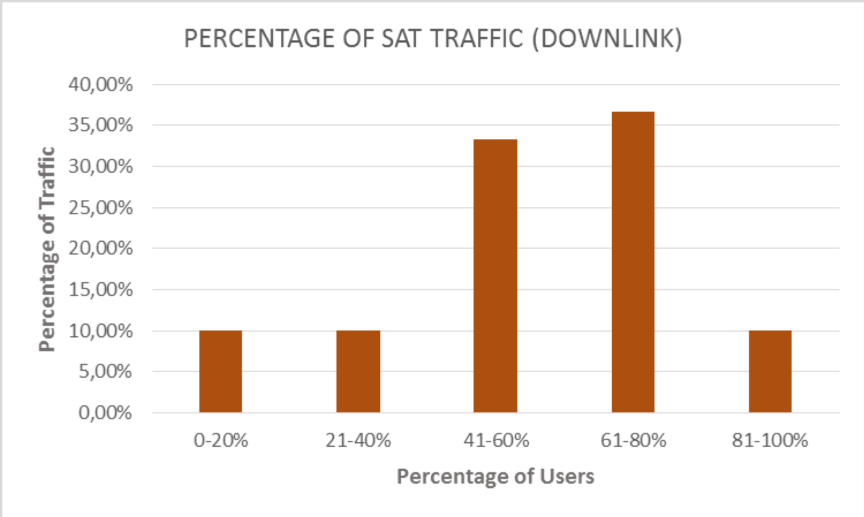


Figure 3-51 Percentage of SAT traffic (Downlink) [Second Period]

3.3.2.3 Percentage of traffic per link (uplink)

DSL traffic dominates the total amount of uplink traffic (about 50%).

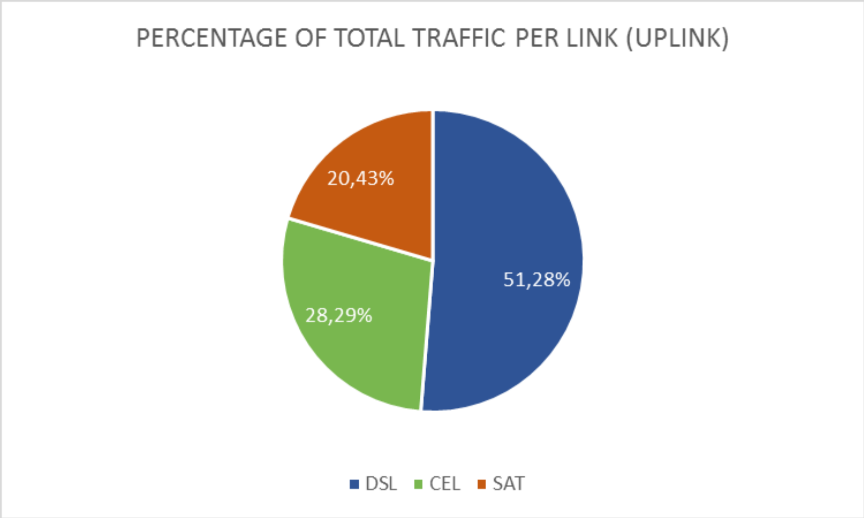


Figure 3-52 Percentage of traffic per link (Uplink) [First Period]

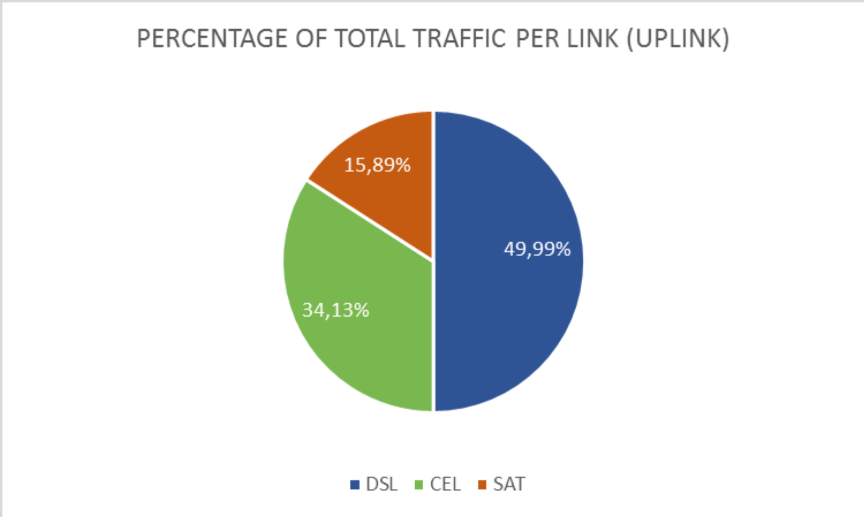


Figure 3-53 Percentage of traffic per link (Uplink) [Second Period]

The following histograms show that, in about 40-50% of the sites, the DSL uplink traffic is over the 60% of the total uplink traffic.

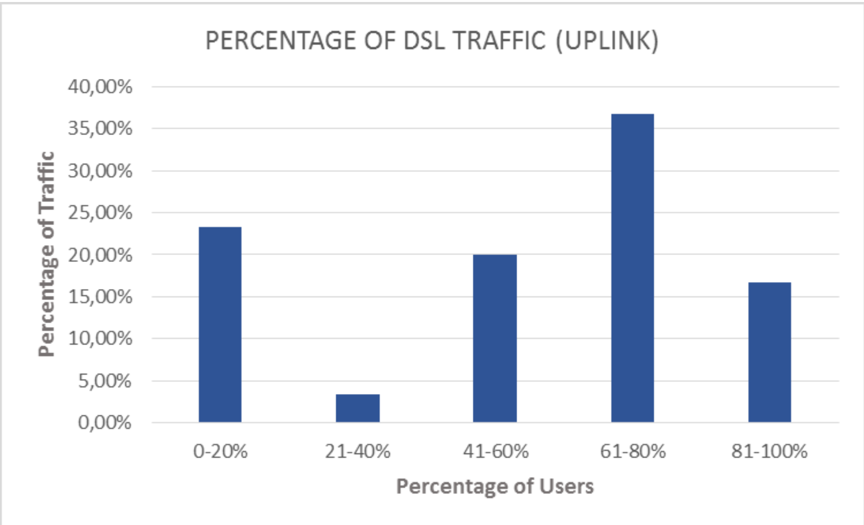


Figure 3-54 Percentage of DSL traffic (Uplink) [First Period]

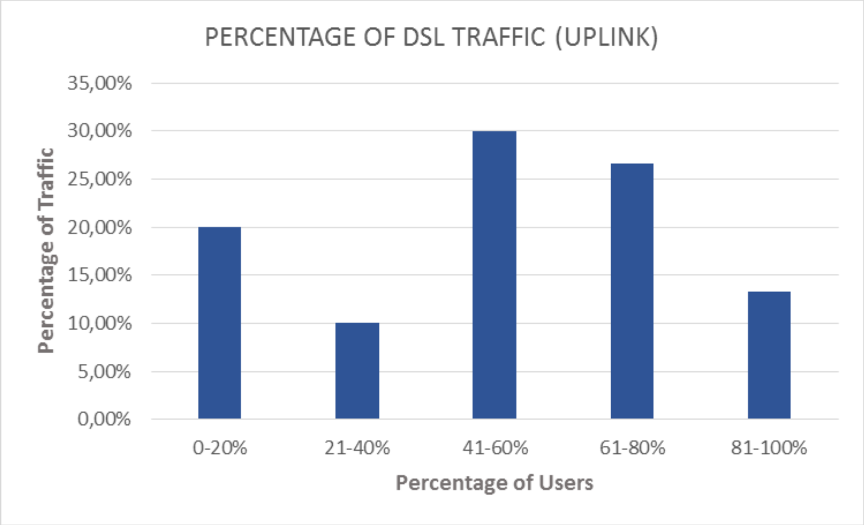


Figure 3-55 Percentage of DSL traffic (Uplink) [Second Period]

3.3.2.4 Average BW (downlink) and RTT per link

The following figures show statistics regarding the average bandwidth and RTT per link.

The reported average satellite bandwidth is over 6Mbps in about 80% of the sites, while DSL and cellular links present more variability.

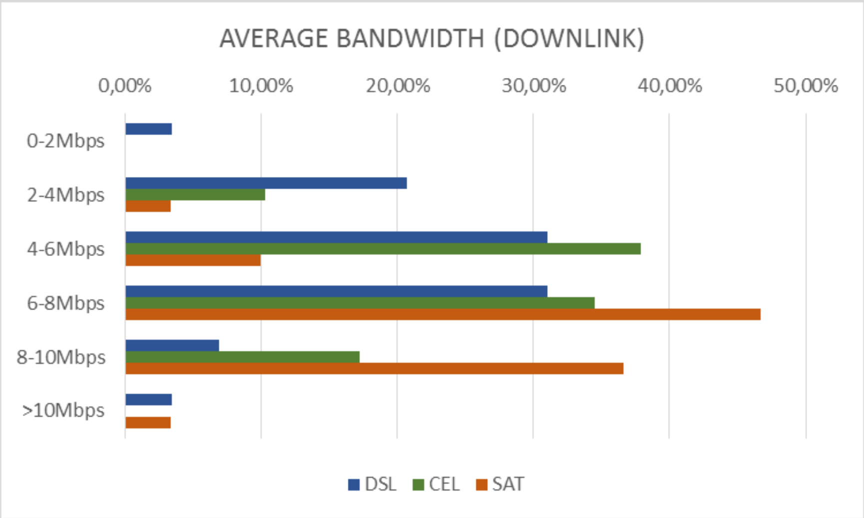


Figure 3-56 Average Bandwidth per Link[First Period]

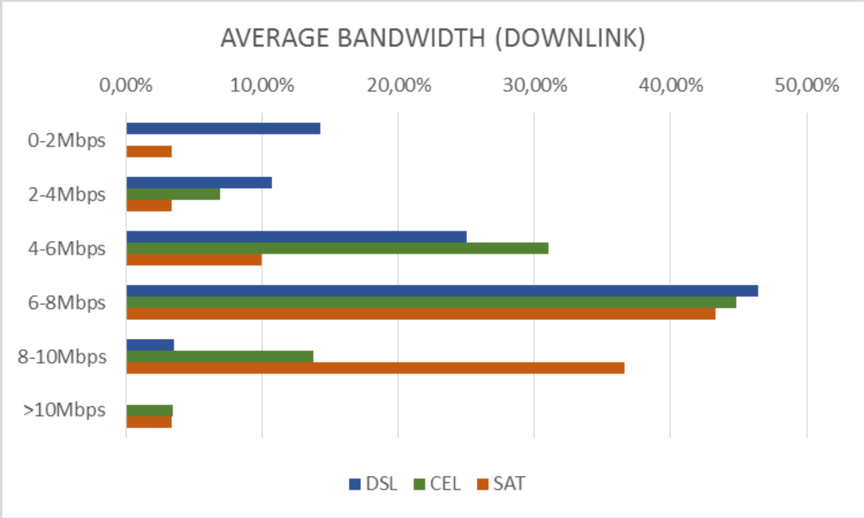


Figure 3-57 Average Bandwidth per Link [Second Period]

The reported satellite RTT is below one second in 100% of the sites, while the cellular RTT shows the higher variability.

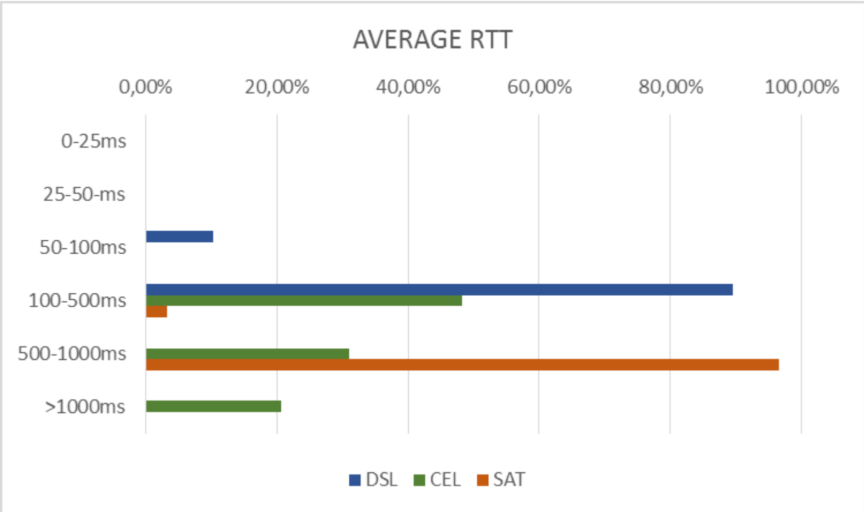


Figure 3-58 Average RTT per Link [First Period]

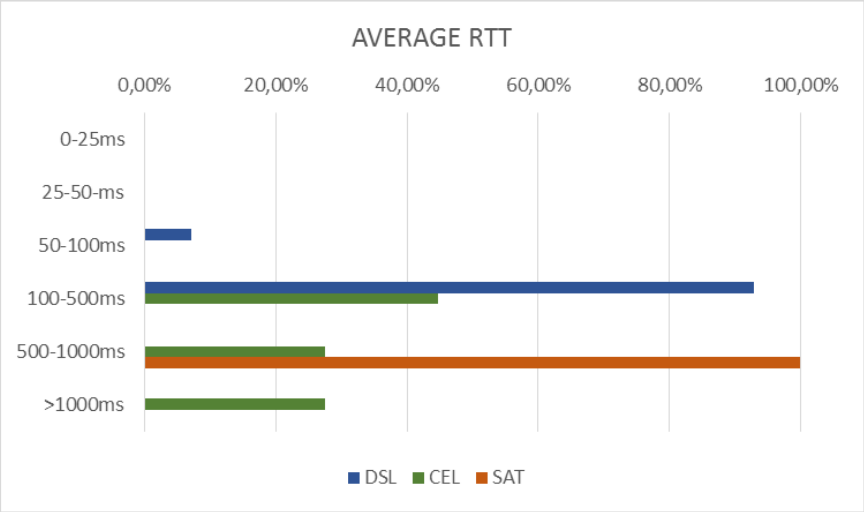


Figure 3-59 Average RTT per Link [Second Period]

3.3.2.5 Correlation between subjective and objective results

In order to find a correlation between the subjective (user feedback) and the objective (technical performance logs) results of the trials, an analysis has been carried out following the procedure described below.

A table has been created collecting the following information:

- Classification of the users based on their reported level of satisfaction regarding the BATS service:
    - 4-5: Satisfied.
    - 3: Neither satisfied nor dissatisfied.
    - 1-2: Dissatisfied.
- Other significant user feedback: quality of the BATS service as compared to DSL, users' opinion about download speed and response time.
- Some objective parameters have been included to carry out the analysis:
    - The results of the performed speedtest, the contracted DSL speed and the increase in the download speed.
    - Average values for the second period of the trials: BW (downlink), RTT, percentage of traffic per link (uplink/downlink) and total daily traffic (uplink/downlink).

Some clarifications are needed:

- Although the increase in the download speed is calculated from the contracted DSL speed, this is only a reference and the real value of the DSL link could be lower.
- The following RTT values are considered as "acceptable":

  SAT (<1500ms), CEL (<500ms) and DSL (<100ms).

  In the table, values of CEL RTT higher than 500ms and DSL RTT higher than 300ms are highlighted.
- The number of analyzed users corresponds to the number of received answers. However, the findings may not be conclusive with such a low number of users.
- The following users should not be included in the analysis:

- ES_12: Only four reported days of activity in this period.
- ES_33: Only one reported day of activity in this period.

The performed analysis yields the following conclusions:

- The high level of satisfaction could be related to the following reasons:
  - A clear increase in the download speed.
  - At least two links (SAT and CEL/DSL) with a good BW.
  - Acceptable RTT values. ES_7 is an exception (high CEL RTT) but only 1.5% (uplink) and 4% (downlink) of the traffic is routed by this link.
- The low level of satisfaction could be related to at least one of the following reasons:
  - No perceptible increase in the download speed (ES_33, ES_18, ES_14), but there are some exceptions (ES_22, ES_12 or ES_35).
  - High RTT for the CEL link and a considerable amount of traffic routed by this link (ES_6, ES_14, ES_8, ES_33). Users such as ES_1 or ES_7 are not included in this category (despite of the high CEL RTT, a low amount of traffic is routed by this link).
  - Five users have consumed their mobile data plan (10GB) at least once during the trials period. Four of these five users are dissatisfied with the system (ES_14, ES_18, ES_30, ES_33).

Table 3-1 Correlation between subjective and objective results (part 1)

USER	SPEEDTEST RESULTS	CONTRACTED DSL SPEED	INCREASE IN DOWNLOAD SPEED	How would you rate your level of satisfaction regarding the BATS service? (1-5)	In general terms, how would you rate the quality of the BATS service as compared to your previous DSL connection? (1-5)	How would you describe the following aspects of the BATS service as compared to your previous DSL connection? [DL Speed] (1-5)	How would you describe the following aspects of the BATS service as compared to your previous DSL connection? [Response Time] (1-5)
ES_25	6,02	3	3,02	4	3	3	3
ES_2	5,3	3	2,3	4	4	3	2
ES_7	6,08	1	5,08	4	4	4	1
ES_24	6,45	1	5,45	4	4	3	2
ES_26	5,42	3	2,42	3	3	2	2
ES_20	4,92	6	-1,08	3	4	2	3
ES_31	6,26	3	3,26	3	3	2	2
ES_22	9,97	3	6,97	2	3	4	2
ES_30	4,18	3	1,18	2	1	3	3
ES_1	4,71	3	1,71	2	2	2	2
ES_12	8,16	3	5,16	2	2	2	2
ES_35	4,98	1	3,98	2	2	4	2
ES_6	Didn't work	3	------	1	1	1	1
ES_14	2,5	3	-0,5	1	1	1	1
ES_18	4,45	4	0,45	1	1	2	1
ES_33	0,855	1	-0,145	1	1	1	1
ES_8	5,79	3	2,79	1	2	2	2

Table 3-2 Correlation between subjective and objective results (part 2)

USER	AVERAGE DSL BW (Mbps)	AVERAGE CEL BW (Mbps)	AVERAGE SAT BW (Mbps)	AVERAGE DSL RTT (ms)	AVERAGE CEL RTT (ms)	AVERAGE SAT RTT (ms)	AVERAGE DAILY TRAFFIC [DOWNLINK] (MB)	AVERAGE DAILY TRAFFIC [UPLINK] (MB)
ES_25	4,23	5,83	8,34	131,35	126,69	750,84	1121,11	19,90
ES_2	7,50	9,47	8,47	280,28	123,50	740,26	321,47	5,97
ES_7	1,50	3,72	7,34	162,25	**1381,89**	730,47	593,45	15,53
ES_24	2,28	2,87	5,28	153,34	403,09	775,60	986,10	24,35
ES_26	6,48	8,66	9,74	146,51	**827,34**	743,02	498,43	23,73
ES_20	6,25	7,88	8,54	130,40	127,85	748,04	1270,69	8,84
ES_31	6,41	6,24	8,22	**408,86**	**904,19**	754,51	884,22	19,20
ES_22	4,54	6,95	6,95	215,40	243,57	782,35	555,38	136,24
ES_30	3,57	5,60	7,78	213,47	373,68	738,01	1442,05	170,50
ES_1	7,08	5,52	8,08	145,39	**18377,67**	788,64	107,08	4,74
ES_12	4,36	7,85	**0,91**	145,06	**5924,29**	45,89	74,14	3,68
ES_35	1,94	4,49	5,76	138,24	406,25	706,59	156,71	20,37
ES_6	5,70	6,83	8,03	187,64	**1737,98**	915,83	399,41	89,24
ES_14	7,00	5,65	6,80	**385,15**	**599,41**	807,36	757,90	449,13
ES_18	6,18	6,94	7,32	84,90	283,89	784,87	1110,14	11,40
ES_33	0,00	6,47	10,21	0,00	**675,82**	735,12	53,89	3,34
ES_8	6,47	7,62	7,78	146,75	**2879,00**	789,22	161,23	5,08

Table 3-3 Correlation between subjective and objective results (part 3)

USER	PERCENTAGE OF DSL TRAFFIC [UPLINK] (%)	PERCENTAGE OF CEL TRAFFIC [UPLINK] (%)	PERCENTAGE OF SAT TRAFFIC [UPLINK] (%)	PERCENTAGE OF DSL TRAFFIC [DOWNLINK] (%)	PERCENTAGE OF CEL TRAFFIC [DOWNLINK] (%)	PERCENTAGE OF SAT TRAFFIC [DOWNLINK] (%)
ES_25	49,89	40,68	9,42	7,75	11,67	80,58
ES_2	47,13	43,14	9,73	11,98	25,17	62,86
ES_7	70,78	**1,46**	27,76	14,66	**4,01**	81,33
ES_24	32,42	0,01	67,57	6,33	0,15	93,51
ES_26	60,89	**28,19**	10,92	18,92	**13,91**	67,17
ES_20	52,43	29,83	17,74	9,24	12,65	78,11
ES_31	**36,63**	**44,73**	18,64	**11,51**	**20,18**	68,31
ES_22	1,44	64,92	33,64	0,44	39,84	59,72
ES_30	46,19	38,34	15,47	13,87	21,09	65,04
ES_1	94,37	**0,00**	5,62	47,46	**0,72**	51,82
ES_12	79,80	**19,87**	0,33	53,42	**46,24**	0,35
ES_35	82,93	1,66	15,42	22,39	0,84	76,78
ES_6	57,18	**26,89**	15,93	36,28	**20,49**	43,23
ES_14	**48,19**	**28,83**	22,97	**28,80**	**30,93**	40,26
ES_18	71,24	16,39	12,37	15,30	26,48	58,22
ES_33	0,00	**52,01**	47,99	0,00	**69,64**	30,36
ES_8	73,22	**21,18**	5,61	26,70	**21,89**	51,42

3.3.3 Technical issues found, system failures and support experience

Some technical issues have been found during the Spanish Field Trials. Two of them, as commented in section 3.1.2.2, arose during the installation phase:

- VoIP: The automatic QoS control currently implemented was insufficient for the VoIP service offered by R.
- LAN configuration: The available configuration options of the IUG were limited and too rigid for SoHo users (port redirections, etc.).

  Due to these reasons, some users, most of them SoHo, abandoned the trials. Furthermore, the lack of configurability, a repeated complaint as described in section 3.3.1.6, also has caused dissatisfaction among some advanced users.

- Mobile data plan: During the second month of the trials, some users complained about a high variability in the speed of the service. It was found that these users had exceeded their mobile data plan (the speed of the service is reduced once the user has reached 10GB/month), so each one of these data plans had to be reset. In order to analyse the specific traffic patterns of these users and to rule out any system malfunction, some statistics were obtained through the technical performance logs and the tool Zabbix, as described in section 3.1.2.5. **Error! Reference source not found.** and **Error! Reference source not found.** show different traffic and link statistics for two of the users in question during the month of October. Figure 3-60 and Figure 3-61 show graphically the total traffic and the percentage of traffic per link for the same period (October). Figure 3-62 and Figure 3-63, generated by Zabbix, show the amount of downlink (green) and uplink (blue) cellular traffic every 5 minutes since October 20.

Table 3-4 Cellular Traffic Statistics (October)

	Total Cellular Traffic (GB)	Cellular Downlink Traffic (GB)	Cellular Uplink Traffic (GB)
IUG14	17.08	5.10	11.98
IUG30	16.79	12.14	4.65

Table 3-5 Cellular and Satellite Link Statistics (October)

	Average Cellular Bandwidth (Mbps)	Average Satellite Bandwidth (Mbps)	Number of days where CEL BW > SAT BW
IUG14	5.46	7.15	10
IUG30	5.35	7.13	7

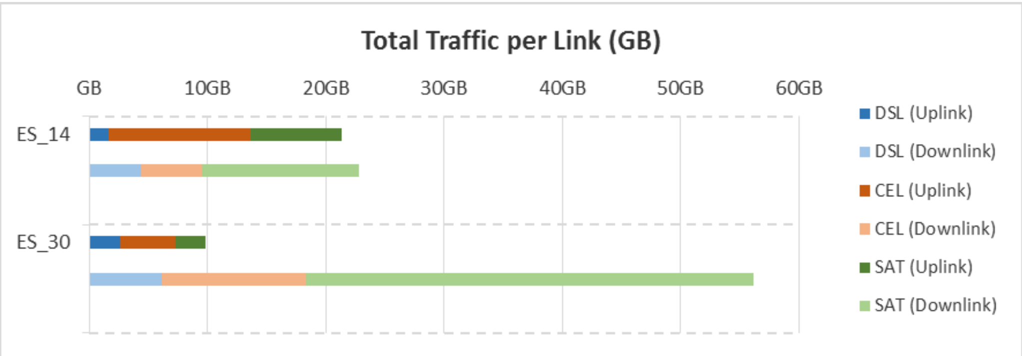


Figure 3-60 Total Traffic per Link (October)

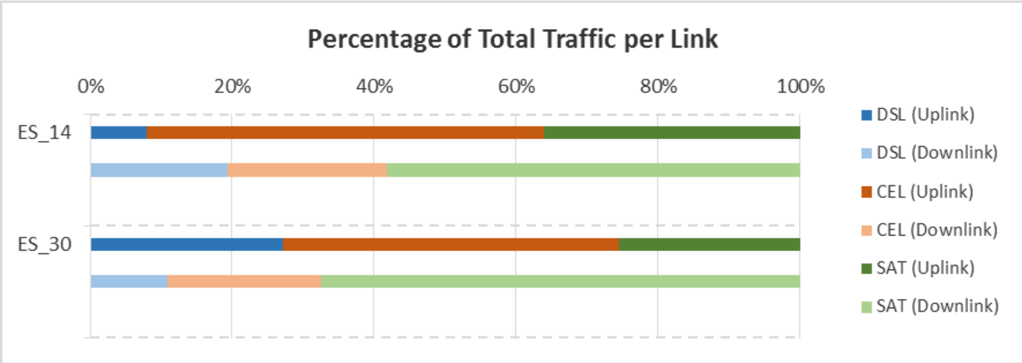


Figure 3-61 Percentage of Total Traffic per Link (October)

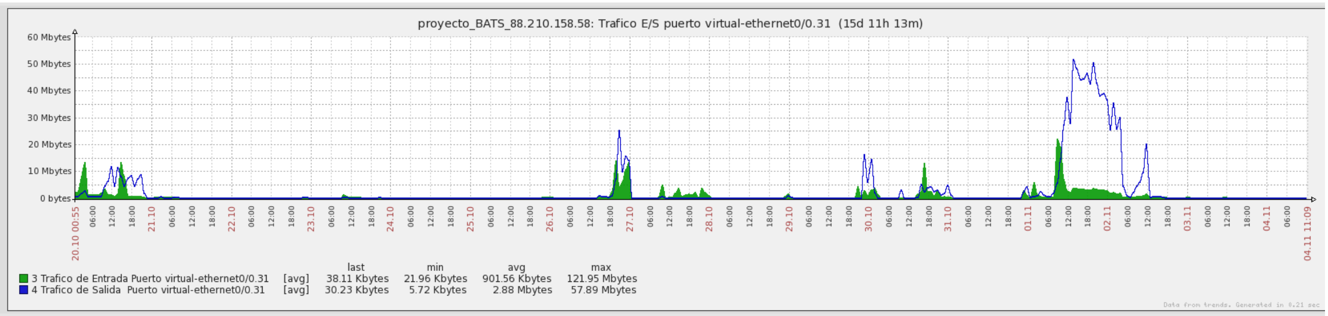


Figure 3-62 In/Out Cellular Traffic (ES_14)

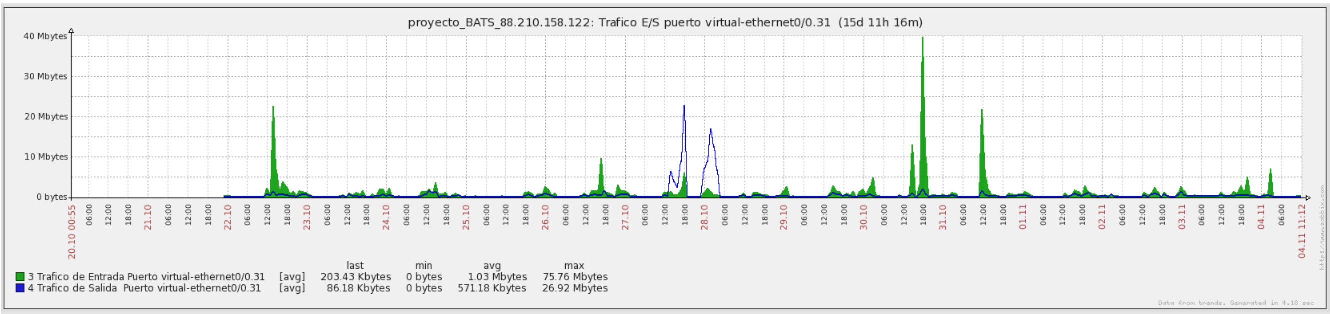


Figure 3-63 In/Out Cellular Traffic (ES_30)

The presented particular cases exemplify two different patterns found among the analysed group of users:

- ES_30 shows a significant amount of monthly traffic (65GB), where the ratio of downlink (85%) and uplink (15%) traffic is highly asymmetric. Due to this, most of the cellular traffic corresponds to downlink (12GB), as can also be seen in Figure 3-63. The satellite link provides a better average bandwidth than the cellular one but, as **Error! Reference source not found.** shows, the cellular bandwidth is higher than the satellite bandwidth near one fourth of the days.
- ES_14 also shows a high amount of monthly traffic (44GB) but the ratio of downlink (51%) and uplink (49%) traffic is almost symmetric. In this case, the cellular uplink traffic (12GB) represents most of the total cellular traffic. As can be seen in Figure 3-62, during the shown period, there were some significant peaks of cellular uplink traffic, reaching 6GB only in one day. The bandwidth figures for the satellite and cellular links are very similar to the previous case.

In both examples, the 10GB monthly data consumption responds to the high amount of traffic generated and the bandwidth characteristics of the links.

A screenshot of the online ticket managing platform employed by R during the trials is shown below.

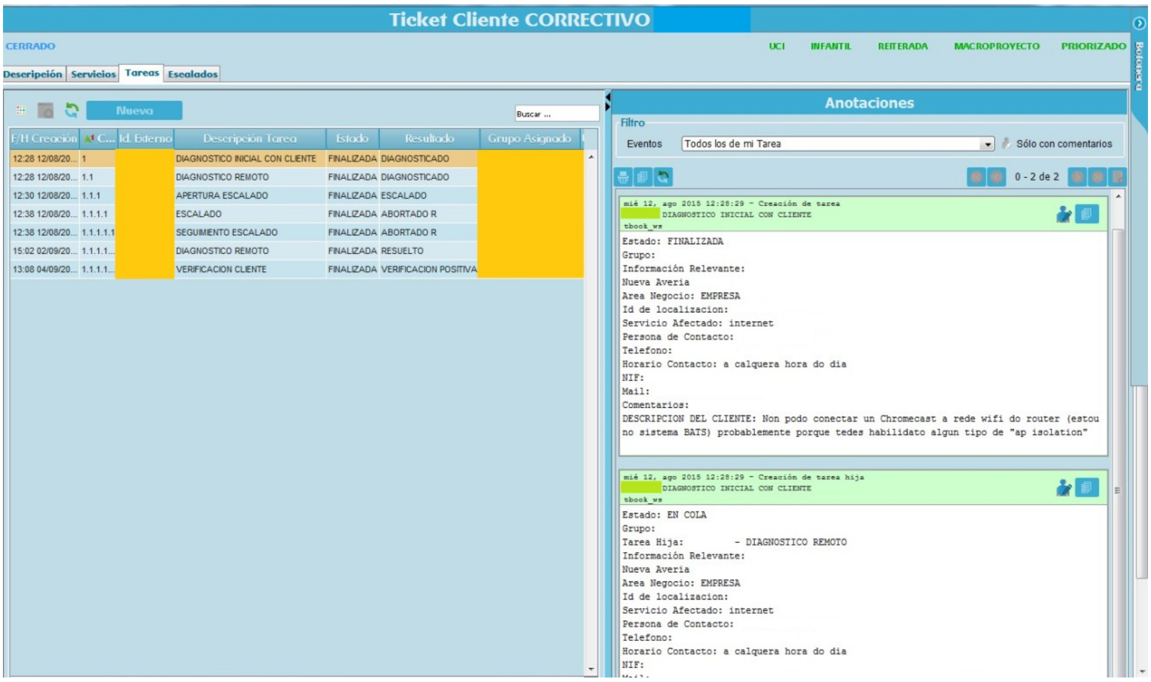


Figure 3-64 Online Ticketing System Employed by R

3.3.4 Field trials in Spain key findings

The number of technical issues found and the nature of the complaints received during the Field Trials are common characteristics of the typical instability of first deployments. As an example of this, Figure 3-65 shows the ratio between support/incident tickets and the number of active devices in the deployment of a new commercial cable router during the first 40-weeks. It can be seen that the first 3-4 months present significant peaks of customer tickets and that these tickets gradually stabilize after this period.

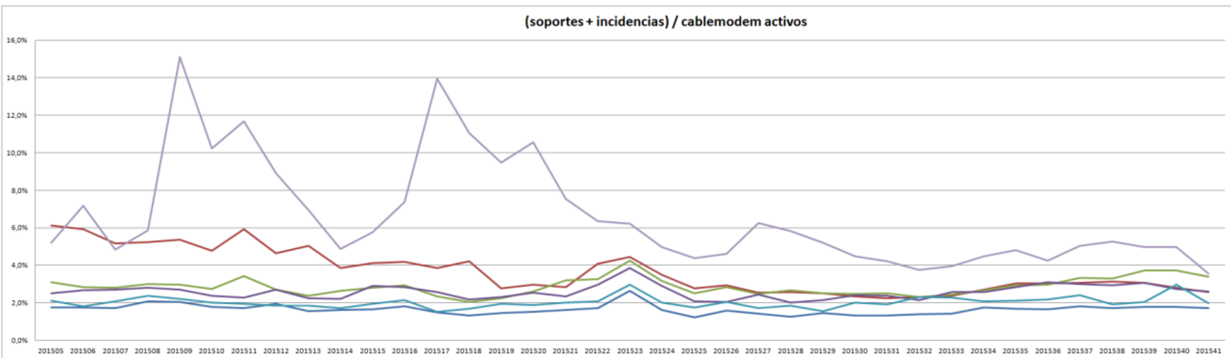


Figure 3-65 Ratio Between Support Tickets and Number of Active Devices in the Deployment of a New Commercial Cable Router

The system achieved a fully stable status with software version 7.1.5, about 2 months after the installation of the first IUG. Users were well aware of the R&D nature of the service so complaints were not the same as in a commercial service. However, they expected, although unstable, a very high speed service, may be not reaching 30Mbps but exceeding what is normally found in satellite speeds.

The BATS service was using all 3 links in a different way. It allowed for more overall throughput, but it did not increase significantly enough peak speed above standard satellite speed.

To explain this fact, a marketing campaign was launched to improve users' perception of the system, communicating how the system actually works and which is its current expected performance. An improvement in the results of the final questionnaire, with respect to the intermediate one, was perceived due to the higher level of stability of the system and the communication campaign carried out. Many users also acknowledged the efforts taken by EU in order to improve rural broadband service. In users' own words:

> *Entiendo que es una prueba y animo a que sigáis investigando, realmente en el rural también son necesarios servicios de alta velocidad y gracias a compañías como la vuestra tenemos una pequeña esperanza. Gracias por todo.*
>
> *I understand that this is a test and I encourage you to keep researching. In the rural, broadband services are also necessary and, thanks to companies like yours, we still have some hope. Thanks for all.*
>
> *O mellor exemplo, aínda que so sexa unha proba, é o PROXECTO BATS, unha marabilla no rural.*
>
> *The best example, even it is only a trial, is the BATS PROJECT, a marvel in the rural.*

The main findings obtained through the users' feedback and the technical issues arisen during the trials are summarized in the following:

- There is demand for effective broadband access solutions in rural areas. The positions for the trials were filled up in 3 days and during the trials many commercial personnel at R kept asking if the BATS system was going to have a commercial launch, due to demand from customers. Many people get engaged in the promise of "satellite speeds with DSL ping" which is our summary of the current BATS promise;
- Users have appreciated the achieved download and upload speeds, reporting an improvement in the QoE mainly for some Internet services and applications (especially for Streaming and for Content Download [P2P] services);
- In other cases, where considerable fluctuations in these speeds have been reported, the system instability has affected the user experience. This is business as usual in new equipment launches and it is not realistic to obtain a 3 months stable trial even with standard commercial equipment in the first software release of the equipment;
- The trials have demonstrated that the initial design is not enough to cover functionalities for SoHo customers. More concretely, the IUG needs many more configuration options (ports configuration, VPN configuration, specific QoS configuration for VoIP) to satisfy SoHo customers;
- Some users were evaluating BATS by the WIFI performance. This is again business as usual and many cable networks get poor feedback because customers rate the cable service exclusively by the speed obtained though WIFI. Further advanced broadband service trials have to assure that the WIFI component is best of class.

Overall, the perception obtained by R as a "user operator" is that:

- The BATS service concept is commercially viable.
- The support tools are key for the operator. As the BATS service uses several networks in parallel, it is key to have an automatic diagnostic tool in order to resolve customer tickets in acceptable time.

- The BATS business plan depends on the system using as much as possible the DSL link. Excessive cellular/satellite data traffic could affect the viability of a cost-effective solution.

3.4 Key commonalities and differences between German and Spanish field trials findings

3.4.1 Initial Setup & User Profiling

The setup of CPE in Spain was performed by R who was also the operator of the service , whilst in Germany the CPE was set up by a partner of Avanti, this differentiation could be seen clearly in the user engagement, user responsiveness, and the understanding of the user characteristics.

In a system like BATS where we are combining all the three links tor the user, it is very important to understand the user characteristics that this addresses and dimension the home network accordingly. An example was SOHO users in Spain that required advanced routing features and could be eliminated at a much early time within the trail as compared to similar users in Germany.

3.4.2 Internet Usage

The internet usage characteristics of the German and the Spanish users appear to be almost identical where 44-47% of the users spend more than 60 hours a week on the internet which relates to 8.5 hours a day on the internet which also suggests that the majority of the users in the BATS trials were heavy internet users and not outliers. The results can be seen in comparisons.

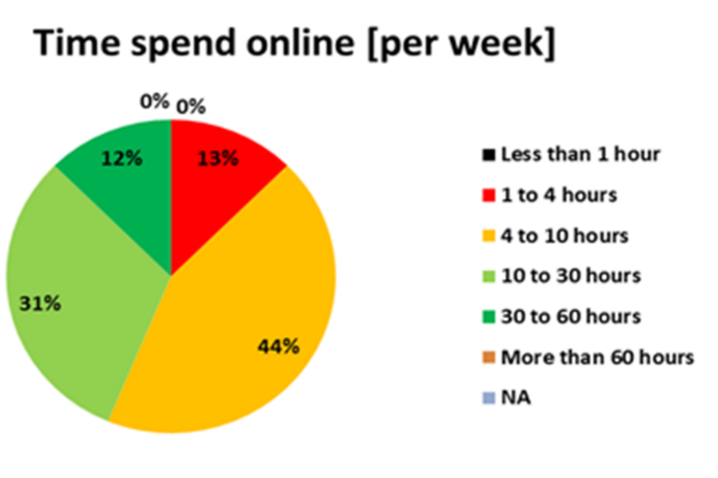


Figure 3-66 Germany

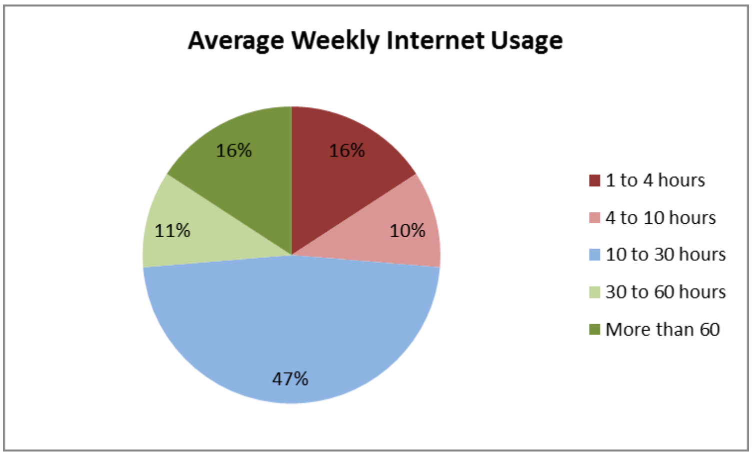


Figure 3-67 Spain

3.4.3 System Installation

Users perspective on the system installation was mostly positive in regards to the antenna size, location etc., the only negative aspect was the size of the IUG.

3.4.4 QoE of BAT's compared with previous DSL service connection..

When we compare the QoE as compared with the previous connection we can see that the QoE for the users experience improved for most of the f applications, but the most marked improvement was in the Download and Streaming applications. If we compare the two trial areas then the QoE for German users was more positive as compared to the Spanish users. One reason for this was the perceived QoE for the Spanish users was much higher than the users in Germany as in Spain the users were given 3 months of 10 Mbps / 2 Mbps satellite-only connection prior to the introduction of the IUG's at their premises.

Video Chatting and VoIP are the only applications where the QoE was not positive from the end users perspective.

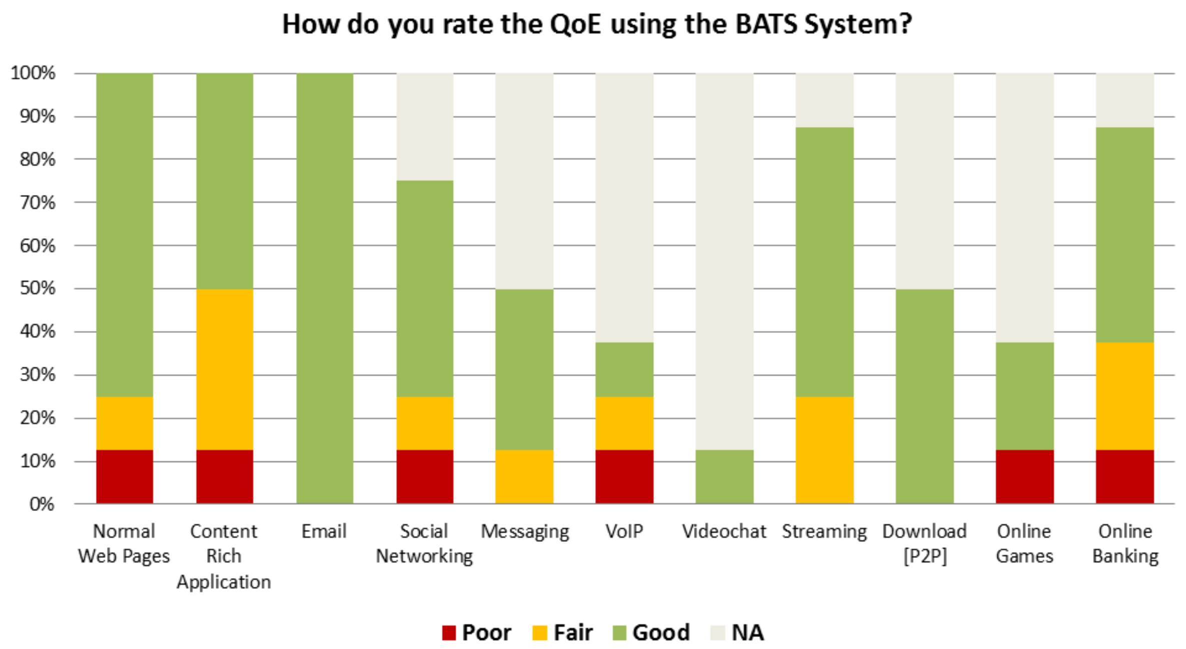


Figure 3-68 Evaluation of the application specific QoE using the BATS System [Second Phase] (Germany)

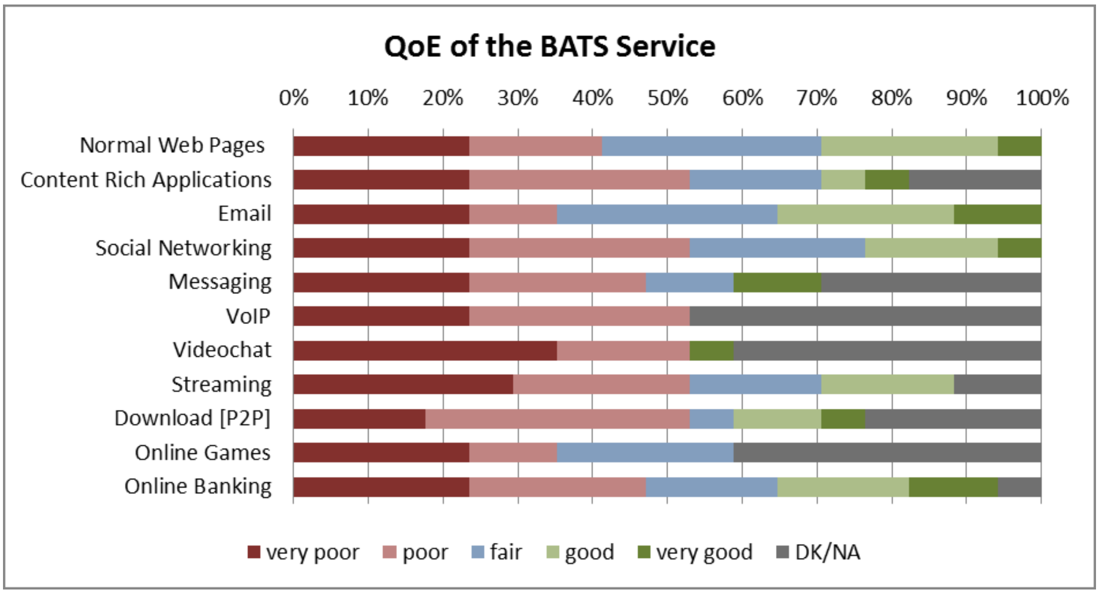


Figure 3-69 QoE for different Internet applications and services with the BATS service [Second Period] (Spain)

3.4.5 General Performance Aspects of BATS

In terms of general performance measured on download, upload, response time and stability the results of both the trials were similar. The download and upload speeds were good or very good while the response time was perceived to be poor / fair in Germany where 0% of users rated it as good / very good as compared to Spain where 60-100% who perceived the response time to be good.

We can also conclude from both the trial areas that stability of the CPE was a cause of concern for most users where users in Germany were more satisfied by the stability as compared to the users in Spain.

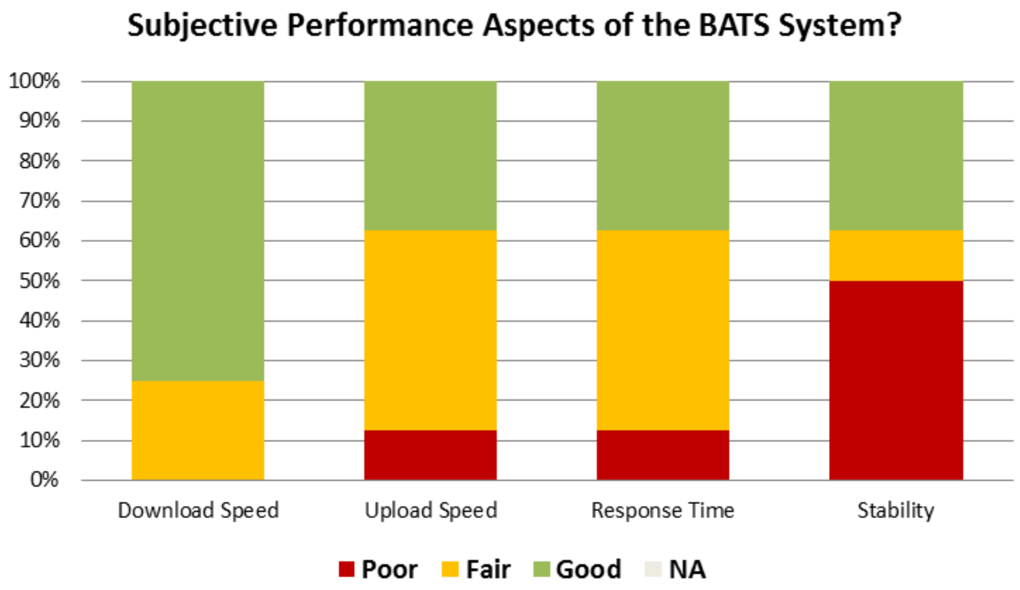


Figure 3-70 BAT's General Performance (Germany)

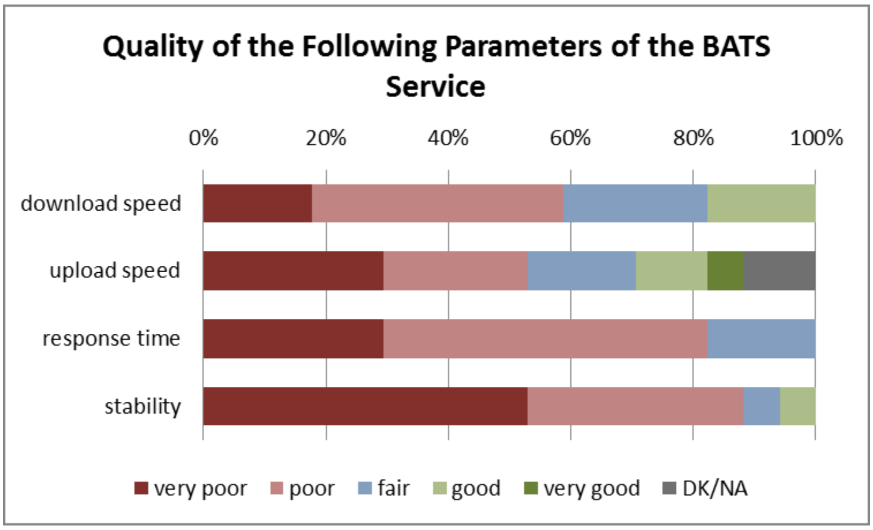


Figure 3-71 BAT's General Performance (Spain)

3.4.6 Level of Satisfaction

The users were more satisfied by the BATS service in Germany as compared with the Spanish users, but the margins are not that different, and only 25% – 30% of the users were not satisfied at all with the system in both the trial locations which may seem to be a large number but in case of BATS where the user base was very small it does not provide a representative outcome.

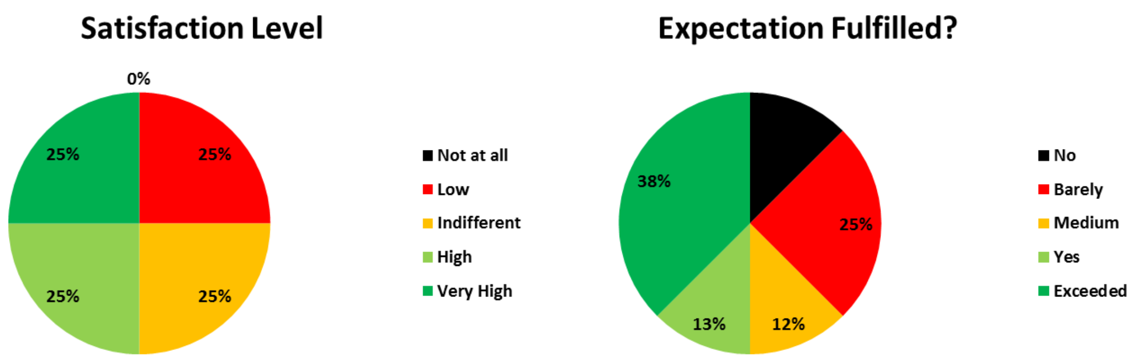


Figure 3-72 Satisfaction level and expectations on the BATS system [Second Phase] (Germany)

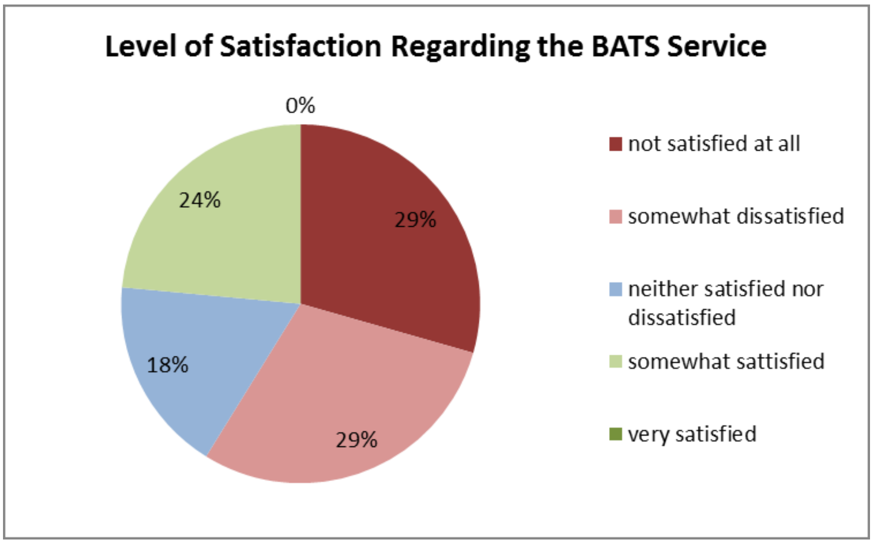


Figure 3-73 Level of Satisfaction Regarding the BATS Service [Second Period] (Spain)

3.4.7 Conclusions and key commonalities and differences

In conclusion most aspects of the BATS trials in Spain and Germany were similar with the exception of a few outliers thus we can say that the service similar to BATS is ubiquitous, at least in the European context.

It is also important to note that when the users were asked if they would continue with a service like BATS at a price point of 40 EUR the opinion was divided almost 50-50, where 50% of users did agree to continue with a service like BATS, which is very positive in the time scales of a prototype trial.

4 Evaluation and Conclusion

4.1 Technical evaluation

4.1.1 Statistical results

4.1.1.1 Field trials results

A detailed QoE feedback per application was obtained to aid future software optimisation as shown in Figure 4-1.

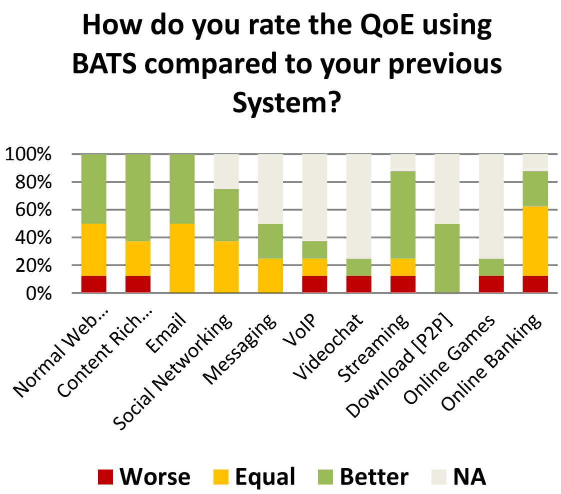


Figure 4-1 QoE improvements per application as expressed by the End Users (Germany)

As an R&D software based service, quality of user results were much higher than expected. In any commercial service, the first 3 months after any major software release are very tricky. This effect was also present in the BATS FT, but most users reckoned improvements in user experience when comparing to their former DSL service.

Figure 4-3 shows how the traffic was balanced between all three links active. As expected, the DSL link was the most used in the upstream direction and satellite downstream.

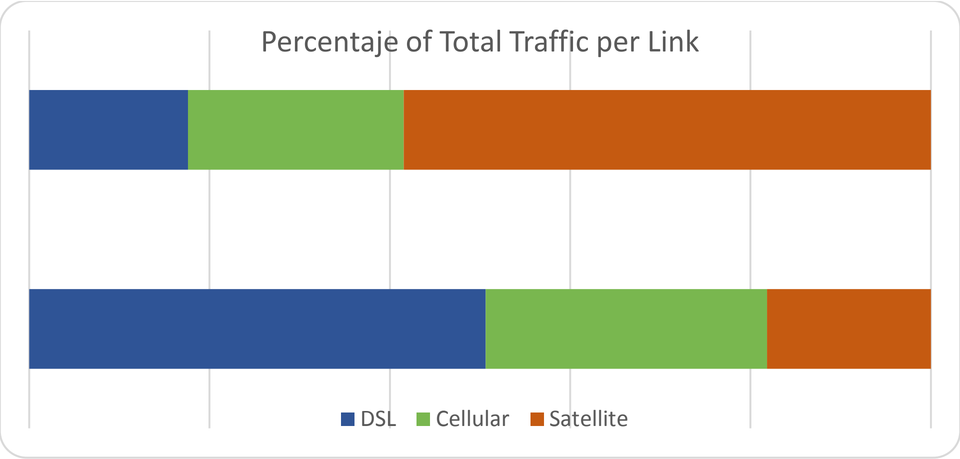


Figure 4-2 Percentage of total traffic per link in Spain

Figure 4-3 shows, in average, how much traffic was routed daily. The average monthly download was 15.8GB and the upload 1.3GB.

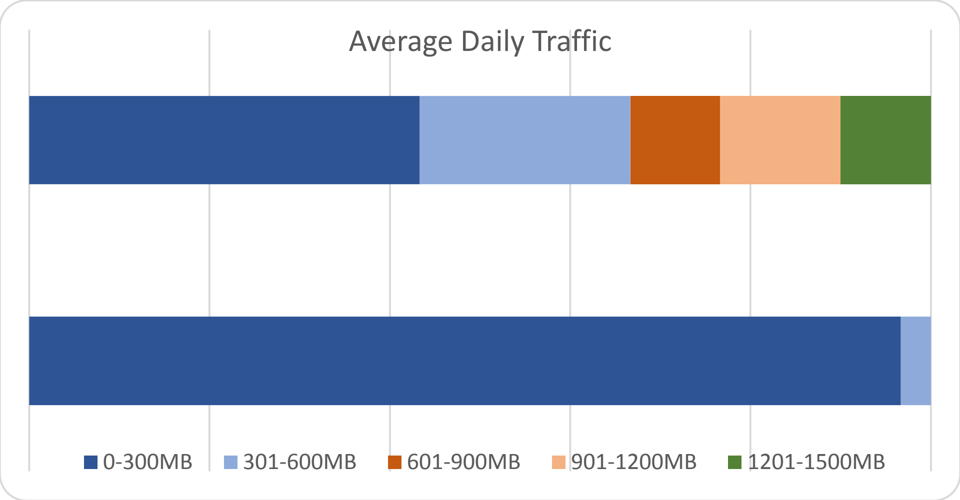


Figure 4-3 Average Daily Traffic in Spain

Figure 4-4 below, shows the average RTT on the different links.

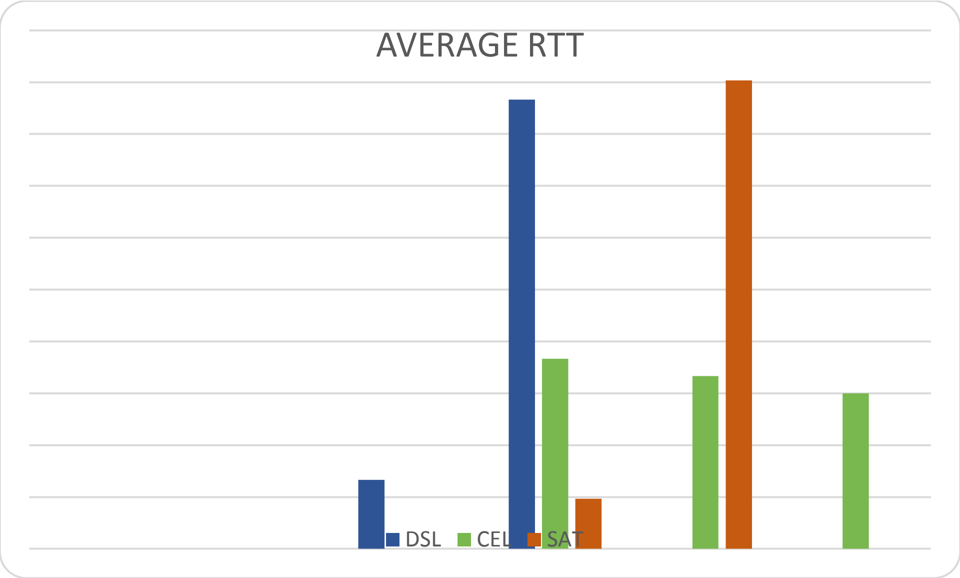


Figure 4-4 Average RTT per Link in Spain

Figure 4-5 below shows the average bandwidth available to the user on the different links.

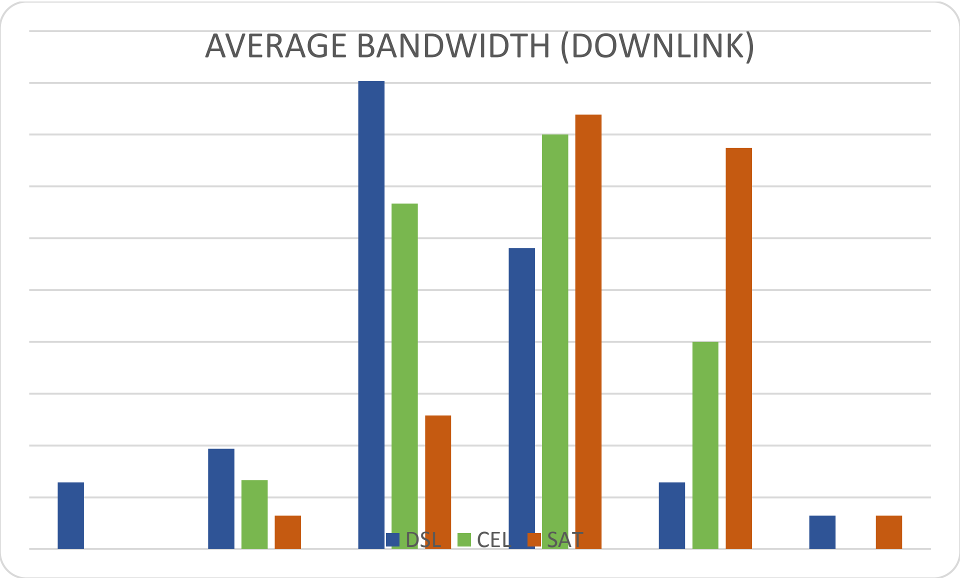


Figure 4-5 Average Bandwidth per Link in Spain

4.1.2 Analysis of user assessment

4.1.2.1 Analysis of field trials user assessment

Figure 4-6 (below) reflects the 2 main points of improvement discovered during the FT. Besides more overall stability, more brute speed is needed, as users dissatisfied with BATS in terms of performance where mainly users with a good satellite service prior to BATS. They expected increases in peak speed, near 30Mbps, something possible only with new satellites.

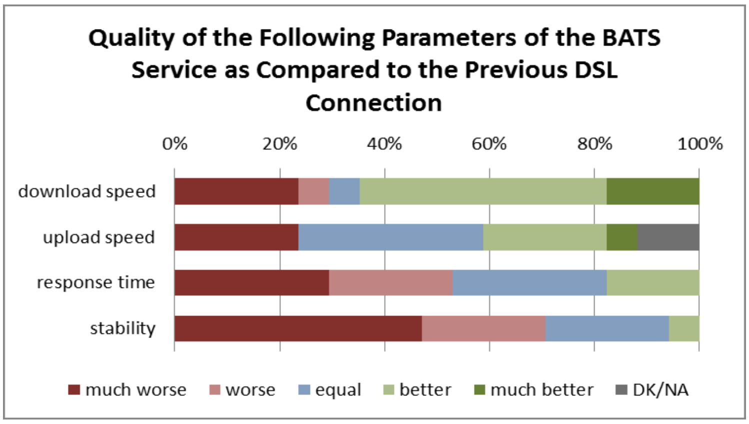


Figure 4-6 Experimental (and quick) BATS vs Mature (and slow) DSL

4.1.3 Technical suggestions for the future

Simplicity: The overall system is quite complex and it presents a main bottleneck in the ING point of the architecture. Perhaps a simplified BATS system, without ING, or with Network Function Virtualization at the network gateway, could have quick commercial acceptance and could evolve to a more complex system as demand grows

- Lack of configurability. The available configuration options of the IUG are limited and too rigid (it does not allow port redirection, etc.). This fact reduces the appeal for SOHO and enterprise customers, and even to advanced residential users. Those are important segments needed for the success of the business plan.
- Enhanced monitoring functionality that the user can perform from the IUG is required as similar functionality is already existent in most over the self-routers, and gives the users confidence in using the service or hardware.
- TV services: support for IP/online/DTT TV service is becoming more relevant as convergent bundles dominate the market. Most of the users expect to reach online video content though BATS. On the other side, a combination of SAT TV services with BATS using combined reception units could be a very interesting option.
- Traffic Engineering: Added features to ensure resource reservation on each link for the most used type of traffic would lead to more stability in the face of individual link fluctuations. This will involve deep packet inspection and further lead to traffic splitting per application.
- Device Form factor: Complexity should be reduced in the end user equipment. BATS integrated silicon could reduce very much costs in the user side.

4.2 Business Evaluation

4.2.1 Business evaluation

Analysis and validation of trial results and impressions (business feedback)

Field Trials have provided a very important demonstration of the BATS concept. We have seen that the basic BATS software has handled all 3 links, and that the BATS head end has integrated all links into a unified user experience. The backup native nature of the BATS concept has also been demonstrated, with users continuing to navigate, using 3G and satellite, unaware that the DSL link was down.

As in every CPE project, until software releases are tested in real field conditions there is no way to assess stability and quality of the software. In ordinary deployments, 3-4 months are always needed to produce a second version of the initial software launch. We feel that the second release of the BATS software released in FT was already very near of the desired maturity.

When we removed the BATS service from users, almost 50% of users asked for how long it will take to launch the BATS commercial service. It is hard for users to go back to the 1-2 Mbps DSL service present in their premises. This is the best assessment of the relevance of the BATS field trials.

In the German trials, no commercial pricing models were investigated.

4.2.2 Potential benefits for the end-users

Validation of potential benefits for the end-users

Users can obtain 2 main benefits from the use of BATS

- Wireless NGA speed combined with TV services: a “cable bundle” for rural areas
- Backup connections: customer tickets take longer to be resolved in rural areas, due to strong meteriological conditions and distance to support services. The 3-link nature of the BATS service creates higher uptime rates for the broadband service, offering advanced and business users a very high quality broadband service.
- Global coverage: Regardless of user locations the end user is guaranteed to have broadband connectivity via satellite connectivity and can further improve performance with any other terrestrial connection.

4.2.3 Market value

Validation of market value

R market value analysis: BATS is a powerful concept with very good commercial acceptance. In addition, the BATS service is a good hook to be used by any operator in order to drag along with the BATS service other important revenue generators, mainly mobile and TV. Customers understand that BATS is a “high installation cost” service and that they have to accumulate services in order to obtain a good bargain overall price.

However, there are 2 main points in the business plan which creates relevant difficulties. First, regulated DSL prices are devised in order to make permanent use of the broadband line. When those costs are incorporated to the business plan, and taking into account that the typical BATS DSL line provides only 2Mbps or less, and those costs have to be added to (variable) satellite and 3G/4G interconnection costs, the business plan is difficult to make. A new regulated and reduced DSL cost should be created for scattered rural areas the BATS business plan to enable it to be positive. Second, provisioning of so many hardware elements in the customer premise also loads the business plan with high costs and points of failure. More research and development should be done in order to provide a simplified BATS CPE with all services included, easy to install and maintain.

From the participating operators' point of view, it is a pity that the BATS concept is not ready and tested to launch as a commercial service. LTE deployments in rural areas advance in a very slow manner, and in many cases with frequency bandwidth allocations (5/10MHz) too small to provide good broadband services. Rural users have demonstrated high interest in the BATS concept, and there are niches, for instance former WiMAX deployments achieving end of life maturity, that could become immediate targets for the BATS service

4.2.4 Lessons learnt

The EC digital agenda for universal availability of broadband internet access is transforming from a being a target to being an absolute necessity for everyday life. End users are more concerned about the reliability and stability of their internet connection. Higher speeds (> 8 Mbps on DL) or extremely low latency comes second to the QoE.

Longer field trial durations should be incorporated in future projects. It was observed that towards the end of the field trials, we received fewer complaints or tickets as the users were now familiar with the BATS system.

The expectation from the field trials were very ambitious for the users as well as the consortium, where the users initially expected their bandwidth to triple in speeds (DSL + Cellular + SAT). In the first phase of the field trials the users were not very satisfied as the total speed from did not triple, but once the user expectations were set correctly they responded more favorably towards the BATS system in the second phase of the trial. In regards to the operators the dynamics of the links was something that had to be monitored on an ongoing basis and problems were handled accordingly.

The IxG had to be simplified to meet the timescales and although it was functional it did not include all the elements researched in WP3

The lab under controlled conditions and field trials under more dynamic conditions have proved to be beneficial for the users and it did improve their QoE while using the BATS system, but it has been analysed that if more time had been spent with in-house testing and fixing IxG's prior to the roll out to real world users.

Network stability issues coloured somewhat the field trial results and this is quite common with new prototyping. Given a longer period of trial these would have been resolved. It was noted that the phase 2 of the trials produced much better results than phase 1 but by this time users perceptions had been coloured.

From the lessons learnt we consider that a simplified initial trial with just the IuG would have been beneficial with the more complex ING being added as a second phase.

Since initiating BATS a number of other projects which integrate delivery have been started and the general concept is gaining momentum.

5 Other proofs of concept developed in BATS

5.1 Scope

A variety of additional lab tests (PoC's or proofs of concept) were carried out in BATS looking at different and detailed aspects of the BATS service.

5.2 Network Coding applications in DVB-S2/RCS2

5.2.1 Motivation and Objectives

The motivation of this PoC is to demonstrate the integration of Network Coding for bi-directional communication and the Network Coding enhanced PEP presented in WP 3.2 into a current satellite standard and assesses their performance in a reference implementation of a real satellite terminal.

The first application, Network Coding for bi-directional communication, is applied in the forward link of a satellite system. An already existing simplified PoC is integrated into the DVB-RCS2 standard and is extended to work dynamically with an arbitrary number of users.

The second application, a Network Coding enhanced Performance Enhancement Proxy (PEP-NEC), is a transparent PEP solution without connection-splitting for satellite communication. It tries to anticipate the performance loss of TCP in case of packet loss errors by using inter-flow Random Linear Network Coding (RLNC) Figure 5-1. A validation of the simulation results that were reported in D3.2.1 with a NS2 simulator was performed using a reference implementation of a satellite terminal.

5.2.2 Network Coding for Bi-Directional Communication

This scheme is a standard application of network coding. Two terminals want to exchange information with each other via a relay node (satellite with on-board processing or a hub station), see Figure 5-1. The hub station receives the information A and B from the two terminals, and instead of just relaying the two packets, it combines them together and sends out the combined packet. The terminals, which stored the information they sent, can decode the new information by combining the incoming packet with the stored one. In this way, capacity can be saved in the forward link.

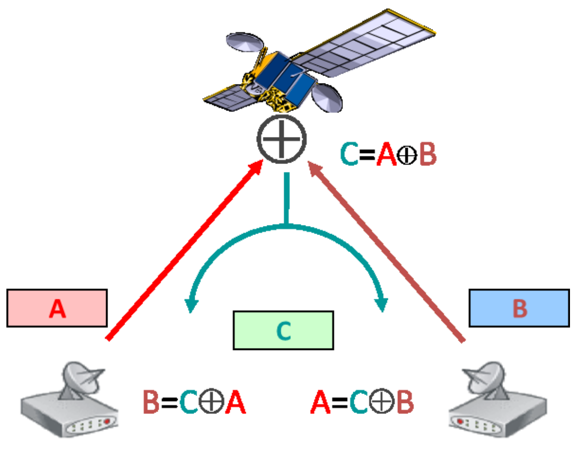


Figure 5-1 Principle of Network Coding

5.2.3 Protocol Design

The implemented network coding protocol is based on NetCoP (version 1) [5] . Since this version is only suitable for coding together two predefined terminals, it had to be extended to work with an arbitrary number of terminals. For this, two address fields are inserted in the header, which allow identifying the two contained terminals in a coded packet.

Protocol Operation

Network Coding is applied between layer 2 and layer 3 in the DVB-S2/RCS2 protocol stack [6], as shown in Figure 5-2. A copy of IP packets originating at a terminal is buffered in the terminal. The return link remains unchanged, so the IP packets are encapsulated in RLE packets and transmitted according to the standard.

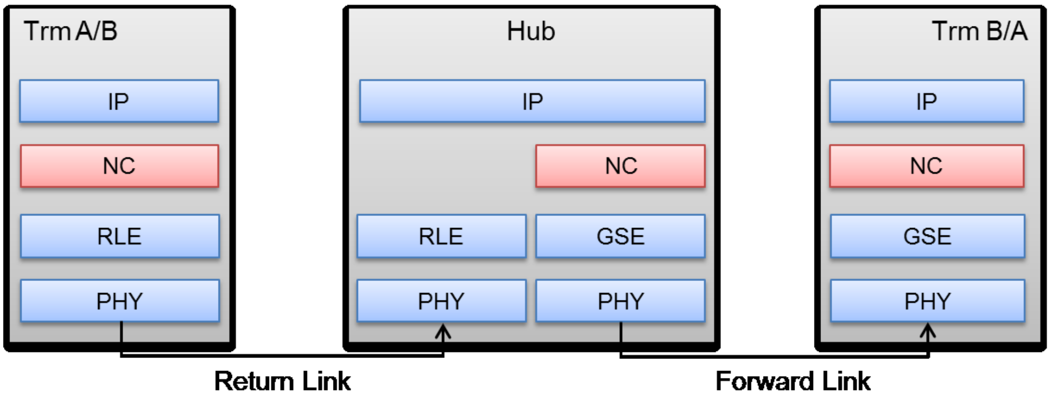


Figure 5-2 Protocol Stack.

In the forward link, network coded packets are transmitted in layer 2 multicast packets with the GSE protocol type set to a specific number used for network coding (0x3045). The operation of the protocol in the hub is shown in Figure 5-3. A coded packet is generated by XORing IP packets that belong to a bi-directional communication between two terminals. In order to align the lengths of the two payloads, zero padding is introduced. The coded packet is prepended with a network coding header before it is encapsulated in GSE packets.

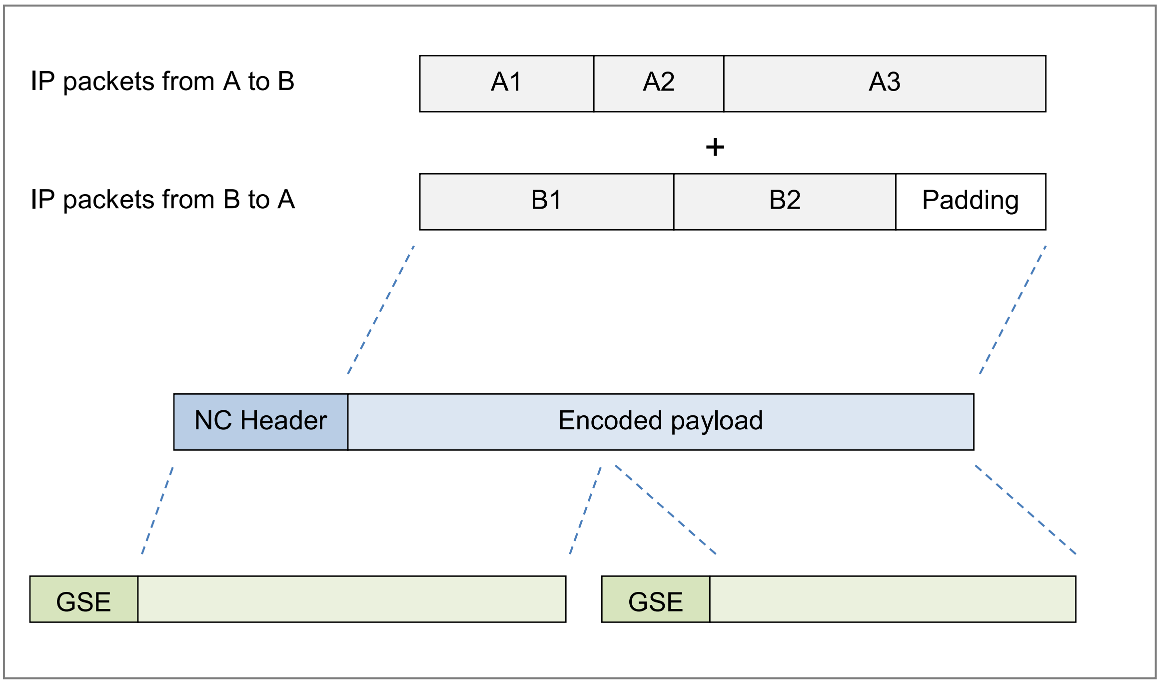


Figure 5-3 Packet encapsulation

Header Description

The format of the Network Coding header is shown in Figure 5-4.

<table>
<tr><td>vsn + flags</td><td colspan="3">address0</td></tr>
<tr><td colspan="3">address1</td><td>def_proto0</td></tr>
<tr><td>def_proto0</td><td colspan="2">Def_proto1</td><td>pcnt0</td></tr>
<tr><td>pcnt1</td><td colspan="3">packet_info_block</td></tr>
<tr><td colspan="4">packet_info_block</td></tr>
<tr><td colspan="4">…</td></tr>
<tr><td colspan="2">…</td><td colspan="2">crc</td></tr>
</table>

Figure 5-4 NC Header format

Description of the fields:

Table 5-1 Fields of NC Header

Field	Length	Description
Version	4 bit	A version number, here 2.
Flags	4 bit	Option flags, specified in Table 5-2: The flags field..
Address0	24 bit	Address of the first terminal.
Address1	24 bit	Address of the second terminal.
Defproto0	16 bit	Default protocol type of the original payload packets of the first terminal.
Defproto0	16 bit	Default protocol type of the original payload packets of the second terminal.
Pcnt0	8 bit	Number of packets from the first terminal.
Pcnt1	8 bit	Number of packets from the second terminal.
Packet_info_block		A packet info block (as specified in Table 5-3: The packet_info_block Table 5-3) for each packet; altogether pcnt0 + pcnt1 blocks.
CRC	16 bit	CRC of the complete header.

Table 5-2: The flags field.

flag	Name	Description
0x1	NC_CRC32	If true, a 32bit CRC is used in the packet info block. Otherwise, 16bit CRC is used.
0x2	NC_DEFPROTO0	If true, the default protocol for the packets of the first terminal is specified.

0x4	NC_DEFPROTO1	If true, the default protocol for the packets of the second terminal is specified.
0x8	NC_ADDRESS	If true, the extra address fields are present.

Table 5-3: The packet_info_block

Field	Length	Description
Packet_len	16 bit	The length of the original payload packet.
Packet_crc	16 bit or 32 bit	CRC of the original payload packet.
Packet_proto	16 bit	Protocol type of the original payload packet. Only present if NC_DEFPROTOX is false.

5.2.4 Implementation

The modules are implemented as independent executables that communicate with the testbed via UDP sockets. The NC terminal module is shown below in Figure 5-5 .

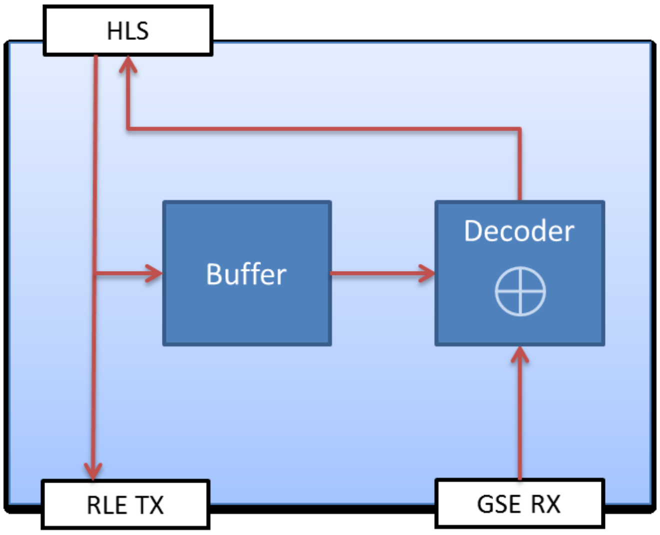


Figure 5-5 NC Terminal Module

Terminal Module

The IP traffic enters through the HLS interface. A copy of the IP packet is stored in the buffer, together with a CRC over the whole packet that is used to identify the packet later on. The original packet is forwarded to the RLE transmitter module. The module has an own buffer for each virtual network the terminal belongs to.

Network coded packets arriving on the forward link are redirected to the NC module by the GSE receiver module, according to the protocol type set. The NC header is read and checked, and the local buffer is searched for the stored packets that are needed to decode the payload.

The decoded payload data is split into the original packets, according to the packet_info blocks, and forwarded to the higher layer module.

The buffer size has to be set large enough to store all outgoing packets when sending with the maximum transmission rate for at least RTT_max + forward_delay in the hub. The default value is 1 MB, which is enough for 1s total delay at 5 mbit/s. There is a timer that removes packets from the buffer, which were not used for network coding and which are already too old.

Hub Module

The hub module receives IP packets from the higher layer module, together with the source and destination address of the terminals (the group-ID and logon-ID is used). Different virtual networks are treated separately; no inter-SVN coding is done.

When a new network coding session has to be started for two terminals, a new multicast group is selected and signaled to the terminals, so that they can adjust their GSE MAC filter.

There are two packet queues for each active network coding session, one for each of the two involved terminals. Packets going out to the terminals are buffered for a short time (forward_delay). If both queues have packets, these packets are combined together and sent on the multicast group. Otherwise, the queue is flushed and the packets are sent out uncoded as unicast.

Each NC session should be assigned an exclusive multicast group, or at least all terminals in that group should have a similar ModCod. Otherwise, the network coding gain could be lower than the efficiency loss with users that have a bad channel.

The NC hub module is shown below in Figure 5-6.

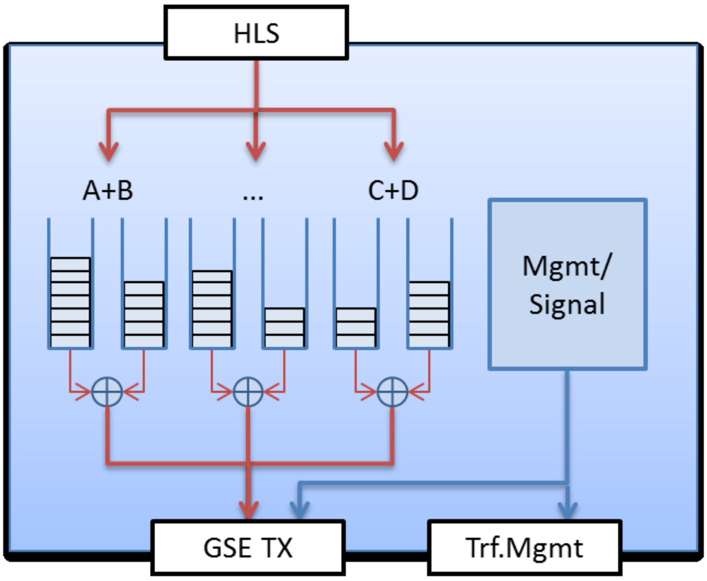


Figure 5-6 NC Hub Module

Statistics Collection

Each module gathers statistics about the number of packets/bytes (un)successfully processed, number of CRC collisions, packets found/not found as well as the number of padding inserted and space used for headers.

5.2.5 Integration

The high level integration of the Network Coding module in the testbed is shown below in Figure 5-6. It is placed between the HLS module, the traffic management and the GSE receiver.

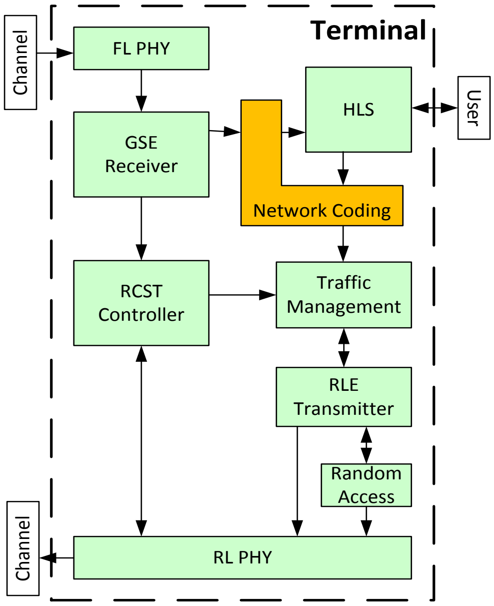


Figure 5-7 Network Coding Integration

Dynamic Session Management

Network Coding sessions are started on-the-fly. Whenever the hub sees a packet going from one terminal to another, a new NcServer instance is created. To reduce the number of unnecessarily started sessions, network coding will only be applied to traffic with AF and EF QoS classes, which are normally used by VoIP and video conferencing systems. After a certain idle timeout, the NcServer instance will be removed again, and the resources will be freed, including the multicast address.

When a new session is created, a free L2 multicast group is chosen from a pool of possible groups. The chosen group has to be signaled to the involved terminals, so that they can adjust their MAC filters accordingly. The signaling is done using TIM-U messages as defined in the RCS2 standard, and a new descriptor, whose structure is shown in Table 5-4.

Table 5-4: MAC filter adjustment descriptor.

Field	Length	Description
Descriptor_tag	8 bit	ID of the descriptor: 0xE0
Descriptor_length	8 bit	Length, bytes directly after this field: 4
Status	8 bit	Only 2 states: - 1: Add MAC - 0: Remove MAC
MAC	24 bit	MAC Address

Packet Identification Issues

When a terminal stores an IP packet before sending it out, it generates its CRC32 checksum in order to identify it later.

At the gateway, the NcServer also generates CRC32 values of the IP packets that are coded together and puts it into the packet header. These values are used by the terminal to select the right packets from its buffer as well as to verify the correctness of the payload after decoding.

Since the IP packets are routed in the gateway before they arrive at the NcServer, the IP TTL value is decreased by one and thus the IP header checksum is also changed. This leads to a different CRC32 checksums at terminal and gateway for the same IP packet.

As a solution, the FreeBSD kernel provides an option called ‘IPSTEALTH’. When enabled, the TTL value in IP packets is not changed when forwarding packets. It can be enabled individually for each virtual network. Since the terminals still perform a normal routing, there is no risk of endless traffic loops.

SNMP Statistics

In order to provide an interface to gather statistics from the network coding modules, the SNMP protocol is used. The RCS2 testbed provides already an SNMP agent based on FreeBSD’s bsnmpd, which was extended to read also the network coding statistics.

5.2.6 Performance Evaluation

The data rates are measured by periodically querying the SNMP daemon for statistics. The SNMP data itself is not included in these statistics.

Setup

In this setup, only two terminals share a multicast group. So the common ModCod for the group is the lower one of the two terminals.

The maximum NC payload for a terminal in one NC packet consists of 10 individual data packets or 10 Kbytes of total data packet size. The return-link of both terminals is limited 1.5 Mbit/s each and is assigned via rate-based capacity requests, with a small constantly assigned share of 16 Kbit/s. The channel conditions are fixed without any packet errors/losses.

Two terminals, A and B, communicate with each other via a gateway, which performs the network coding. The communication itself was done through iperf server and client instances on both of the terminals.

Data rates

The data rates are graphed in Figure 5-8: Data rates.Terminal A starts to send data to terminal B with an information rate of 1 Mbit/s at t=0s. At t=25s, terminal B also sends data with 1 Mbit/s to terminal A and at t=100s, terminal A stops sending, while terminal B continues sending.

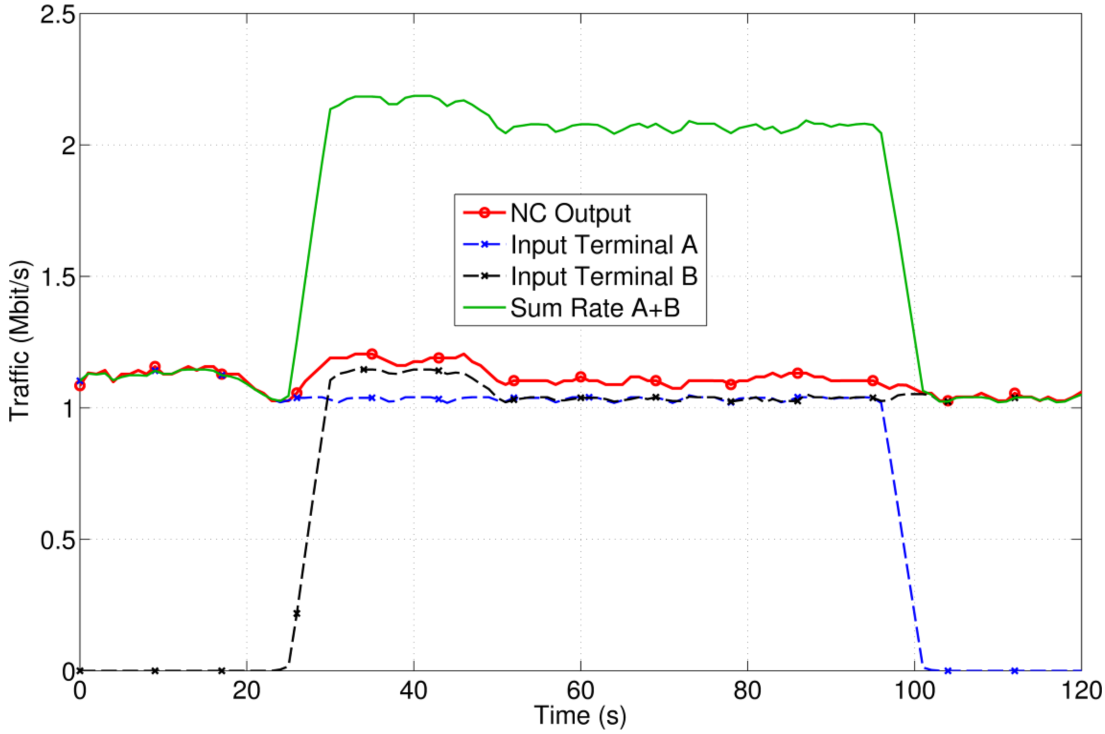


Figure 5-8: Data rates.

The shown input data rates are measured at the input of NcServer in the Gateway and include the IP and UDP headers of the information packets. The sum rate is just a summation of the two input data rates. The NC output rate is measured at the output of the NcServer, and includes the whole NC packet consisting of NC header and payload. Any further protocols or framing structures are not reflected in this graph.

The slightly increased input data rate at the start of each terminal activity results from the traffic that is queued during the capacity request round-trip delay.

Gain and Signalling Overhead

Figure 5-9 shows the saved bandwidth and the header overhead. In the case where only one terminal is transmitting, the overhead is around 0.5%. With both terminals transmitting, there are more payload packets in a NC packet, and the header overhead grows to 1%.

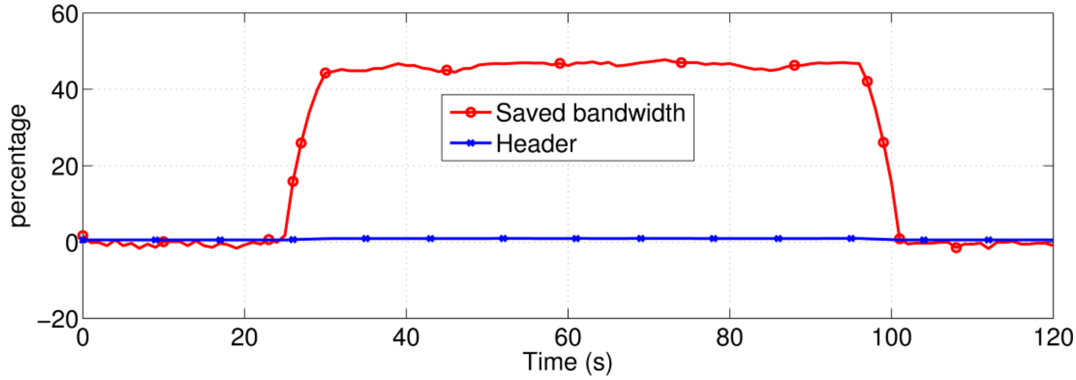


Figure 5-9: Gain and signaling overhead.

The saved bandwidth is computed by dividing the NC Output rate by the sum rate of the two terminals. In the case with one terminal transmitting, there is a loss of bandwidth because of the NC header. When both terminals are transmitting, around 45% bandwidth can be saved. The remaining 5% are used for the NC header and some padding. The padding is necessary because the packets of both terminals do not arrive at exactly the same time. If two packets from terminal A arrive one after the other without a packet from terminal B in between, and the first packet fills up the NC packet, the NC packet is flushed with some padding for terminal B.

5.2.7 Network Coding based Performance Enhancement Proxy (PEP-NEC)

5.2.7.1 High-Level Description

The Network Coding based PEP was introduced in WP 3.2. It is a transparent PEP without connection splitting that combines packets of different TCP flows (inter-flow coding). The system setup is shown in Figure 5-10. File transfers are carried out from servers over a satellite to the terminals. The PEP is placed on the both ends of the satellite channel, in the gateway and the terminals.

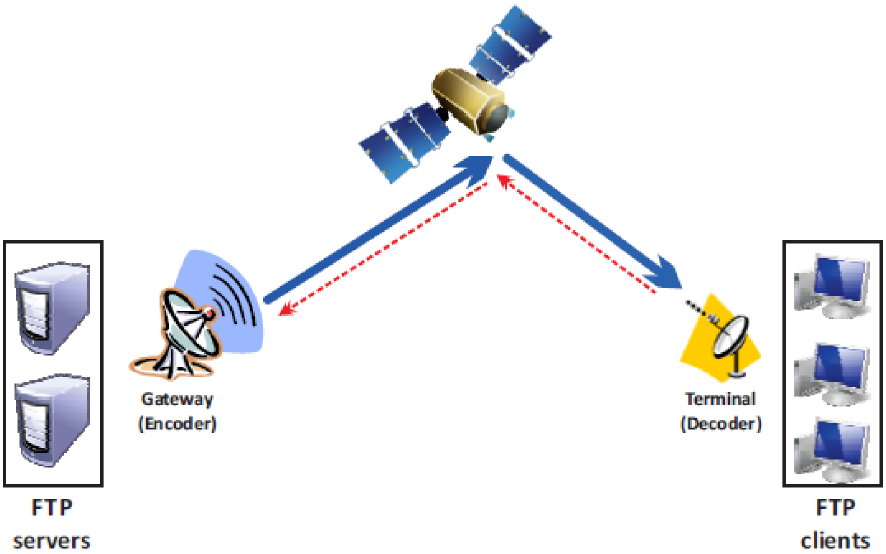


Figure 5-10 System Scenario for PEP-NEC

The packets of different TCP flows destined to one terminal are gathered in the PEP encoder on the gateway side. Random Linear Network Coding (RLNC) is applied over these packets and the encoded packets, which consist of a header and linear combinations of the data packets, are sent to the terminal. The number of packets that are sent out is generally higher than the number of input packets, to overcome the link losses.

On the decoder side, the encoded packets are collected. As soon as enough packets are collected, depending on the selected coding scheme, the original data packets can be decoded. If too many packets were lost, the terminal sends negative acknowledgements (NACKs) back to the encoder, and requests additional data.

5.2.7.2 Implementation

The general principle of operation follows the one presented in D3.2.1. The high level architecture of the PEP-NEC modules is shown in Figure 5-11.

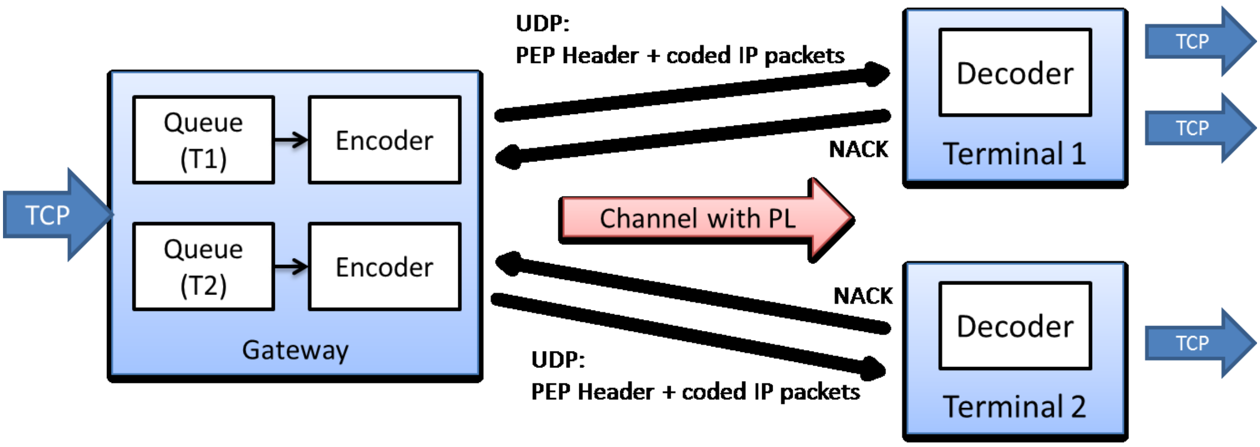


Figure 5-11 PEP-NEC implementation

On the encoder side, there is a queue for every logged-on terminal, where the TCP packets destined to the corresponding terminal are put. Each queue has its own encoder instance, which waits until there are either a configurable number of k source packets in queue, or an idle timer times out. The idle timer is required to ensure that if less then k packets are in the queue for a while, the packets are being sent out anyway.

A second timer deletes blocks of already sent out linear combinations, if no NACK messages are received after a certain period, in order to free resources.

On the terminal side, each decoder collects at least k packets per block. If after a short period of time after the last received packet, the k packets are not yet reached, a NACK is sent back to the encoder to request additional linear combinations.

Once a block is decoded and the original source packets are restored, the decoder waits before forwarding the packets to the client, until all previous blocks are processed. Otherwise, the order of the packets would be destroyed and the TCP protocol would be affected.

The header of the encoded packets is shown in Figure 5-12. It has a fixed size of 16 byte and is contained in every encoded packet and followed directly by the encoded data.

block_id	block_size
packet_len	flags
seed	
timestamp	

Figure 5-12 PEP-NEC Header

Description of the header fields:

- The **block_id** (16 bit) is a tag for a group of n linear combinations that are encoded together. It is also used to identify the block in the NACK messages.
- **block_size** (16 bit) specifies the length of the data block in terms of linear combinations, i.e. the parameter k.
- **packet_len** (16 bit) specifies the length of the encoded data in terms of bytes.

- The **flags** (16 bit) field currently has two values:
    - 0: Packet is a data packet.
    - 1: Packet is a NACK packet.
- The **seed** (32 bit) that was used to generate the random coefficient.
- A **timestamp** (32 bit) specifying when the linear combination was created. It is used only for statistics.

The CRC field, which was present in the NS-2 version of PEP-NEC, is not used in this implementation, since the data integrity is assured by the lower layer error checks.

5.2.7.3 Integration

The PEP-NEC is placed in the HLS module, as shown in Figure 5-13. The activation of the PEP-NEC is negotiated by the PEP Negotiation procedure of RCS2. Once the usage is agreed by gateway and terminal, the routing tables of the corresponding satellite virtual networks (SVNs) are changed in a way that the TCP traffic is forwarded to the PEP. The encoded packets are delivered to the traffic management modules and finally sent over the satellite.

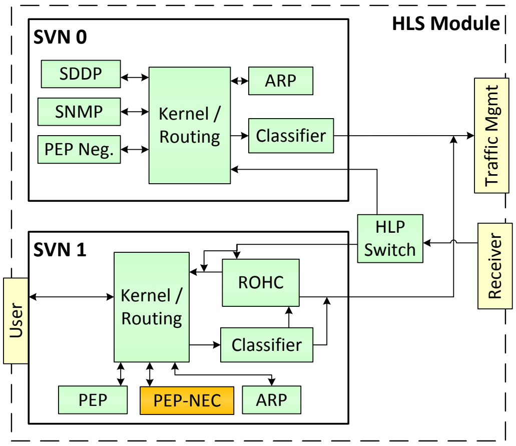


Figure 5-13 PEP-NEC integration

To be compliant to the DVB-RCS2 standard, the PEP-NEC module is only present in the traffic SVNs, SVN1 and above, but not in the management SVN, SVN0.

There are no further modifications needed to integrate the PEP-NEC modules, since the encoded packets are sent as UDP packets between the PEP instances, and thus are treated as normal traffic.

5.2.7.4 Results

The throughput of a TCP connection was compared for the case with PEP-NEC and without PEP over a satellite link with frame errors. TCP New Reno was used in the end-to-end connection. The physical layer was set to a throughput of 50 Mbit/s and the one-way delay was set to 250ms. For each of the investigated frame loss rates, 10 file transfers were carried out with duration of 1000s each. The coding rate was tuned for each frame loss rate individually.

The average end-to-end throughput is shown in Figure 5-14. While the normal transmission is heavily affected as the frame error rate increases, the PEP-NEC is able to mitigate some of the losses and maintain a reasonable throughput.

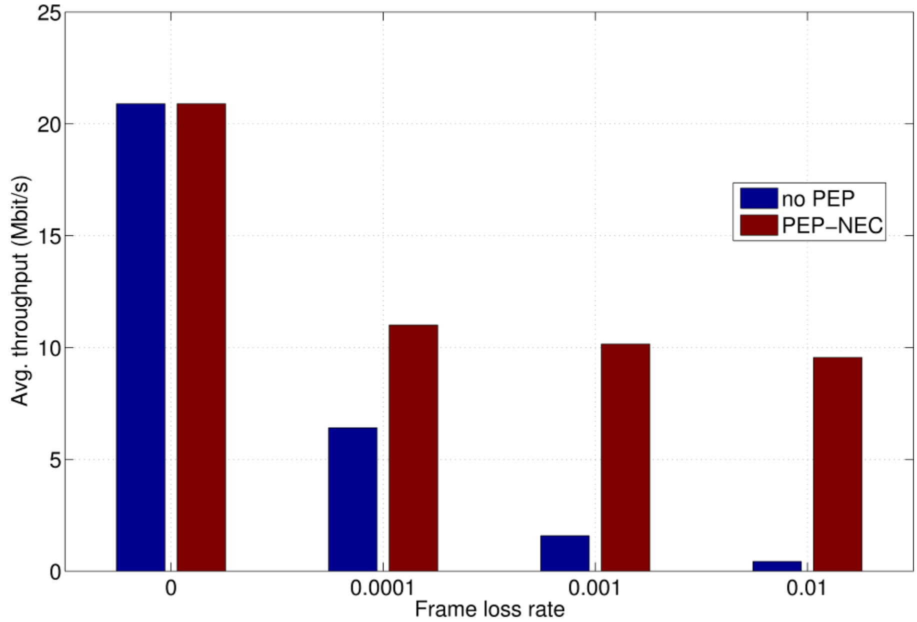


Figure 5-14 PEP-NEC performance results

In comparison with the NS-2 simulation results shown in WP3.2, where the throughput was constant over the increasing losses, the results obtained by the described implementation are worse. One reason for this is that in the simulation, an equally distributed packet loss error was assumed, while in this implementation, due to DVB-S2, frame errors occur. A lost frame causes the loss of several consecutive linear combinations, and thus the decoder has to request additional data using the NACK mechanism.

The extra delay caused by the NACKs sometimes leads to TCP timeouts in the end-to-end connection, causing retransmissions on the sender side. These retransmitted packets also lower the throughput. A countermeasure could be a connection-splitting PEP, but this was explicitly avoided in this version.

5.2.8 Conclusions

The outcome of this proof-of-concept activity shows that the application of network coding in bi-directional communication is a promising technique that can save almost half the required bandwidth. A small adaption of the DVB-S2/RCS2 standard is proposed in order to make the protocol fully flexible to the underlying resources, in terms of multicast group management. A BATS service could be offered implementing this technique, which offers resource-saving communication applications.

The PEP-NEC implementation shows that the PEP is able to mitigate some of the frame losses, but also adds quite some complexity. Especially on channels with low error probability, the gain is very small compared to the introduced overhead. Common broadband channels, for which the BATS system is designed, normally provide these low error rates due to adaptive coding and modulation techniques and forward error correction mechanisms.

5.3 Disruptive Satellite Radio Interface

5.3.1 Motivation and Objectives

The objective of this activity has been to develop a proof of concept based on SC-FDMA (Single-carrier Frequency Division Multiple Access) air interface on satellite, outcome of WP4.4 activity. SC-FDMA has been, indeed, investigated in the framework of WP4.4 as one of disruptive solutions for the satellite air interface to be adopted in the BATS system. The outcomes of such analysis have proven that these kinds of waveforms, with the proper studied adaptations, are very promising to be applied to the satellite context.

For this reason, the decision to implement a test-bed focused on a SC-FDMA scaled system has been taken with the aim to validate the results achieved in the research activity on the feasibility of the disruptive air interface concept for High Throughput Satellite systems.

5.3.2 High Level Design of SC-FDMA Test-Bed

The implemented test-bed is able to proof some of the functionalities of a SC-FDMA based air interface for the access network in the satellite environment. In particular, the SC-FDMA test-bed concentrates on **a single return link** (from a single terminal to the gateway), **with a particular focus on the synchronization stage at the gateway physical layer,** addressed in details in the framework of WP4.4 (see BATS deliverable D4.4.2).

The terminal is assigned with a programmable subset of subcarriers, so as to achieve configurable user traffic. The potential interference arising from other users terminals accessing the channel on the same frequency band can be modelled as Gaussian noise, additive with respect to the conventional thermal noise.

As mentioned, the test-bed is focused on the satellite return link so the forward channel is not emulated. However, in order to provide the gateway receiver with the time reference, an alternative way to give coarse time synchronization has been designed. It is based on the use of a preamble and a set of pilot symbols interleaved with the transmitted payload data to establish a sort of frame structure that allows the receiver to detect the symbol boundaries. Although the introduction of the known symbols reduces the spectral efficiency of the access system, this allows more robust synchronization.

The frame structure hereby included is for demonstration purposes only and does not reflect any proposal for the complete system. In BATS the forward channel, indeed, is foreseen to provide with a time reference to the terminals in a way inspired to a conventional DVB-S2/RCS system, [6].

Base band processing has been implemented in the form of a software application running on a PC. The application software is developed using the GNU radio suite and other custom libraries, running on a Linux Ubuntu operating system.

Conversion from the baseband to RF is performed by a USRP N210 transceiver, interfaced to the PC by means of a Gigabit Ethernet cable. Data transfer across the I/F is mediated by flow control.

Figure 5-15 summarizes the SC-FDMA test-bed architecture.

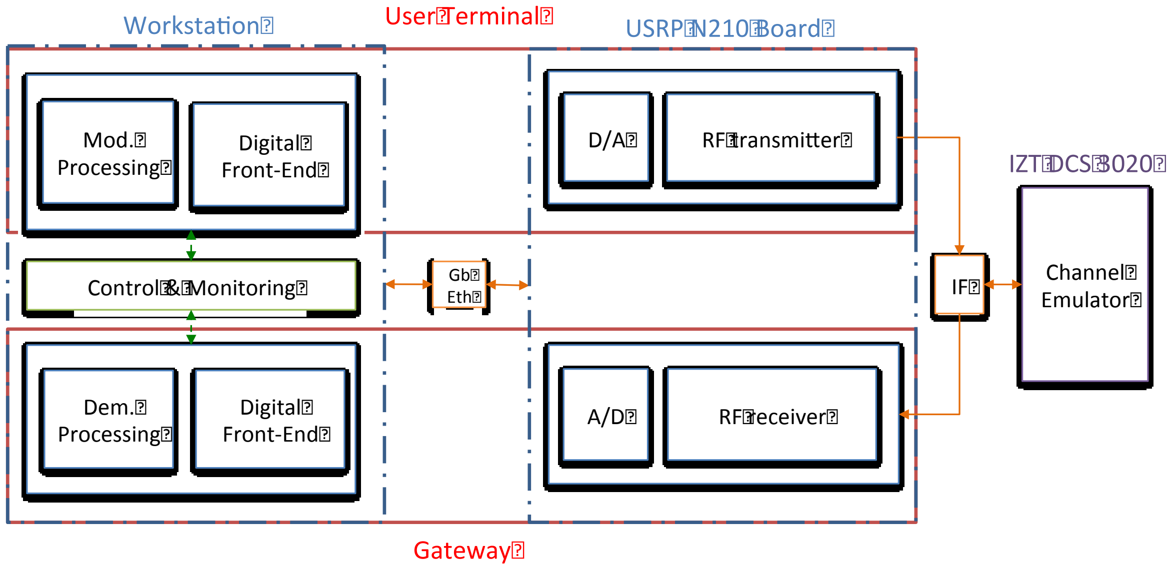


Figure 5-15: SC-FDMA Test-Bed high-level architecture

The design, implementation, and integration activities have been organized in Tasks as follows:

- **Task 1)** High level design of the SC-FDMA test-bed
- **Task 2)** Detailed design of the SC-FDMA test-bed
- **Task 3)** Development of the SW modules (terminal and gateway)
- **Task 4)** Integration of the SW modules (terminal and gateway)
- **Task 5)** Testing of the SC-FDMA test-bed
- **Task 6)** Validation of the SC-FDMA test-bed

5.3.3 Detailed Design and Implementation of SC-FDMA Test-Bed

5.3.3.1 Baseband processing

Figure 5-16 reports the detailed design of the digital transmitter at the User Terminal.

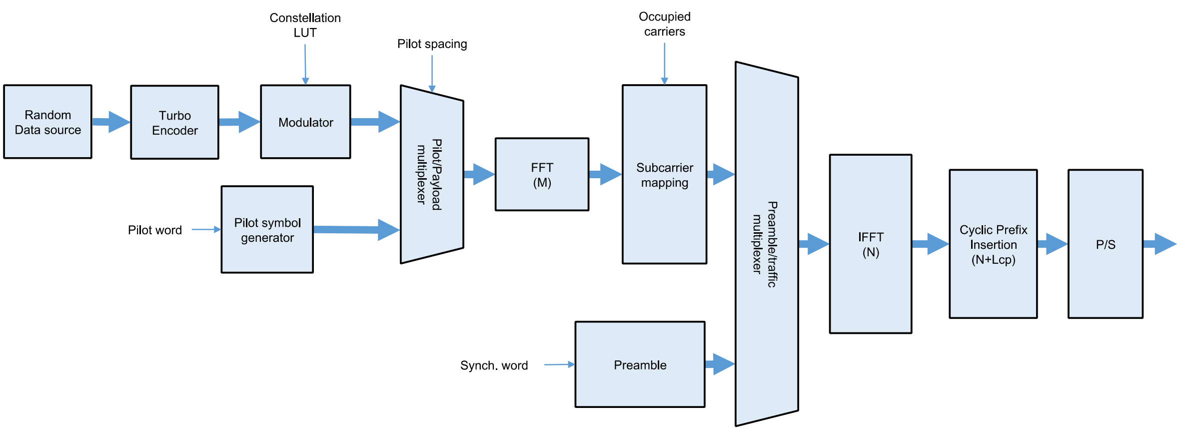


Figure 5-16: User Terminal: TX Baseband processing

According to the above scheme, the Turbo Encoder as well as the Modulator is defined as in the DVB-RCS2 standard, [6][1]. The output of this module is the SC-FDMA digital signal and the adopted frame structure is presented in Figure 5-17. A preamble and a set of pilot symbols interleaved with the transmitted payload data are used for the coarse and fine synchronization. Although they reduce the spectral efficiency of the access system, they allow more robust synchronization.

More in detail, the preamble has been designed in order that (coarse) time synchronization shall be achieved with an uncertainty region **lower than or equal to the cyclic prefix length.**

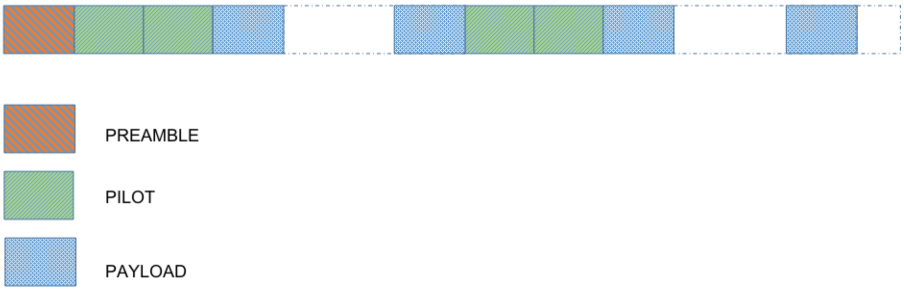


Figure 5-17: Frame structure

Looking at RX part, Figure 5-18 shows the design of the Gateway Baseband section.

The preamble is detected in the form of a **correlation-based time-domain search**, i.e. processing the serial stream of samples coming from the A/D converter.

This is due to the fact that the processing in the frequency domain (FFT) that is typical of multicarrier signalling receivers can be performed only after that the symbol boundaries have been detected.

In parallel to the preamble search in the time domain, the receiver shall store a suitable number of samples in the receive buffer (e.g., a number of samples equivalent to a couple of OFDM symbols), to be ready for the subsequent parallel processing.

The preamble is used to mark the symbol boundaries in the receiver buffer and to discard the cyclic prefix from each OFDM symbol.

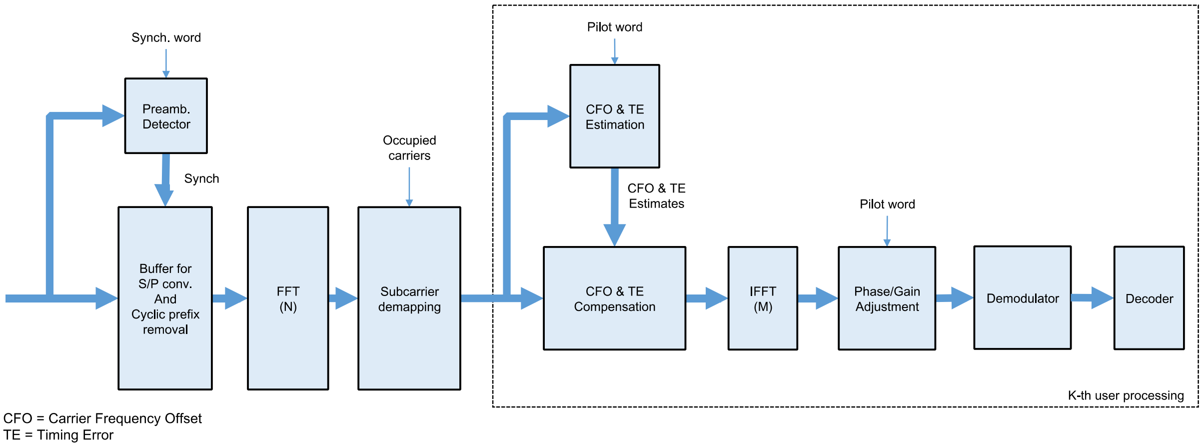


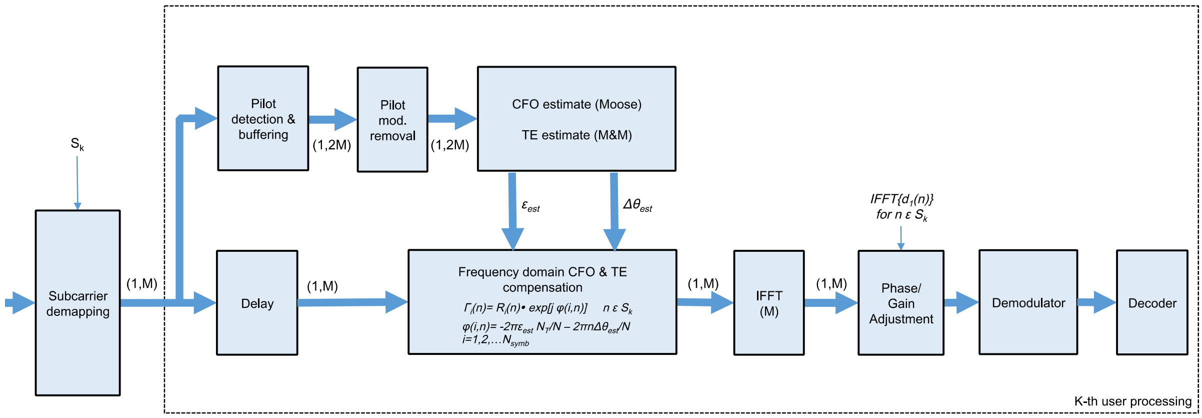
Figure 5-18: Gateway: RX Baseband processing

Focusing on the synchronization stage (Figure 5-19), the carrier frequency offset and the timing error result in a differential phase shift, appearing both in the time domain (index *i*) and in the frequency domain (index *n*). It is convenient to skip the absolute phase offset and concentrate first on the differential angles, leaving the absolute phase and gain adjustments at the end of the chain. To simplify the structure, we have assumed that the pilot symbols are placed in the first two symbols only in each frame (*i* = 1, 2).

Some comments on the notation are beneficial:

- S_k = subset of the sub-carrier indexes relevant to the *k-th* user
- M = number of elements in S_k
- = number of «OFDM» symbols in a frame, that is the number of symbols between two consecutive preambles.

The estimate of the parameters is based on the pilot symbols only. Two pilot symbols must be buffered. The known complex samples associated to the pilot symbols must be removed before entering the estimation process, so that the effects of the synchronization errors can be easily detected.



CFO = Carrier Frequency Offset
TE = Timing Error

Figure 5-19: Gateway: RX Baseband processing – focus on synchronization modules

More in detail, the **carrier frequency offset estimation** is based on the **Moose's algorithm**, [7]. The carrier frequency offset is due to residual frequency difference between the transmitter and the receiver and to the Doppler effect caused by satellite movements around the nominal GEO orbit. In the algorithm, two identical pilot symbols are transmitted in a couple of adjacent symbol intervals. The parameter estimate is based on the comparison of the two FFT vectors associated to the pilot symbols.

The channel impulse response is assumed to be identical in the two symbols, so the only cause of difference between the pilot symbols themselves is due to the carrier frequency offset.

The **timing error** can be estimated in parallel to the carrier frequency offset. To specify the mathematical model of the effect of a timing error, let us denote by $\Delta\theta$ the timing error normalized to the sampling interval. The received sample $R_i(n)$ can be expressed as:

$$R_i(n) = e^{j2\pi\Delta\theta/N} H(n)d_i(n) + W_i(n) \qquad 0 \leq n \leq N\text{-}1$$

where N is the number of considered subcarriers, $H(n)$ is the frequency response of the channel at the $n\text{-}th$ subcarrier frequency, $d_i(n)$ is the transmitted sample, and $W_i(n)$ is the AWGN sample.

As it can be seen he timing error appears in the form of a phase shift that linearly increases with the index n. Due to the mathematical equivalence of the model, for the estimation of $\Delta\theta$ we can use one of the algorithms proposed for the estimation of the frequency of a sinusoid embedded in noise. In this case the selected algorithm is the Mengali-Morelli algorithm (M&M), [8].

5.3.3.2 Front-End processing

As reported above, the conversion from the baseband to the RF is performed by a USRP N210 transceiver (https://www.ettus.com/product/details/UN210-KIT), interfaced to the PC by means of a Gigabit Ethernet (GbE) cable. The PC acts as an asynchronous data source/data sink while the USRP implements in addition to an input buffer, up/down conversion and DAC/ADC functionalities.

In the full resolution option, the GbE I/F transfers full-duplex I/Q base band samples (the amplitude of the signal is normalized to 1 by the PC to match the constraints in input to the Front End) with a resolution of 16 bits per symbol. Data transfer across the I/F is mediated by flow control. Indeed, the USRP can only consume samples at a fixed rate, determined by its internal clock rate (DAC sample rate is 400 Msamples/s) and its internal interpolation factor. Since the PC Application SW could generate samples too fast, the USRP stores samples in its internal buffer and once this is full enough, it sends a "`pause_frame`" back to the PC to stop the transmission for a set time. This mechanism is implemented at Data Link level on the Ethernet link.

On the other hand, at the gateway, USRP generates data as fast as samples are created by ADC sample rate (100 Msamples/s) divided by decimation factor. The samples are sent over the Ethernet and, in this case, if the PC cannot process them, it does not send a "`pause_frame`" to the USRP but only print an error message on the shell.

The design of the Front-End and its interfaces with the Baseband section is reported in Figure 5-20 for the User Terminal and in Figure 5-21 for the Gateway.

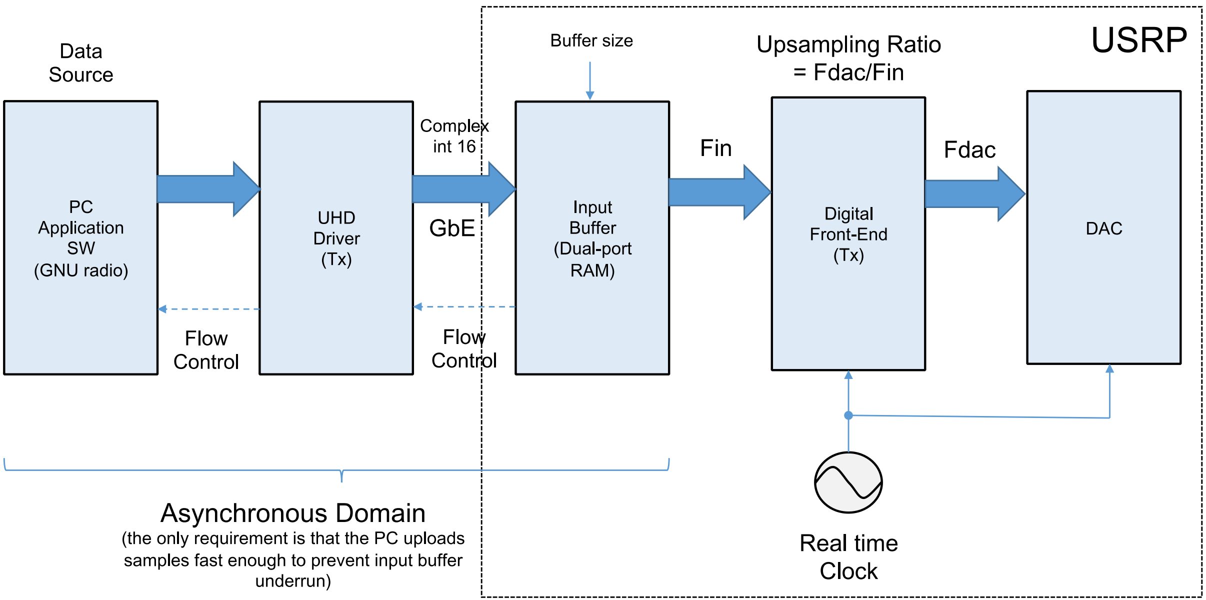


Figure 5-20: User Terminal: Baseband to Frontend interface

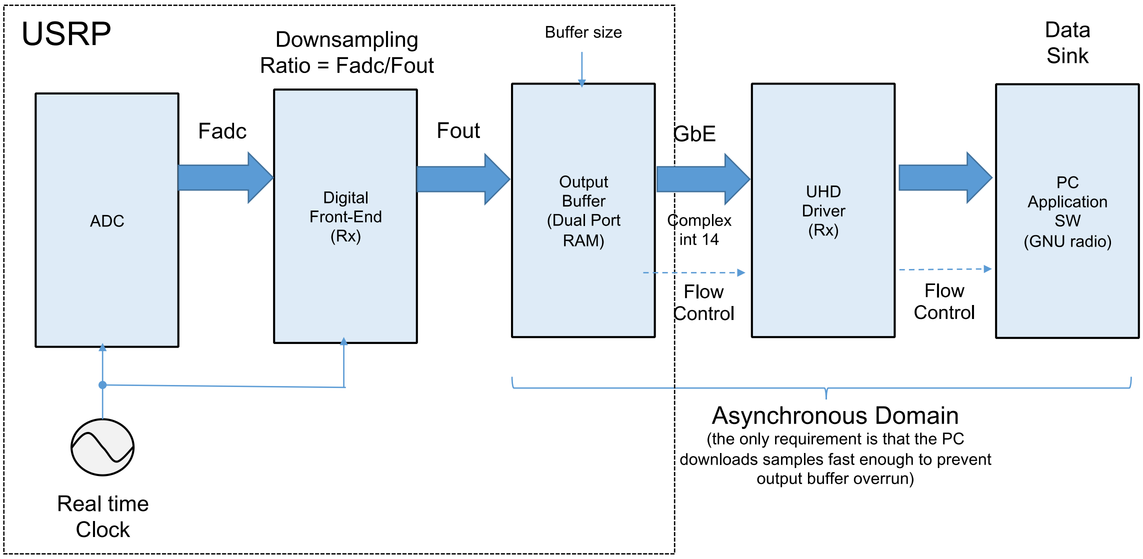


Figure 5-21: Gateway: Front-End to Baseband interface

5.3.4 Integration of SC-FDMA Test-Bed

The activity of integration of SC-FDMA Test-bed has foreseen three integration steps, as reported below:

- In **STEP 1** the Baseband section of the User Terminal has been integrated with the Baseband section of the Gateway (Digital-to-Digital integration).
- In **STEP 2** the integration between the Baseband and Front End sections has been performed and the system performance has been tested considering a digital channel module.
- In **STEP 3** the integration of the Test-Bed with the Channel Emulator has been addressed in order to be able to finally test and validate the performance of the demonstrator.

The final set-up of the SC-FDMA Test-bed is shown below in Figure 5-22.

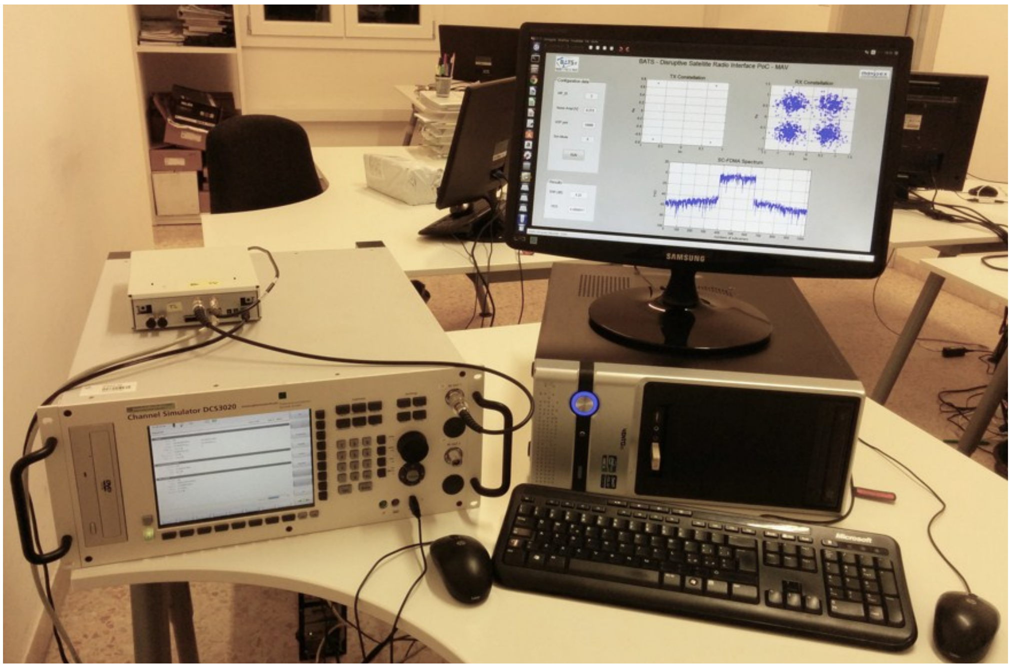


Figure 5-22: SC-FDMA Test-Bed - STEP 3 integration with the Channel Emulator

5.3.4.1 Control & Monitoring: GUI implementation

The SC-FDMA Test-Bed is configured and controlled through a Graphical User Interface (GUI) developed with the toolkit PyQt4 (http://zetcode.com/gui/pyqt4/introduction/), a blending of Python programming language and the successful Qt library.

The GUI enables the configuration of the scenario to be tested in terms of DVB-RCS2 Waveform_ID, UDP port, scenario (Sim Mode), and Noise Amplitude (to be set when a digital channel module is used).

On the other hand, it shows the statistics in terms of Packet Error Rate and estimated SNR in addition to the plots of the transmitted and received constellations and the transmitted SC-FDMA signal spectrum.

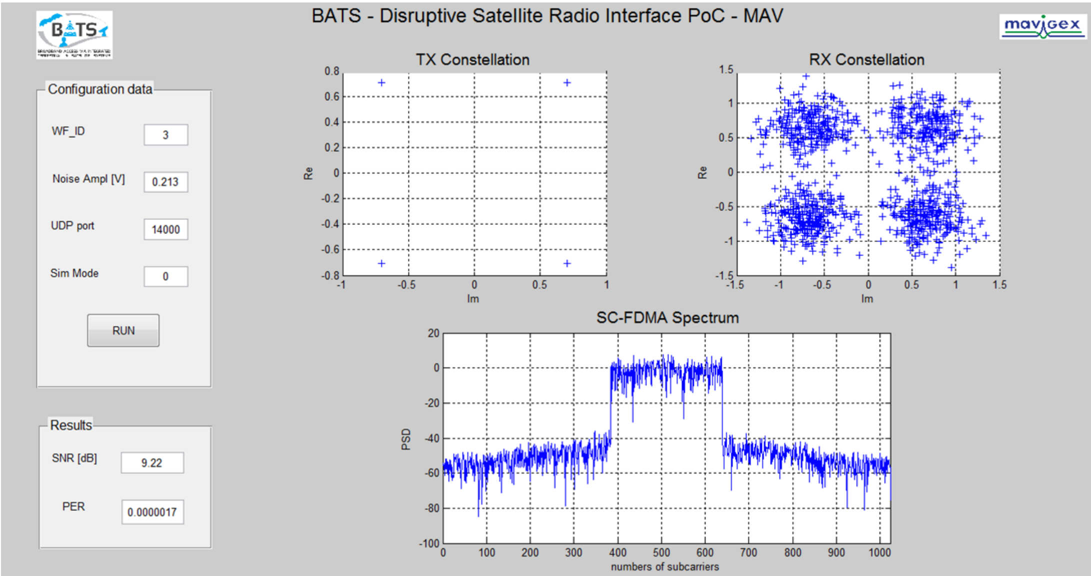


Figure 5-23: SC-FDMA Test-Bed: GUI implementation

5.3.5 Testing and Validation of SC-FDMA Test-Bed

Preliminary results achieved in the STEP 1 of integration activity, are reported in the Figures below. They show the proper working of the compensation algorithms through the use of scatter plots of the received constellation (QPSK in this case): starting from the cases reported in Figure 5-24 where the effects of non-compensated offsets can be seen, Figure 5-25 presents instead the received constellation after the estimation and compensation stage.

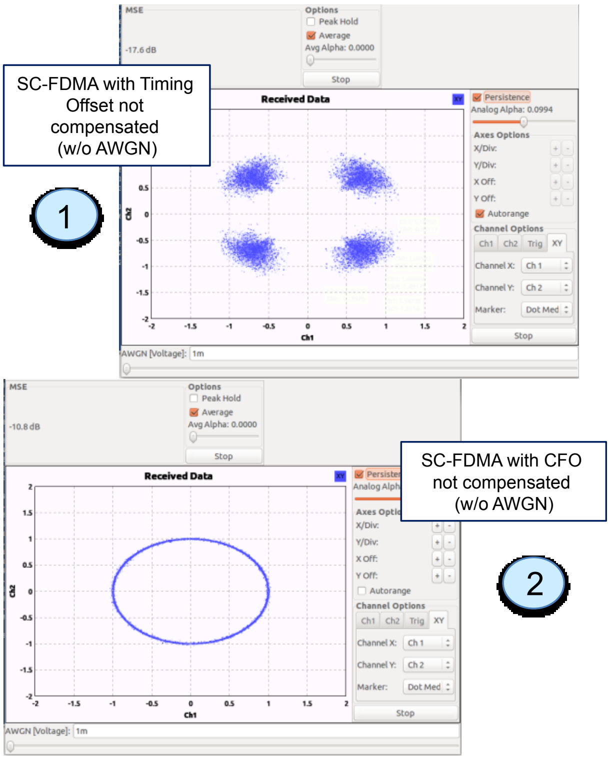


Figure 5-24: Timing offset (left) and CFO (right) not compensated

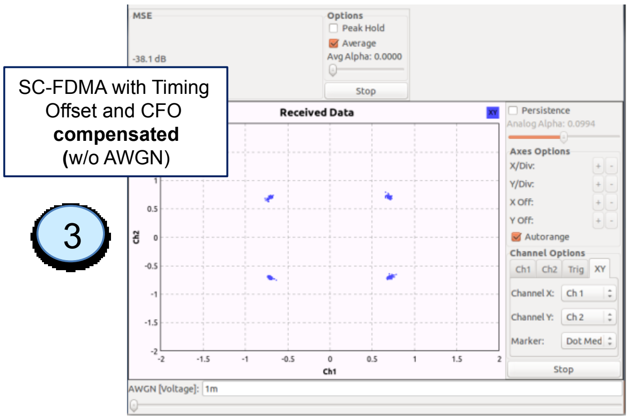


Figure 5-25: Timing and CFO compensated

In STEP 2, the digital sections of the Test-Bed have been integrated with the Front-End sections. Figure 5-26 shows the Power Spectral Density (PSD) of the SC-FDMA signal in input to the Front End. It is possible to see the 256 subcarriers of the total 1024 ones allocated to the user under consideration.

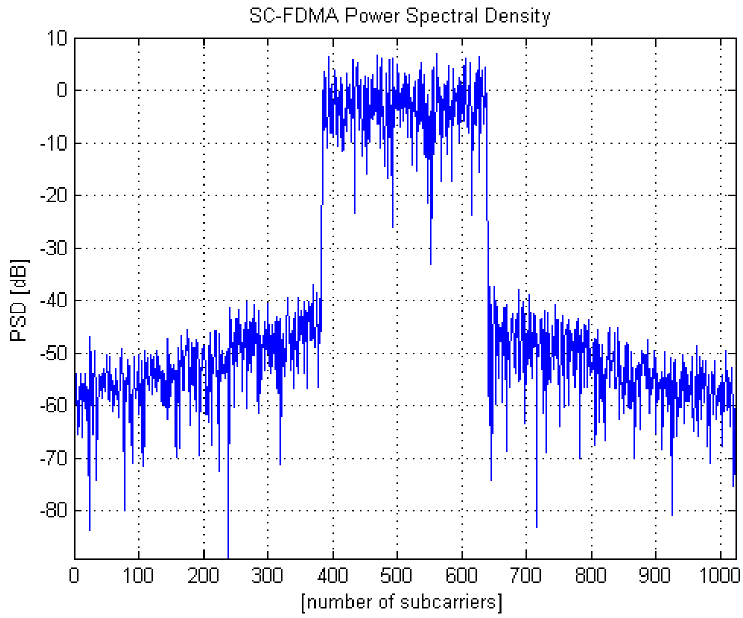


Figure 5-26: TX SC-FDMA signal spectrum - system FFT size: 1024 – user FFT size: 256

Figure 5-27 shows together with the transmitted signal PSD (TX in the Figure) also the received signal PSD (RX in the Figure) in output to the Front-End (and before of the digital channel module, if used). The achieved PSD is very similar to the transmitted one and this demonstrates how the Front End does not add frequency offsets.

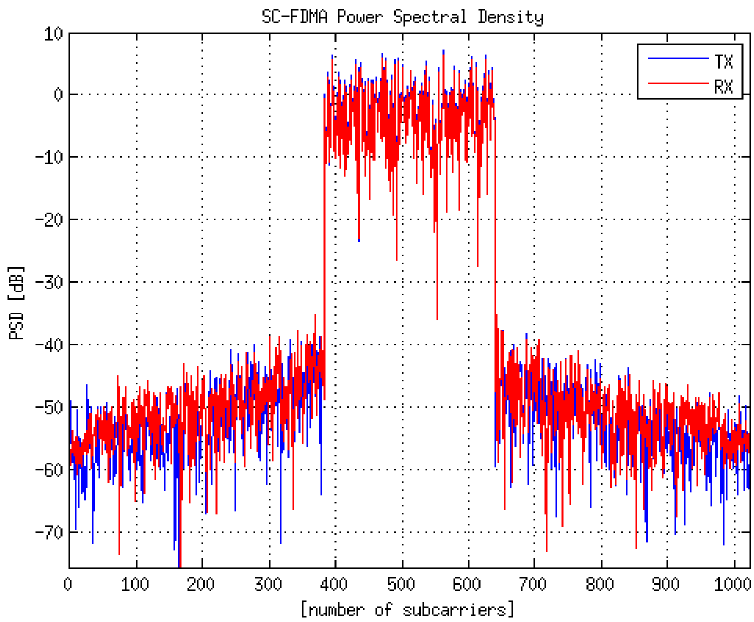


Figure 5-27: TX and RX SC-FDMA signal spectrum - system FFT size: 1024 – user FFT size: 256

In this phase of the integration, the following DVB-RCS2 Waveform IDs have been tested and the Packet Error Rate performance has been computed and compared with the digital-only system.

Table 5-5: Tested DVB-RCS2 Waveform_IDs

DVB-RCS2 WF_ID	
QPSK 1/3	Short Burst
8PSK 3/4	Short Burst
16QAM 5/6	Short Burst

As can be seen in Figure 5-28, Figure 5-29, and Figure 5-30, the performance of the three Waveform_IDs achieved after the integration with the Front End are in line with those obtained without the USRP integration. This validates the proper integration of the Baseband and Front End sections.

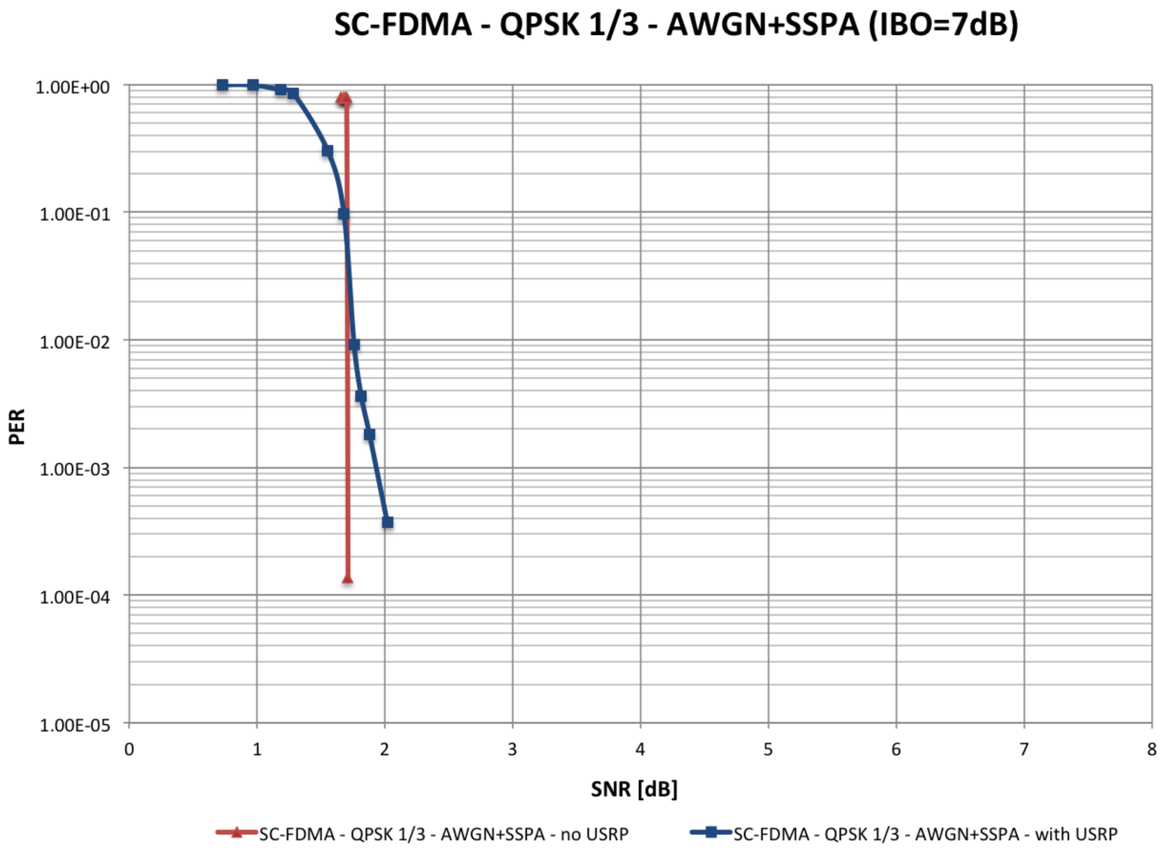


Figure 5-28: Packet Error Rate – QPSK 1/3 – AWGN+SSPA – with and without USRP

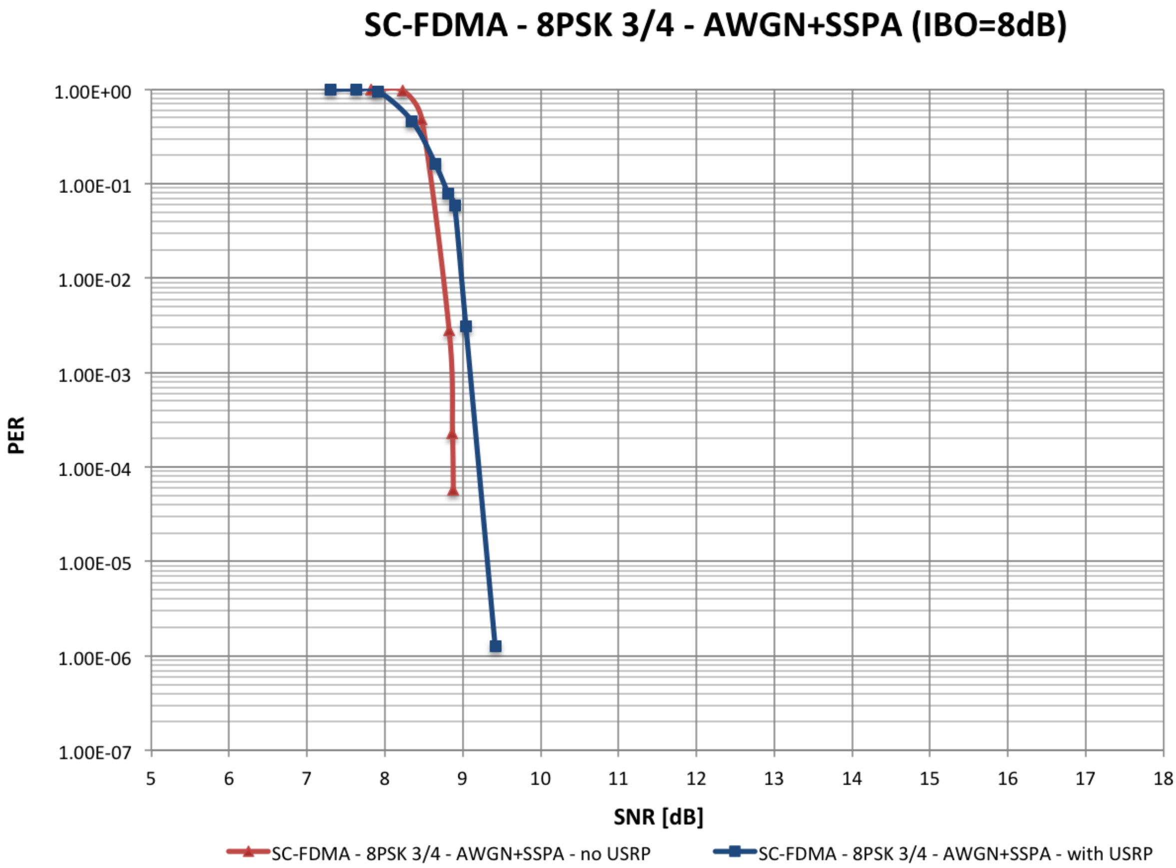


Figure 5-29: Packet Error Rate – 8PSK 3/4 – AWGN+SSPA – with and without USRP

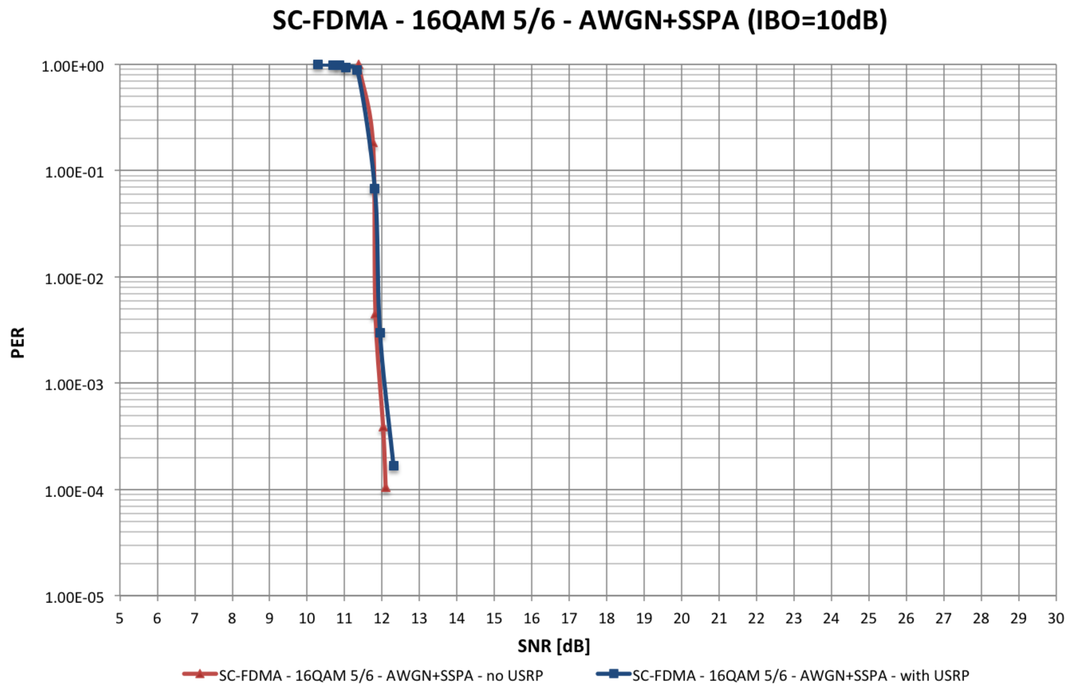


Figure 5-30: Packet Error Rate – 16QAM 5/6 – AWGN+SSPA – with and without USRP

Afterwards, the system has been tested considering the presence of timing and frequency offsets (non-ideal synchronization). In particular, a normalized CFO of 0.1 (this means that terminal and gateway oscillators are misaligned of 0.1*Δf, where Δf is the inter sub-carrier frequency space) and a TE of 2 (this means that the acquisition stage outputs a signal with a relative drift of 2 sample with respect to the nominal start of frame) have been considered in these tests. If no specific algorithms are applied, the system is not able to demodulate data. On the other hand, as shown in Figure 5-31, Figure 5-32, Figure 5-33, if the selected compensation algorithms described above are applied, the system works properly, although with a degradation in terms of PER with respect to the AWGN-only scenario (ideal synchronization).

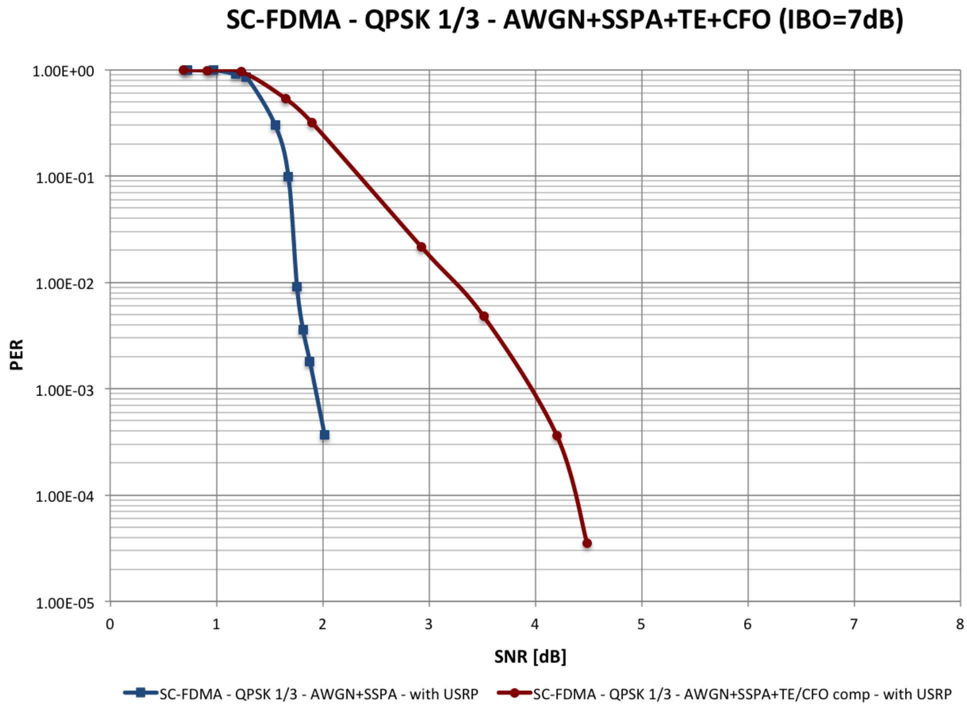


Figure 5-31: Packet Error Rate – QPSK 1/3 – AWGN+SSPA and AWGN+SSPA+TE+CFO with USRP

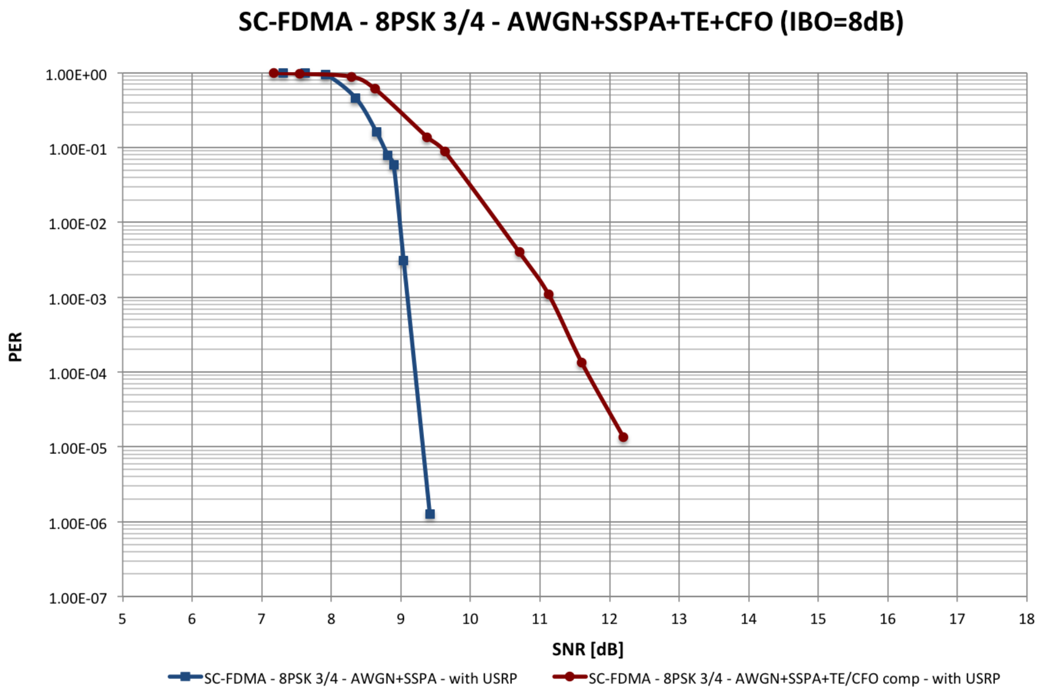


Figure 5-32: Packet Error Rate – 8PSK 3/4 – AWGN+SSPA and AWGN+SSPA+TE+CFO with USRP

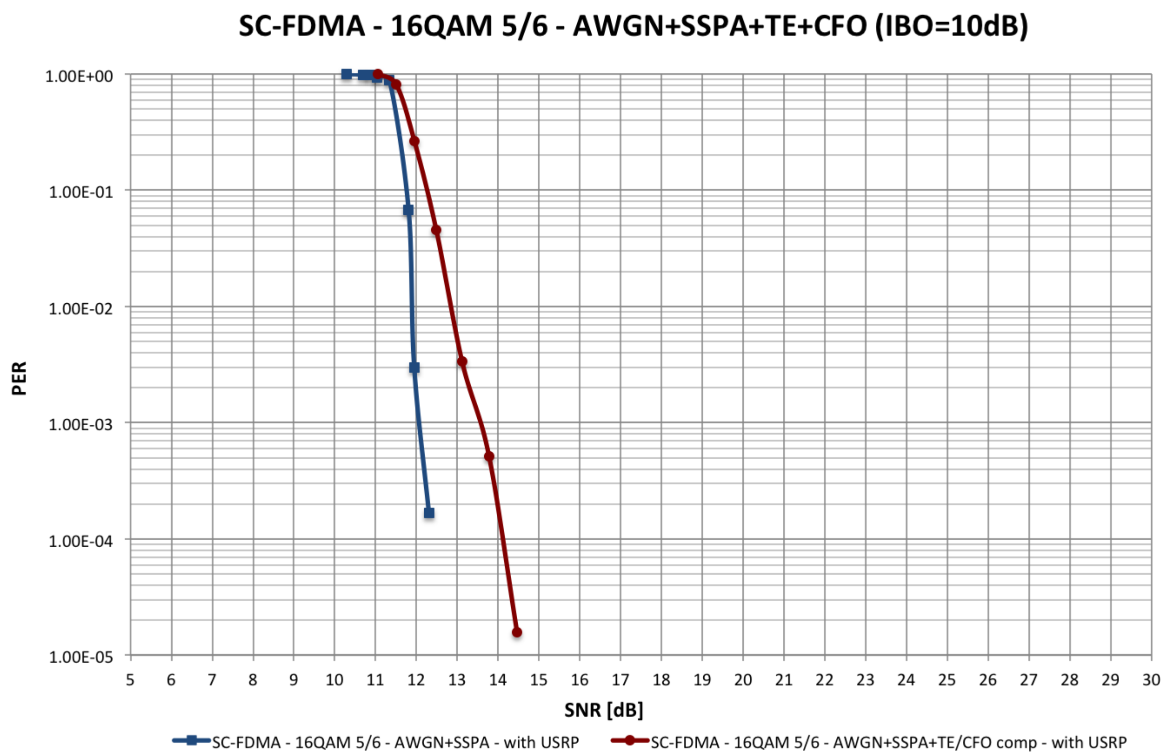


Figure 5-33: Packet Error Rate – 16QAM 5/6 – AWGN+SSPA and AWGN+SSPA+TE+CFO with USRP

Step2 also required putting the attention to some issues that often arise in the integration of the USRP front-end with the digital part of the system. In particular, the *"underflow"* and *"late packet errors"* conditions have to be kept under control.

More in detail, when transmitting, the device consumes samples at a constant rate. *Underflow* occurs when the host does not produce data fast enough. When the PC Application SW detects the *underflow*, it prints a "U" to the standard output. The causes of this error are usually attributable to a high CPU usage and therefore to over-exploitation of the resources of the machine and to complexity of the code used to implement the communication chain. It is important therefore to find a trade-off between the set sample rate and the optimization of the code.

On the other hand, *late packet errors* concern sending late data/commands to the USRP. There are however some specific functions like "`set_time_now()`" that set the reference time in the USRP. Then the transmission and the reception of data is initialized using the function "`set_start_time()`". The FPGA inside the USRP reads the timestamp on the sent packet and if this is in the past when command reaches the device, the USRP drops the packet and prints "L" to the standard output. The solution in this case is to set the start time forward in the future so that the timestamp takes into account of the latency and clock drift between PC Application SW and USRP.

Finally, in the **STEP 3** of the integration activity, the Test-Bed has been connected to the Channel Emulator (IZT DCS 3020, http://www.izt.co.jp/pdf/izt_dcs3020_02.pdf) and some tests have been performed in order to check the performance in presence of a more realistic channel. The parameters (noise gain, AGC gain, output power, etc.) of the Channel Emulator have been properly set up and configured in order to emulate the AWGN and non-ideal synchronization conditions.

Figure 5-34 shows the user signal (QPSK constellation in this case) sent through the Channel Emulator and received from the Front End before and after the timing offset compensation stage. Also in this case, the proper working of the synchronization algorithms on the received symbols can be highlighted (see the right side of the Figure).

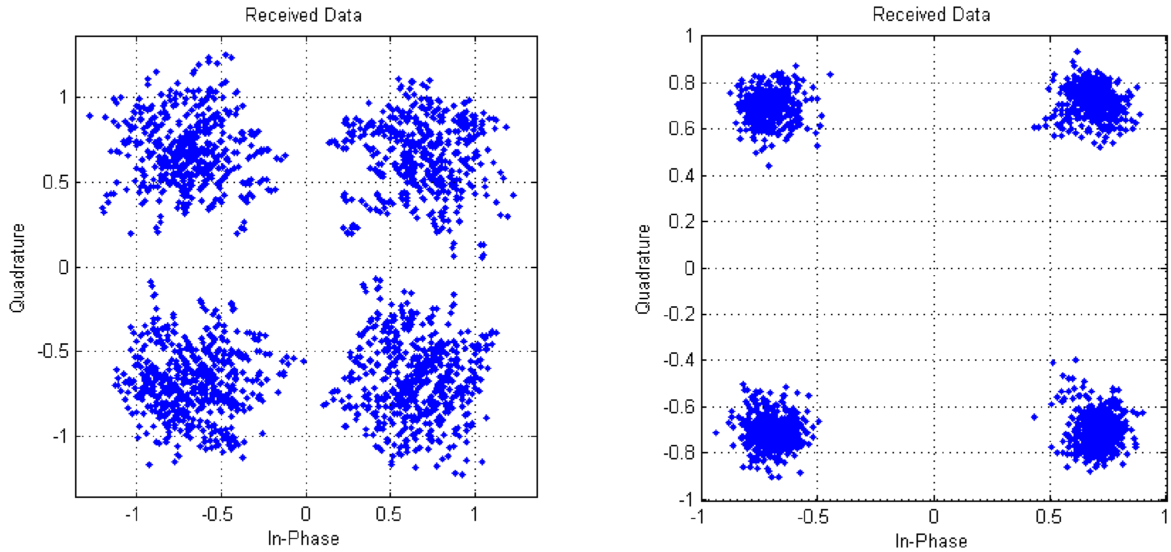


Figure 5-34: Not compensated (on the left) and compensated (on the right) constellation

Moreover, Figure 5-35, Figure 5-36, and Figure 5-37 report the achieved PER performance in presence of the Channel Emulator compared with the ideal synchronization case (when the digital channel module is used to simulate only the AWGN conditions). The Figures show how also in this case the compensation algorithms are able to compensate the impairments introduced by the Channel Emulator, although a slight degradation is introduced.

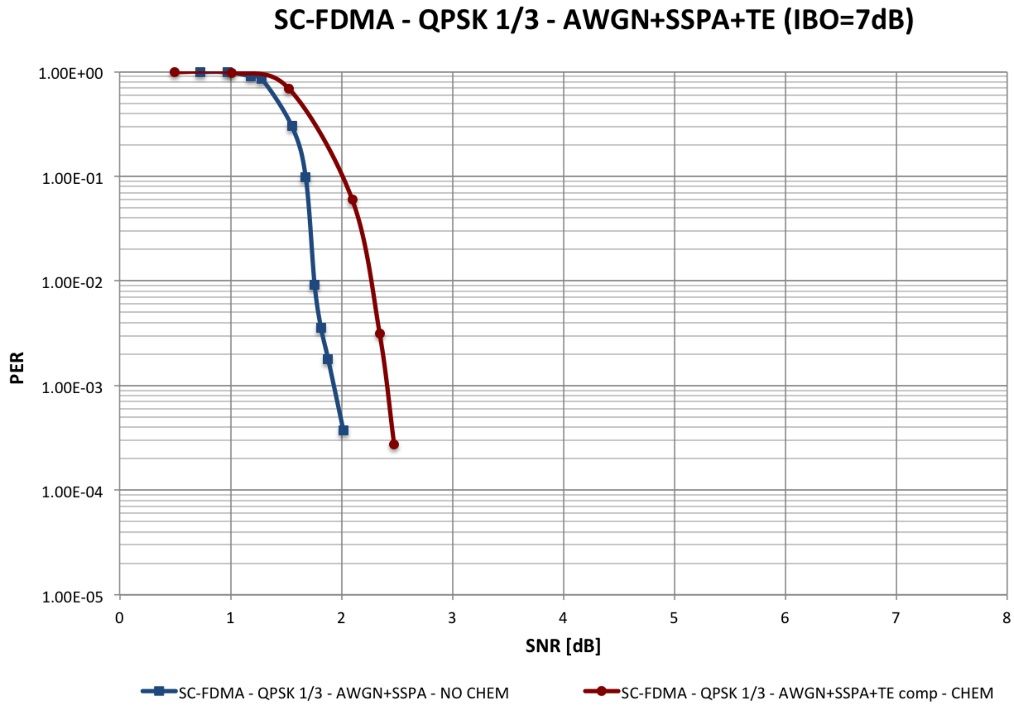


Figure 5-35: Packet Error Rate – QPSK 1/3 – AWGN+SSPA NO CHEM and AWGN+SSPA+TE with CHEM

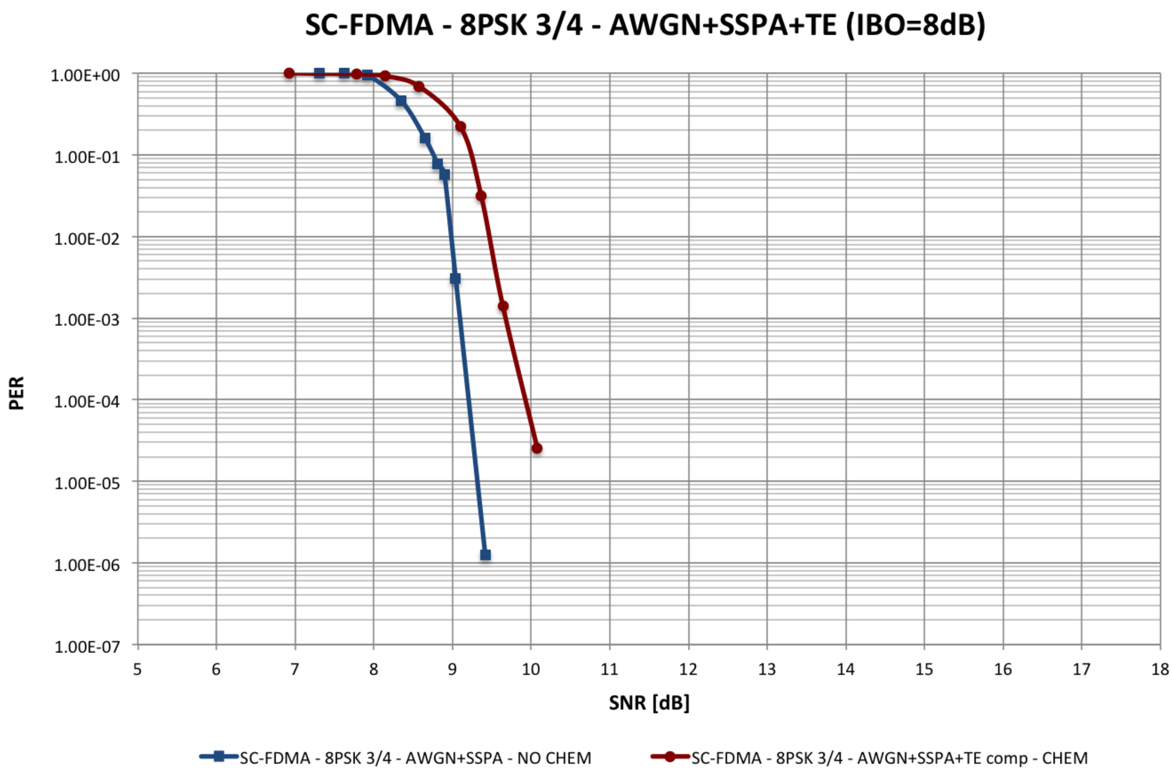


Figure 5-36: Packet Error Rate – 8PSK 3/4 – AWGN+SSPA NO CHEM and AWGN+SSPA+TE with CHEM

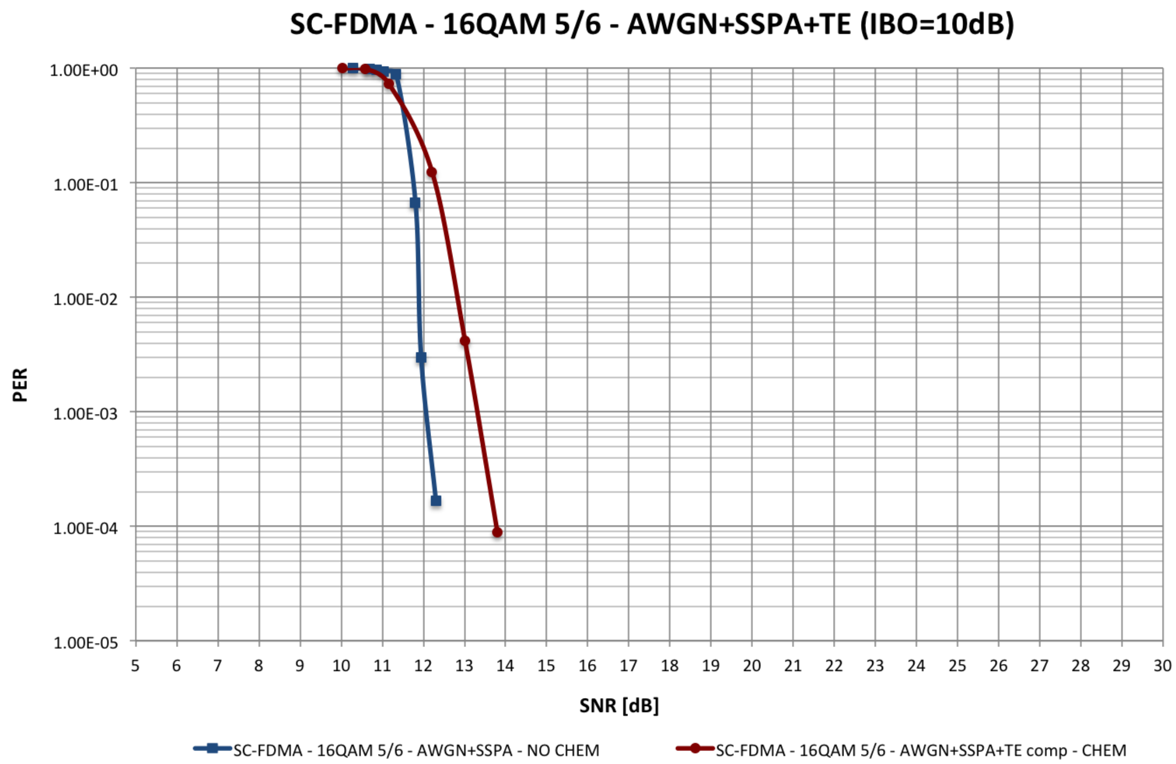


Figure 5-37: Packet Error Rate – 16QAM 5/6 – AWGN+SSPA NO CHEM and AWGN+SSPA+TE with CHEM

5.4 FBMC vs OFDM

Refers to work performed in WP4, where a theoretical analysis has been performed.

5.4.1 Motivation and Objectives

The extension of mobile networks with satellites is a promising step to solve the lack of high speed connectivity in rural areas and to provide service continuity by allowing vertical handover to terrestrial radio interfaces. Satellites can provide coverage and capacity for large areas and by using independent spot-beams in combination with spectral reuse over large number of beams, as depicted in Figure 5-38.

Thus, load balancing and flexible resource management between spot-beams can account for varying and inhomogeneous traffic demands within the coverage zones and increase the system performance. In order to allow flexible and efficient access of the spectrum, multi-carrier (MC) transmission schemes are discussed for Satellite Communication (SatCom) systems like single carrier frequency domain multiple access (SC-FDMA) and orthogonal frequency division multiplex (OFDM).

However, due to the good spectral properties and robustness to time and frequency synchronization error, one of the promising candidates for satellite MC transmission is based on filter bank multicarrier (FBMC), which is also discussed for 5G mobile networks. Initial conceptual studies investigating the performance of FBMC versus OFDM for SatCom applications have been presented in WP4, especially with focus on non-linear distortion.

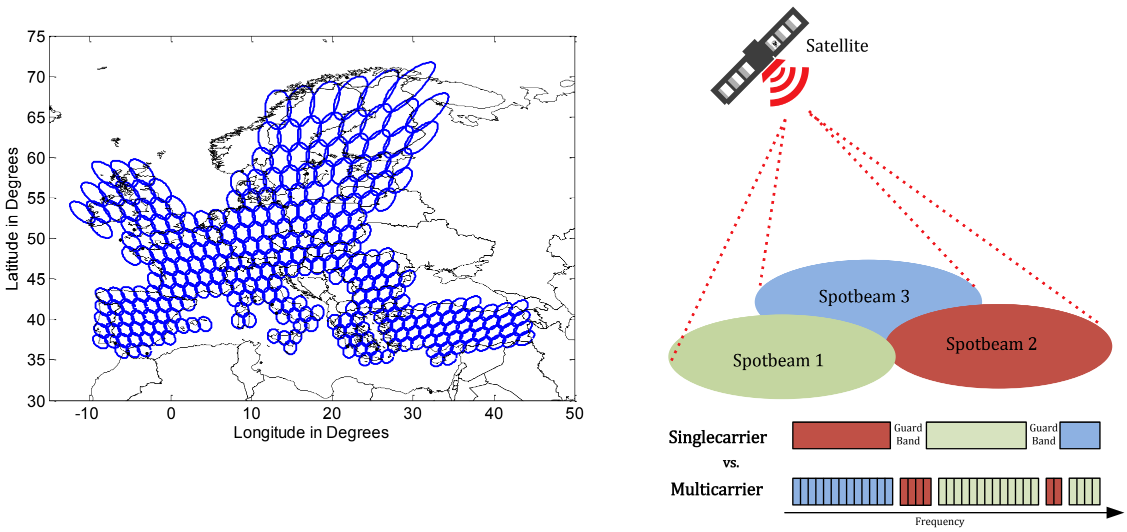


Figure 5-38 Flexible resource allocation using multicarrier transmission for spot-beam satellite systems

As a consecutive step, a proof-of-concept based on a real hardware implementation is in the focus. In this paper, the experimental testbed setup is described, using software defined radio (SDR) platform and satellite channel emulator to assess the performance of different MC techniques under realistic conditions.

5.4.2 Multicarrier Implementation

Generally, a MC system can be described by a synthesis/analysis filter bank, i.e. a trans-multiplexer structure, as depicted in Figure 5-39. The synthesis filter bank is composed of all parallel transmit filters, while the analysis filter bank encompasses all matched receive filters, where ptx(t) and prx(t) denote the transmit and receive prototype filters, respectively.

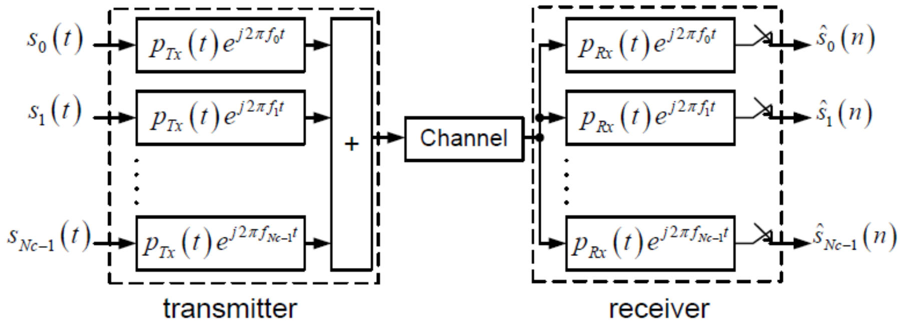


Figure 5-39 Block diagram of a multicarrier transceiver

The prototype filter is the first filter in the bank which is associated with the zero frequency carrier. All other filters are deduced from it through frequency shifts and for each subcarrier k, the filter is the prototype filter modulated by e^j2fkt and the phase shift in the time domain implies a frequency shift of fk in the frequency domain.

In OFDM, the inverse and forward discrete Fourier transform (DFT) is used for the analysis and synthesis filter-bank and the prototype filter is a rectangular window, which results in relatively large side lobes in the sub channel spectrum.

The implementation of the SMT-FBMC de-/modulator is based on the PHYDIAS framework, where an efficient implementation based on poly-phase networks is proposed. The Rx/Tx module is implemented using MATLAB and the parameter which can be modified. The parameters are summarized below in Table 5-6.

Parameter	Symbol	Description
Number of sub-carrier	M	Is chosed to be a power of two
Number of symbols per frame	N	
Overlapping factor	K	Parameter of the prototype filter
Type or the prototype filter	Type	Here we use PHYDIAS
Modulation order	q	Q-ary modulation

Table 5-6 Parameter of FBMC/OFDM Multicarrier Module

The modulator as depicted in Figure 5-40 is used to generate time discrete IQ-samples of finite length, denoted as frame. A frame consists of N M symbols.

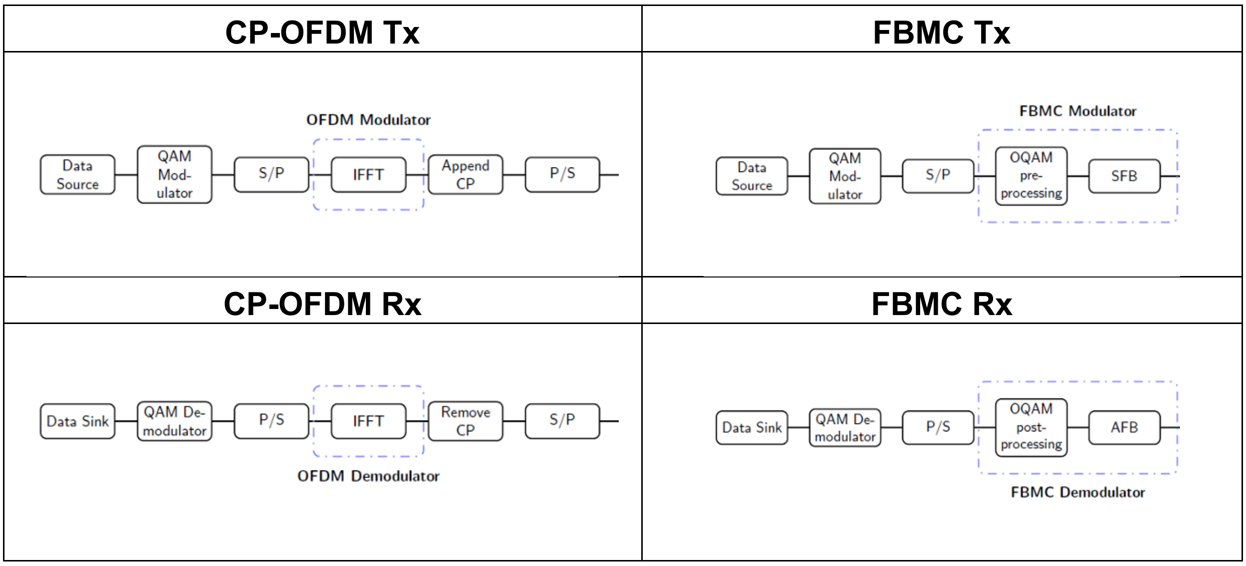


Figure 5-40 Implementation of Multicarrier Modulator/ Demodulator

The resulting time domain signal is illustrated in Figure 5-41, where the amplitude of the real part of the first time-domain samples of an IQ multicarrier-frame is depicted.

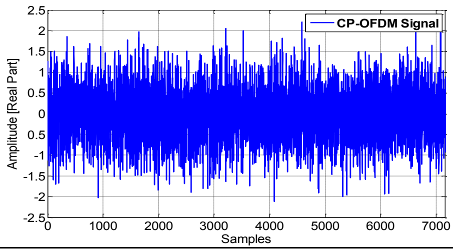
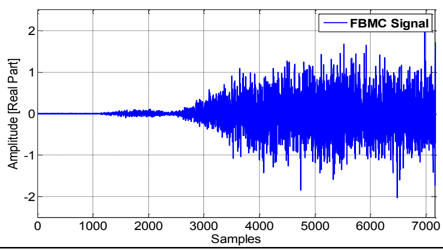
CP-OFDM	FBMC
	

Figure 5-41 Time domain signal of CP-OFDM and FBMC

5.4.3 Testbed setup and Integration of MC-Modulator in HIL chain

The general Hardware in the Loop – setup is depicted below Figure 5-42, where the components and the connections are depicted.

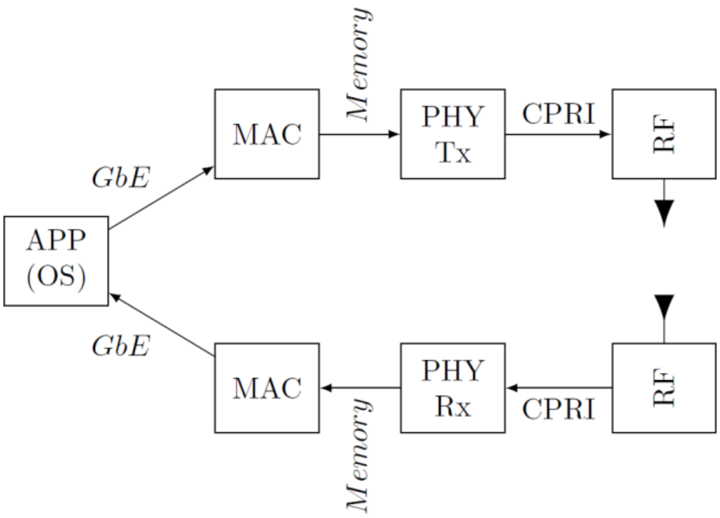


Figure 5-42 HIL experimental setup

Including the multicarrier modulation into this framework is depicted in Figure 5-43.

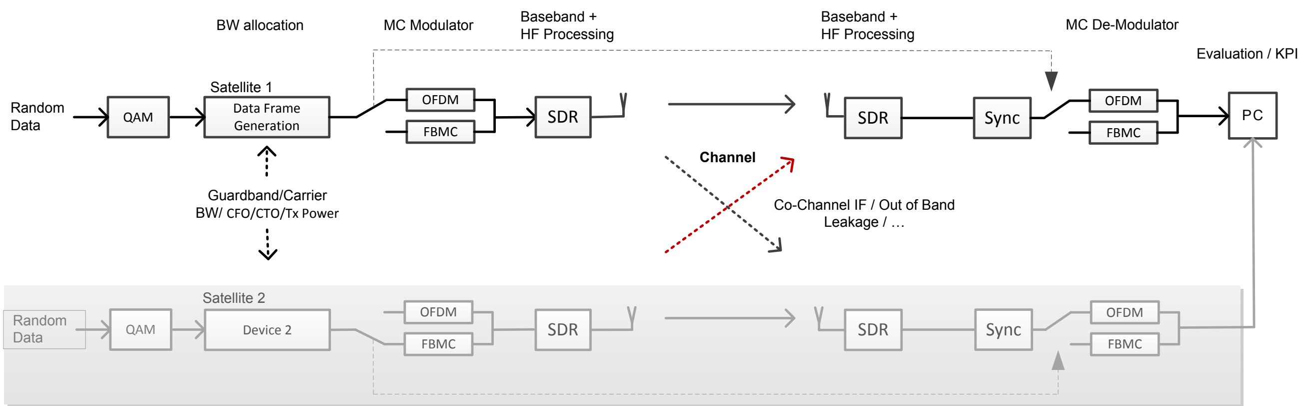


Figure 5-43 Integration of multicarrier modulation into demonstrator

Random binary data is modulated using an q-ary QAM – modulator. Then, the qam-data is mapped to a predefined grid of subcarrier – timeslots, which is referred to as “frame”. This frequency-domain representation of the radio-frame is then modulated into complex baseband signals by using the MC-modulator as described above.

The PHY and RF processing is performed at the SDR unit.

To control and parametrize the measurements, a MATLAB – based GUI was developed where all relevant settings can be configured. A screenshot is depicted in Figure 5-44.

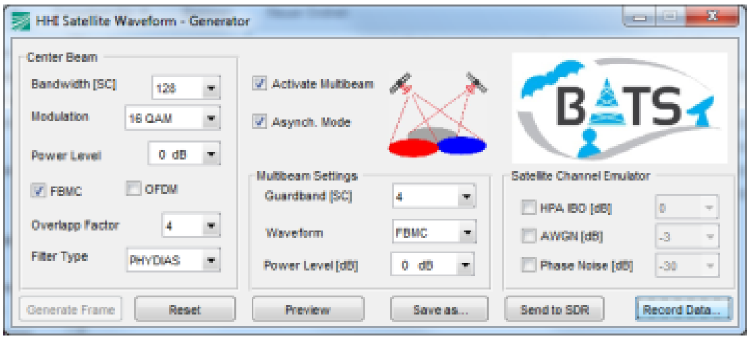


Figure 5-44 Screenshot of the MATLAB-based control-GUI

Measurement workflow

- First, the measurement is parametrized by setting the number of subcarrier, channel impairments, selected waveform, etc.
- Then the data-frames are generated with 307200 I/Q samples per frame which corresponds to 10ms @ 30.72MHz sample rate. A resolution of 12 bit is used.
- The data frame is send to SDR devive using GbE and internal RF processing modulates the signal to the selected carrier frequency.
- Frames are cyclically looped to simulate a continuous transmission. The Rx unit records pre-defined number of samples between 10..50ms @30.72MHz.
- The recorded IQ samples are send to PC using GbE and an offline synchronization based on zadoff-chu sequences is performed.
- The post-processing is performed using MATLAB and the demodulated data frames are analysed in order to extract the KPIs at the PC.

The setup is shown as-built in the HHI laboratories is shown in Figure 5-45 below.

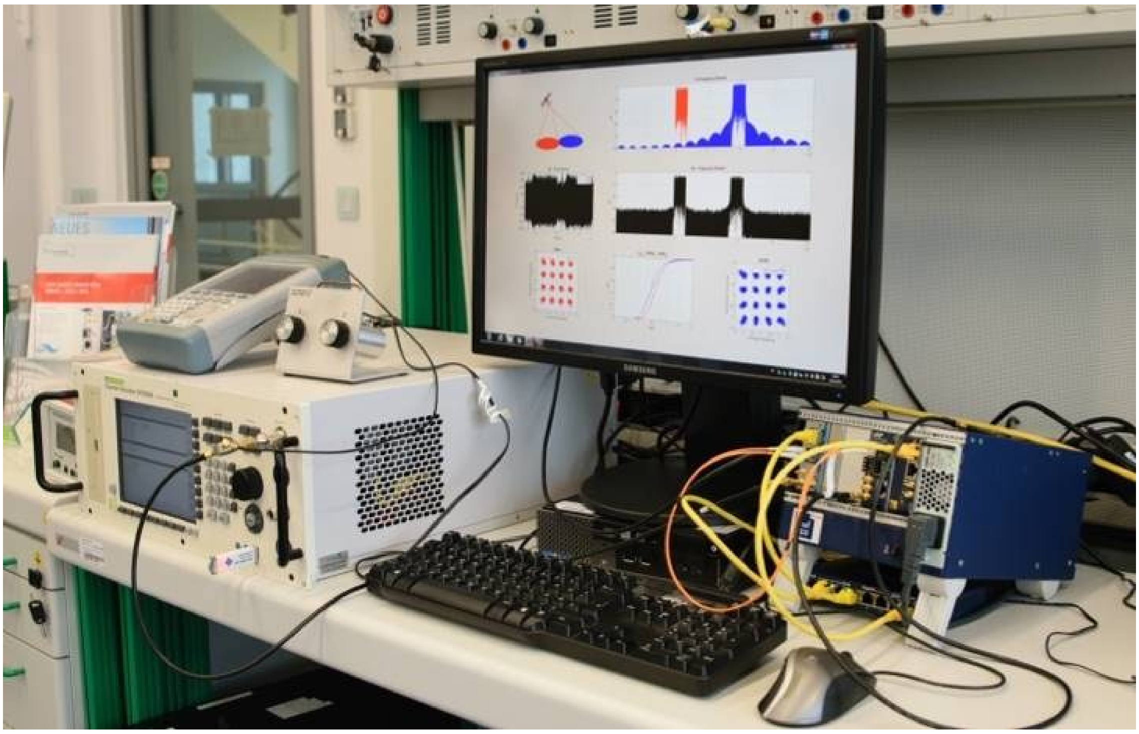


Figure 5-45 Testbed setup in the laboratory

In order to compare the performance of an FBMC and OFDM signal, a signal frame as depicted on the top right of Figure 5-46 is generated, comprising two multicarrier signals, 128 subcarrier each with 15kHz subcarrier spacing for FBMC (red) and OFDM (blue).

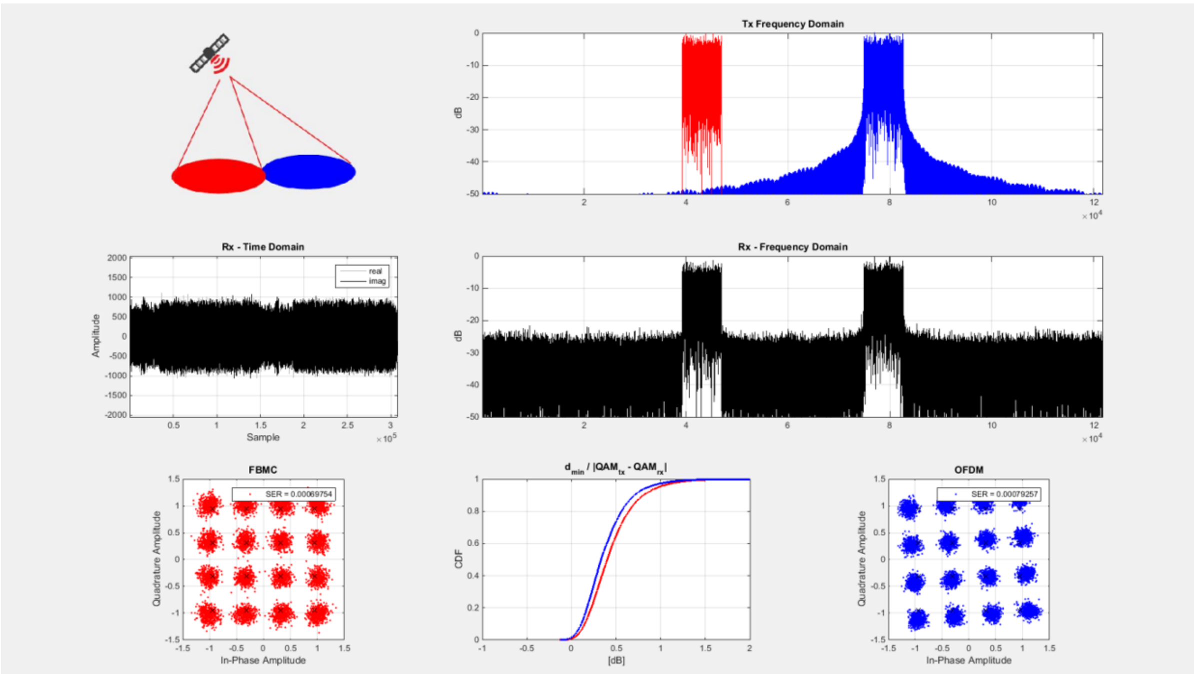


Figure 5-46 Scenario: two multicarrier components: FBMC (red) and OFDM (blue) each comprising 128 subcarrier with 15kHz subcarrier spacing.

On the top left of Figure 5-46, the scenario illustration is depicted including one satellite with two spot beams on orthogonal frequency resources). The two beams using FBMC (red-curves) and OFDM (blue curve) as multicarrier modulation, respectively. On the top right, the respective signals are depicted in the frequency domain prior to quantization/transmission. The high side-lobe attenuation of FBMC (> 50dB) compared to OFDM is distinguishable.

In the center-left of Figure 5-46, the real – and the imaginary part of the measured time-domain signal at the Rx – unit of the SDR is depicted and the corresponding power density spectrum is given on the right.

On the bottom-left and right of Figure 5-46, the IQ-constellations are depicted after synchronization and equalization of the FBMC (red) and OFDM (blue) beam. The black dots correspond to the transmit QAM constellation (QAM_{Tx}), the red dot the decoded QAM constellations including the impairments (QAM_{Rx}).

In the bottom-center the empirical cumulative distribution function of the normalized error for all symbols within the respective beams is depicted. The error is defined as ratio: the distance of the Tx to the Rx constellation in the denominator and d_{min}, in the numerator. Here, d_{min}, is given by the minimum distance between two (ideal) constellation points, divided by 2 and depends on the modulation order. Note that d_{min} defines the decision region of at the QAM demodulator. If the error of a received constellation point is smaller than d_{min}, the Rx symbol can be detected correctly. That means if the normalized error value is positive in dB, the symbol can be decoded correctly.

5.4.4 Evaluation Results

In the following, the results of the measurements performed with the testbed described above are summarized. In Figure 5-47, the symbol error rate (SER) performance over a linear channel (without channel impairments) is depicted for 128sub-carrier and 16QAM. It can be seen that CP-OFDM shows a slightly better performance in terms of SER in the high SNR regime.

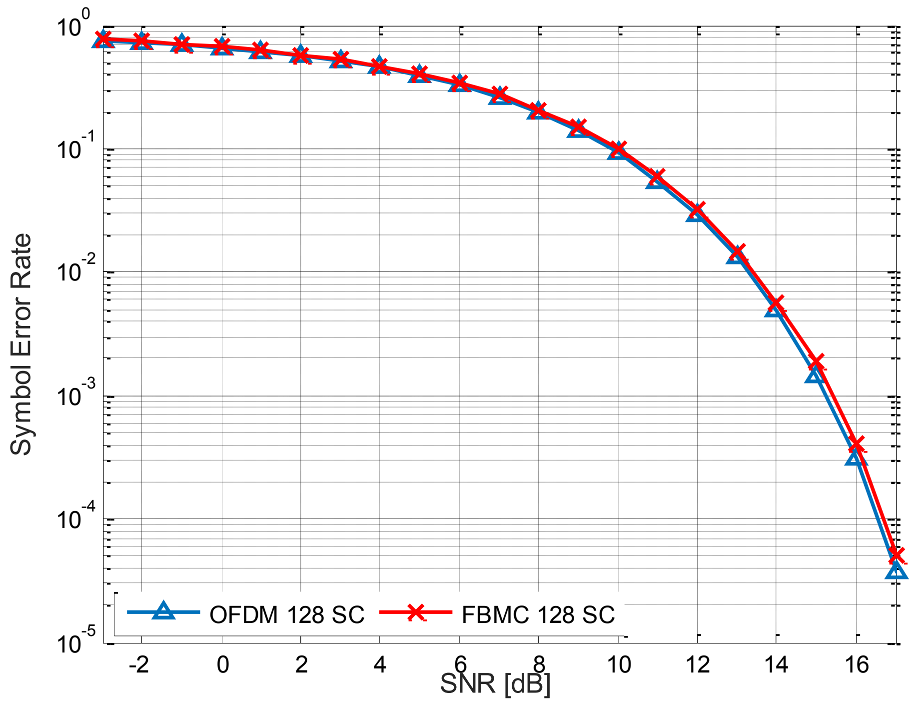


Figure 5-47 Reference SER performance measurements without channel impairments

In Figure 5-48, the measurement results including the effect of non-linear HPA are depicted for different IBO values versus SNR.

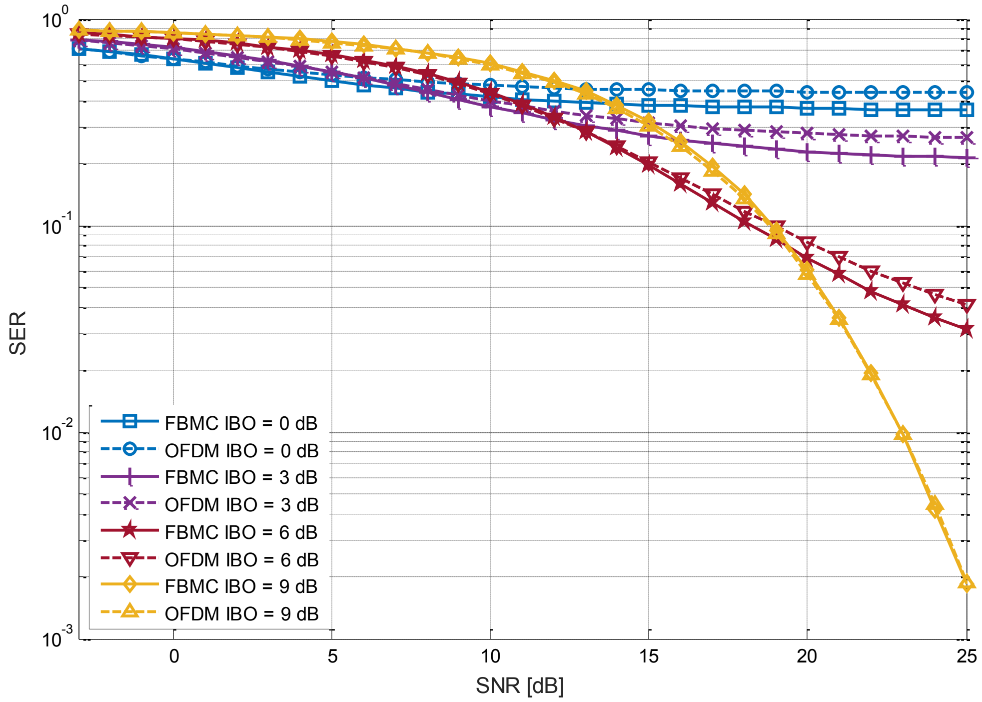


Figure 5-48 SER for different fixed IBO values versus SNR

In Figure 5-49, the measurement results including the effect of non-linear HPA are depicted for different SNR values with fixed IBO.

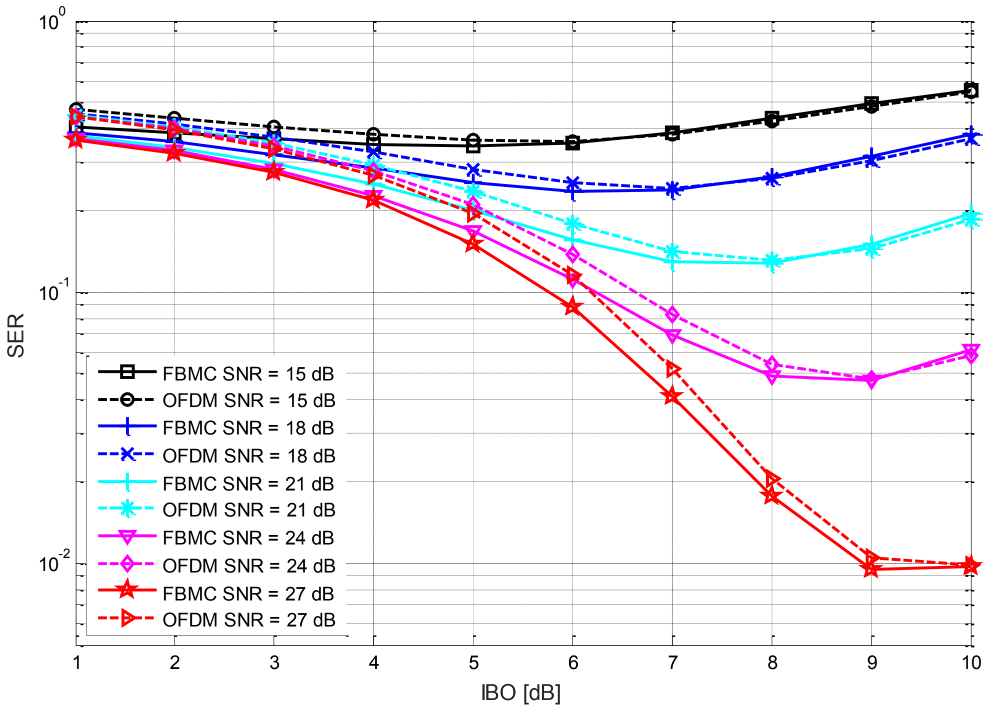


Figure 5-49 SER for different fixed SNR values versus IBO

5.4.5 Conclusion – what does that mean for BATS

The SER performance of OFDM and FBMC is summarized for variable SNR and IBO values in Figure 5-50. It can be seen that direct comparison in terms of SER between FBMC and OFDM reveals that in low SNR regions the performance is comparable whereas for higher SNR regions and strong non-linear distortion (low IBO), FBMC shows better performance.

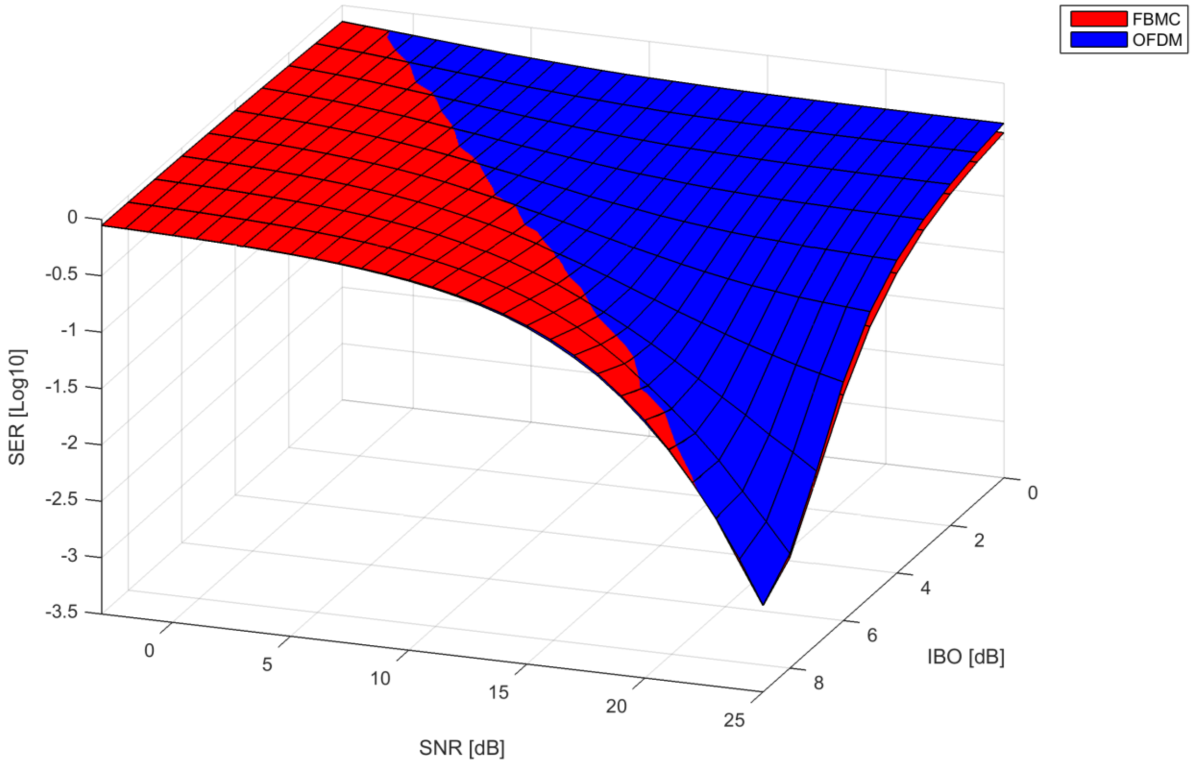


Figure 5-50 SER performance comparison FBMC vs. OFDM

Aligned with the theoretical analysis performed in WP4 it is seen that, under non-linear distortion, both schemes show similar performance in terms of peak-to-average power ratio (PAPR) and symbol error rate (SER). However, FBMC is less sensitivity to carrier frequency offset (CFO) which remains valid even under non-linear high power amplifier (HPA) and allows a guard-band reduction and thus increase bandwidth efficiency.

In this PoC we compared the re-use of OFDM / FBMC multicarrier scheme over satellite to ease as much as possible the integration with terrestrial infrastructure. One of the main impairment in satellite communication, especially with MC systems, is the non-linear power amplifier. The FBMC sub-channels are in general well separated thanks to the properly designed prototype filter however both FBMC and OFDM experience similar spectral regrowth at the output of the amplifier which degrades the performance and creates out-of-band interference as shown in analytical results in WP4. Within this PoC, the measurement of the SER in the testbed showed that FBMC outperforms OFDM for different IBO in low SNR regimes. Together with the theoretical analysis of WP4, these results prove that advanced multicarrier is feasible for satellite communications and that reduced guard bands among physical carriers with FBMC could still be considered even for satellite systems. However, further R&D has to focus on how to integrate these advanced MC concepts into practice and how to cope with the high PAPR of the signal in order to increase energy efficiency.

5.5 *Network Management MTOSI Interfaces implementation*

The objective of this activity was develop a proof of concept, using the MTOSI (Multi-Technology Operations Systems Interface) interfaces as a basis, to support the service provisioning processes for a complex service like BATS integrating heterogeneous technologies from terrestrial and satellite operators. The choice of MTOSI interfaces is an outcome of the WP5.2 activity (see D5.2).

The MTOSI interfaces offer a horizontal abstraction for the interconnection of different components needed on the Telco service activation, and connects with the vertical components through an integration layer to simplify the adoption of the MTOSI interfaces in the scope of the PoC.

The aim for the implemented test-bed is the testing of some processes needed for the activation of services based on several technologies as BATS service defines. The tests focus its activity on the complete lifecycle process use case, from the feasibility to the activation and finalizing with the termination of the service, always considering special cases useful in the telco environment.

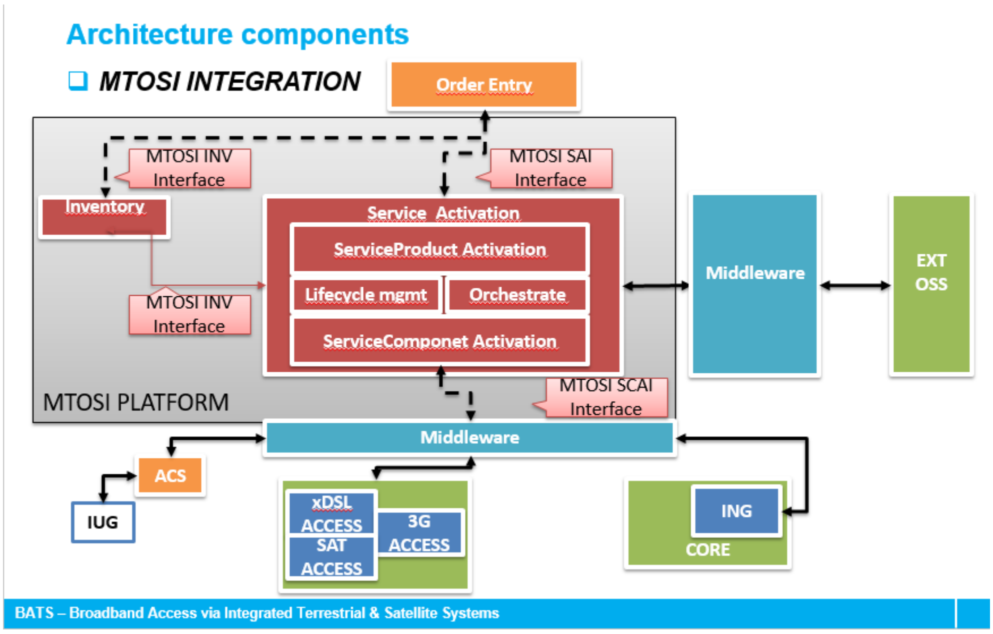


Figure 5-51 POC Architecture

The external OSS used for these tests included the Avanti satellite OSS which has a set of functions accessed through a defined programmatic interface (REST or Representational State Transfer based)

5.5.1 Implementation of MTOSI Interfaces

This proof of concept has selected several processes associated with the service activation area and evaluates the capacity of the MTOSI interfaces for offer support for managing these processes completeness. The MTOSI interfaces have been defined for managing multi technology communication support systems. It has evolved from a first well defined version to new modified versions that support small changes and there is no reference implementation that could offer guarantees for the support of complex and heterogeneous services like BATS.

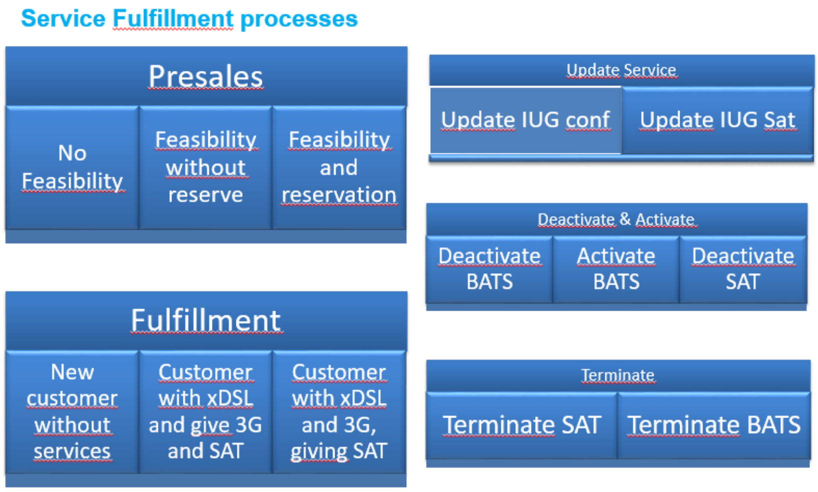


Figure 5-52 Service Activation processes considered in the PoC

Several versions were evaluated during the project to accommodate the evolution of the interfaces and its new functionalities. The first version implemented was version 3.0 and the last was the update to the version 4.0 at the beginning of year 2015. From the several subprojects in the MTOSI interfaces we select the necessary for the support of service activation processes and in the next subsections we offer a detailed view of the interaction with the different modules.

5.5.1.1 Service Activation Interface

The Service Activation Interface (SAI) is the definition of the northbound interface of the Service Domain towards the Product Domain to allow the activation of the Customer Facings Services (CFS). It offers several operations to manage the process (described deeply at D 3.5.2). In the PoC an implementation of the interfaces and a default logic was built to understand the capabilities for the service management processes.

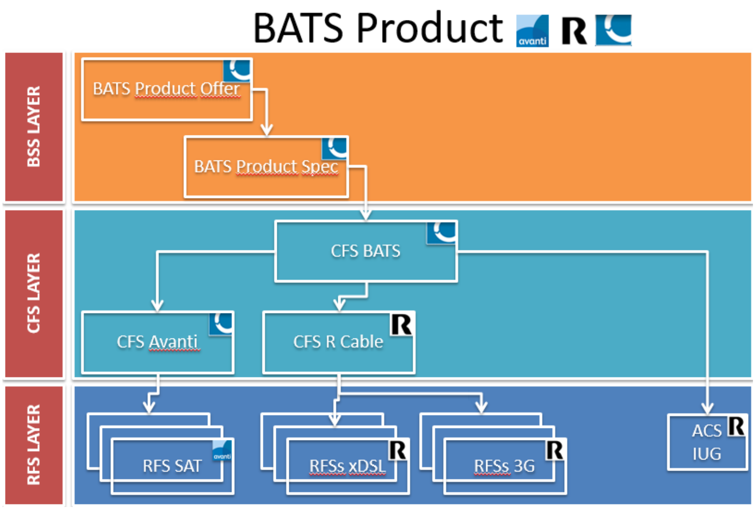


Figure 5-53 BATS Definition

The interfaces where built over an asynchronous behaviour receiving the requests over a web service interface deployed on an application server using an open source persistence framework. It is supported by the inventory API in the persistence operations needed for the management. The operations follow in a default behaviour the recommendations of the TM Forum in the use of MTOSI and perform a plain hierarchized orchestration for activate and deactivate the services that compose a BATS product as is detailed in the previous figure. The SA interfaces performs de default logic supported by the inventory and the service components through the SCA interface. All the mappings between the SAI and SCAI objects are performed in a simple operation taking in account only the templates for each service. This mapping between the CFS and RFS characteristics is defined in one class per product in the catalogue.

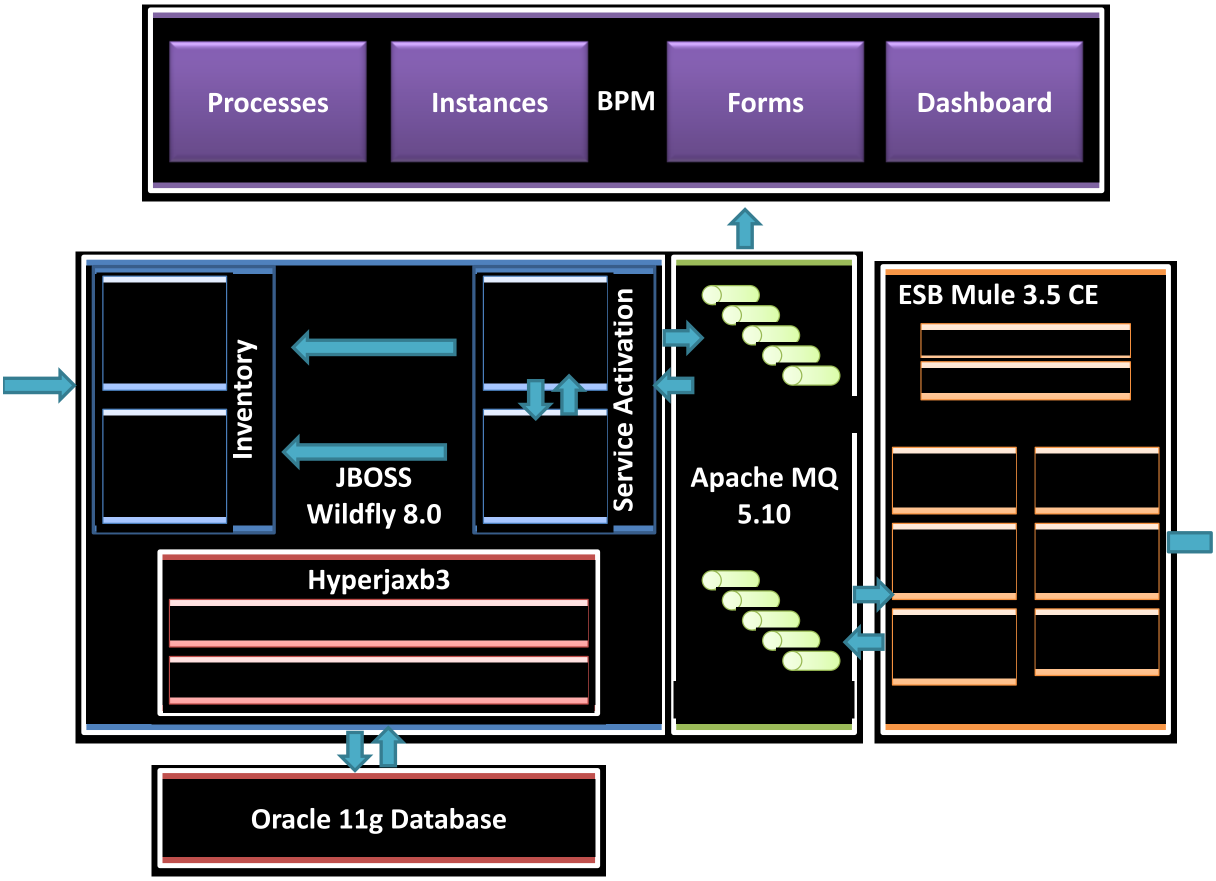


Figure 5-54

The following table details the different components selected for the implementation of PoC:

Table 5-7 Version of the different components used in PoC

Component	Technology	Version
App server	JBoss	Wildfly 8.1.0
Persistence framework	Hibernate	3.5.8
Message Broker	Active MQ	5.10.0
Database	Oracle	11.2.0.2
Deployment	Maven	3.0.5
Continuous Integration	Jenkins	2.0
ESB	Mule	3.5.0
Language	Java	1.8.50
Memory	8	GB
CPU	2 Xeon	1,5 GHz

This environment has shared the scenario with the SCAI and inventory interfaces that will be detailed later. In the development, deployment and testing we have found these noticeable issues related with each operation.

Table 5-8 Issues and Workarounds

Operation	Issues	Workaround	Functionality
Feasibility check	No async behavior is allowed. No capacity to inform a problem if the feasibility fails	Define elements to store problem and allow async behavior	Uses an enumerated as response, difficult to build
Design	Only it is included in the API a definition of which product is going to be designed. Perhaps some kind defined design could be included to determine several behaviors with the same logic	Simple design/orchestration functionalities were built to support the reference implementation. Delegates complex orchestration in extensions in the operations per product spec	Only allows simple design/orchestration operations. A extension for support different types of orchestration could be useful
Reservation	The definition of the reservation is proposed at product level, so it is going to perform a complete reservation for the product and not for composed services	Delegate the logic of reservation for different composed services in the orchestration definition generated in the design operation	The interface is enough for its purposes. An extension to include the services could be more flexible. The proposed date for the product help in its management. Also it can free resources after some time without provision
Provision	The same issue as reservation, but in provision could exist great delays between several components in one product. Difficult to retry some operation related with one composed service	Delegate the logic of provision for different composed services in the orchestration definition generated in the design operation. Use simple logic for the implementation. The system wait for the finalization of all the composed services, so it is difficult to manage	The interface is enough for its purposes but it could be extended to include flexibility per composed service avoid complex orchestration management
Activation	Use the same limited approach of activate product and not the composed services included.	Delegation of the logic in the orchestration	The interface is enough for its purposes but it could be extended to include flexibility per composed service avoid complex orchestration management or include a scheduling for the activation
Deactivation	Has a very limited interface without access to the composed services. Also cannot be included a reason for the deactivation or any characteristic needed to configure the deactivation operation	The deactivation process has no possibility to perform over a service and this was modeled first with a modification (also not enough) and finally with custom inventory operations	The deactivation operation only supports the deactivation of an entire product. A definition over the composed services with information related the cause of deactivation might be included
Termination	Has a very limited interface without access to the composed services. Also cannot be included a reason for the termination or any characteristic needed to configure the termination operation	The termination process has no possibility to perform over a service and this was modeled first with a modification (also not enough) and finally with custom inventory operations	The termination operation only supports the deactivation of an entire product. A definition over the composed services with information related the cause of termination might be included
Retiring	Cannot be included a reason for the termination or any characteristic needed to configure the retiring operation	The retiring process has only be tested product oriented performing the retiring operation in cascade	No information could be added to define the cause of the retiring a product
Amend	It has no support on the interface, it seems that it is missing	Modeled like a modify operation	The amend operations seems that doesn't have a good definition to be supported
Modify	It is supposed that this operation could offer an interface for change the services included in the service, but only can support the upgrade of the characteristics value	It was used in combination with inventory for the support of modifications on the product ordered	Use intensively the inventory system/interface, but it is difficult to offer logic associated to the modification of service's components.

In a performance analysis we have seen that with enough resources the behavior of the global system (SAI point of view) is lineal (see next figure) but when the resources are exhausted some problems appears. The performance test was performed with 1, 5 and 10 parallel requests to the SAI interface with request injection each 30 seconds and while the pool on database connection is enough (100 connections at maximum) we can see a lineal performance. When test with 25 parallel requests is executed the system consumes all the database connections so some inconsistences/rollbacks are needed causing an incomplete activation process. There is no buffer definition for the request to avoid that, something that in a production environment might be considered

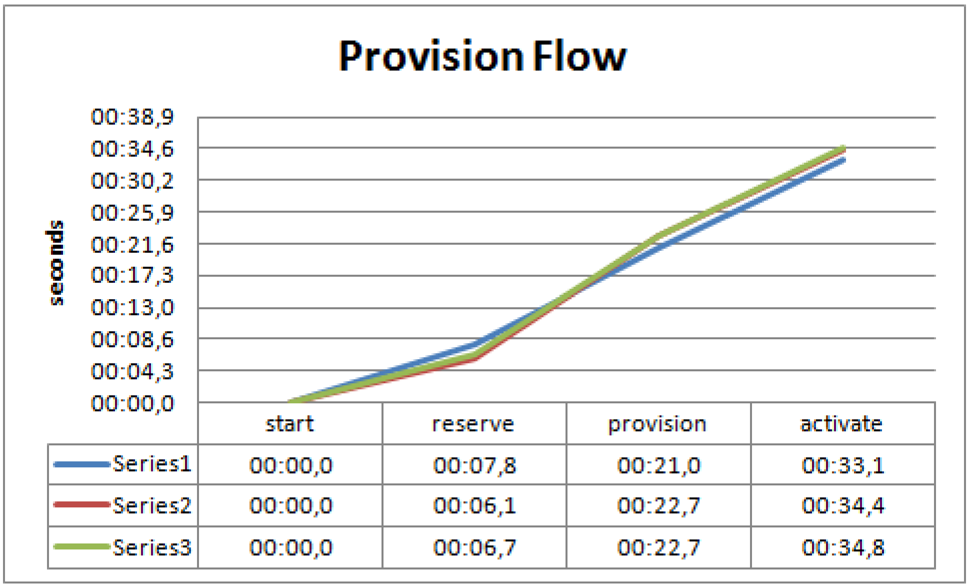


Figure 5-55 Performance testing

5.5.1.2 Inventory

The Manage Service Inventory Interface (MSI) supports the capability for a requesting system to retrieve the service related entities from a Service Inventory repository through a unique operation supporting instance and bulk inventory retrieval

The inventory interface focuses its behavior in the request and storage of the entities that are used to manage the service activation processes. These interfaces acts as basis for the others supporting the management of the different entities that were used in the systems built. In MTOSI there are several interfaces at service and resource level. The aim of the project is the composition of services and not the composition of resources or technology. Then only the inventory service interface was used.

In the evaluation of the interface we could check that only the retrieval operation was available making impossible it use on the prototype. Then a new operation in the service inventory was needed and developed in the project by Optare Solutions (now it is pending to be published to the TM Forum for a future approval). In parallel the TM Forum generates a new version of MTOSI.

The inventory uses the different entities defined in MTOSI and this set of interfaces uses a complex generated key for support the identification of the objects via different identification perspectives making that an object could be recovered with different identifiers depending on who is calling the interface. This trivial requirement is not so trivial at implementation and the use of techniques combining UUID (*Universal Unique Identifier*) and Hibernate identifier generators allowed the agile creation of entities using the persistence framework.

The intensive use of the persistence to guarantee the transactional behavior of service management processes increment the load to the database. Also there is a big hierarchy generated by the transformation from the MTOSI definitions to elements in the database creating a lot of small tables with a high number of references.

This modelling helps a lot in the consecution of zero downtime in the systems but as counterpart in load conditions the systems need lot of resources (database connections and memory) because its quick consumption. Also the queries for retrieve the information from the database needs one of the latest editions of the selected database (Oracle) because of the database definition performed trough the persistence framework generate extremely longer queries with 11 deep levels.

In the interfaces there is a method for perform a direct query or use an iterator pattern in an asynchronous request. Only the synchronized operation was checked to simplify the scope of the PoC.

The catalog definition of RFS/CFSs and products for BATS used the inventory interface and the set of elements for defining, the characteristics, its values, its domains, its templates and relationship among them is very rich and allow almost any use case that could be proposed. The same is for the different instance of the running services. In this case some relationships between the CFS and RFS were missing. It was corrected and used to support the different entities that were needed in different stage of the service activation process.

Table 5-9 Issues and Workaround

Operation	Issues	Workaround	Functionality
Inventory Retrieval	The use of the base instance method to recover the information limited the possibilities to recover different objects in one call. Also in many circumstances the filter applied was not directly related with the attributes of the entity but it was used some attributes for the inner elements of the principal object	Ii was necessary to use a simple language based on XPath to set the complex filter base on attributes of internal elements to accelerate the adoption of this interface. Without that workaround it was impossible to work with the interface. In some scenarios some cache was generated on memory to speed up the processes	The retrieval can recover the objects of the main types used in service activation but it has a rigid definition of components with complex indexes that made difficult the effective use of the interfaces. The simple language facilitates a lot the process of create complex queries
Inventory Update	This interface did not exist on MTOSI and this was useless	Develop a definition for this interface allowing the creation, modification and deletion of different entities taking as basis the same entities as in retrieval operation. The update operation must deal with actions like if we have a part of an object without the references, we must maintain the references and object referenced. The MTOSI identification of entities is complex and required a definition of a generator based on a UUID	This new functionality allows the development of the PoC though all the steps defined. The definition will be presented to the TMF to be incorporated to a future release of the MTOSI interfaces

5.5.1.3 Service Component Activation Interface

The Service Component Activation Interface (SCAI) is the interface between the CFS and the RFS entities. It allows for the activation of Service Components given specific service related information defined in a Service Template. The operations of this interfaces share the asynchronous behaviour from the SAI interface through a webservice – JMS channel where the requests are gathered ant later recovered by a specialized system.

In the PoC this interface is the limit for the application server that manages the horizontal software components and then sends the SCAI requests to an ESB system to perform the different operations through the custom OSS systems with vertical integration of each OSS that participates on BATS project.

In the design of the PoC a first option was to develop from the point of view of the service providers an implementation of the MTOSI SCAI interface on its OSS, but this was impractical because of the problems of integrity that had the set of interfaces used in the project. With this premise and a higher control of the status of the interfaces and its evolutions a new integration layer was built in the ESB to support the SCAI interfaces over the OSS' providers.

The initial request on the SAI interfaces performed a mapping between the business data (sent in the characteristics stored in the product) and the CFS. At this point a new mapping will be performed from the CFS to the RFS prior to store the message relative to the needed operation in the scope of the SCAI. In many of the operations it is needed to send the base information to store the RFS objects and the template to filter the information exchanged.

The communication pattern is established through two queues (Request/Response) and also some event and notifications are generated to the respective queues and if it is needed a supra order could be instantiated/updated in the product order lifecycle.

Table 5-10 Issues and Workaround

Operation	Issues	Workaround	Functionality
Feasibility check	No async behavior is allowed. No capacity to inform a problem if the feasibility fails	Define elements to store problem and allow async behavior	Use of a more complex data for this operation will help to understand which the cause is.
Reserve	The interface only allow the reserve for each RFS. We cannot send several	The option of generate several was not used because the use case with individual operations was enough for the PoC	It allows the invocation and characterization of the new or yet created RFSs and this is enough for most of the use cases
Provision	The interface only allow the provision of each RFS. We cannot send several	The option of generate several was not used because the use case with individual operations was enough for the PoC	It allows the invocation and characterization of the new or yet created RFSs and this is enough for most of the use cases
Activation	The interface only allow the activation of each RFS. We cannot send several	The option of generate several was not used because the use case with individual operations was enough for the PoC	It allows the invocation and characterization of the new or yet created RFSs and this is enough for most of the use cases
Deactivation	The interface did not allow to send information relative to the characterization of the deactivation process	Use the index as and storage of small characterization or a better solutions it would be create a possibility for characterization	The interface has low elements to be configured but its seems that in many cases this is enough
Terminate	The interface did not allow to send information relative to the characterization of the deactivation process	Use the index as and storage of small characterization or a better solutions it would be create a possibility for characterization	The interface has low elements to be configured but its seems that in many cases this is enough
Modify	The interface only allow the modification of each RFS. We cannot send several	The option of generate several was not used because the use case with individual operations was enough for the PoC. Maybe in the case of modify this could affect because of the interest of commit several coordinated modifications	It allows the invocation and characterization of the new or yet created RFSs and this is enough for most of the use cases

5.5.1.4 Other interfaces

The MTOSI frameworks comprises of several interfaces and some small reference implementation were built for other interfaces with less interest for the project but interesting for the feasibility of the MTOSI supporting the processes from the use cases.

These are:

- **Problem Management:** The interface is defined on the set of Web services listed in the subdirectories of ResourceTrouble Management. It proposed a solution for problem management in the field of resources and very close to the area of the network
- **Performance Management:** The interface is defined on the set of Web services listed in the subdirectories of ResourcePerformanceManagement. It proposed a solution for performance management at resource level and definitions are very close to the network area

5.5.2 Base deployment

5.5.2.1 Interface generation

The great number of entities makes difficult its management, so a continuous integration approach was used to align the interface definitions with its generation. To perform it we used a SVN repository where it is stored the different version of official MTOSI and also the modified version to become MTOSI real implementation. The project used a maven tool for the building of the different interfaces reading the definitions on the WDSL and XSDs and then perform a binding generation to support later the annotations through Hyperjaxb3 (a combination for generate JAXB and persistence binding and reduce the integration effort and helping in the reduction of the complexity to be managed to automate it). A Jenkins system later detects the changes in the SVN and performs automatically the build and the deployment of the project maintaining always a fresh version deployed on the PoC

5.5.2.2 Persistence

The Hyperjaxb3 technology was tested with success to reduce the amount of time to create all the staff needed to support the interface. From the definition of the interface some bindings are defined after an analysis of the information stored in the schemas and WSDL and with that create the needed POJO classes with its annotations for support JAXB 2.2 and JPA 2.0. Only small workarounds are needed by special names of some objects related to the coding scheme, the length of the generated method/class and similar names used at different interfaces. In the interface generation the resources need for the persistence layer are created and configured automatically.

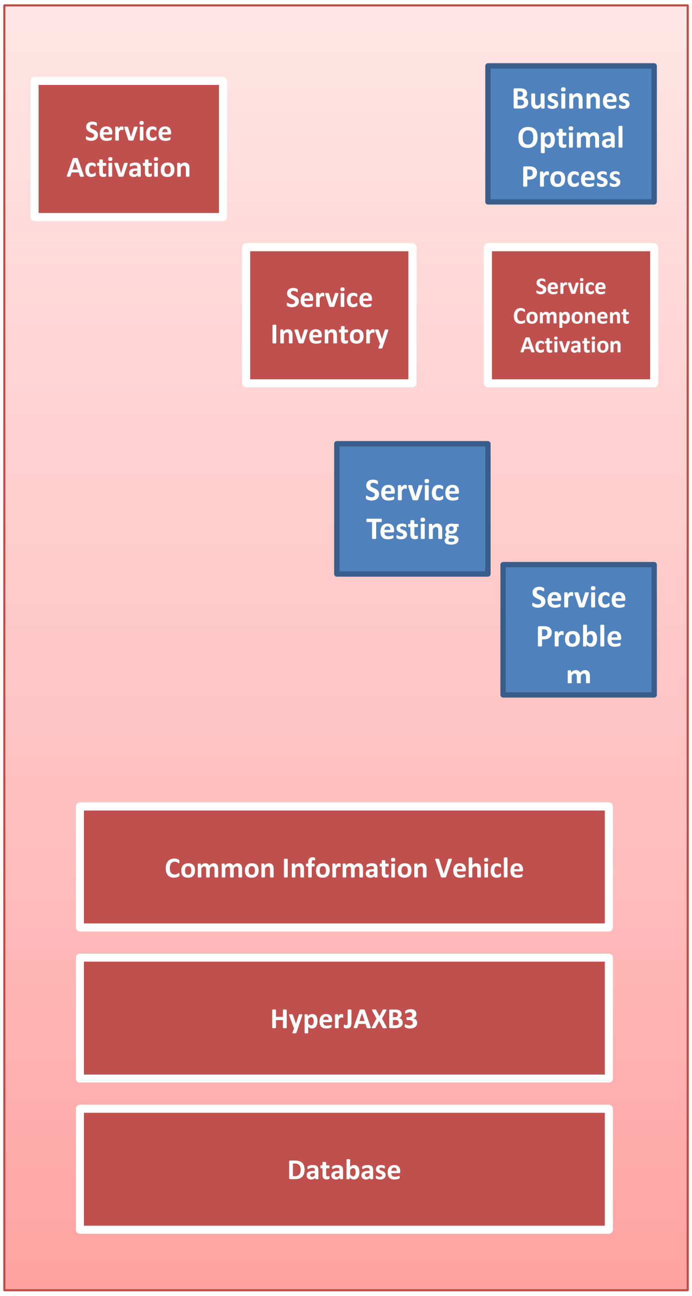


Figure 5-56 Components over the persistence layer

The interfaces implemented uses the persistence layer to store relevant information about specifications, templates, characteristics, relations, instances as it can viewed in the previous figure.

5.5.2.3 Lifecycle management

The instances of a service managed by the platform evolve among the different statuses in their lifecycle. A support for an easy control of these instances is performed in two ways. One is the repository of instances that use the inventory API and the persistence layer to store the information of each instance. The other is a Business Process Module process that shows the different statuses where the instance is evolving feed by events generated in the platform associated with the lifecycle.

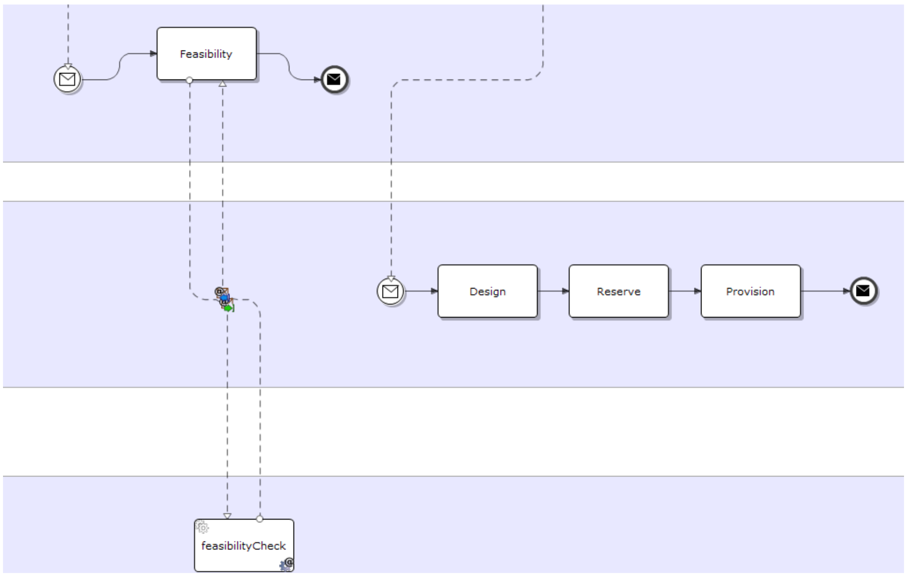


Figure 5-57 Service Lifecyle representation

5.5.3 Vertical SCAI Integration

In BATS scenario synchronous requests from SAI (Service Activation Interface) are inserted in a messaging queue for asynchronous processing. These requests are processed by an ESB Middleware which represents the integration layer, a set of connectors/transformations between SCAI and other interfaces with the external providers and partnerships.

Next figure represents the structure of the SCAI's integration layer:

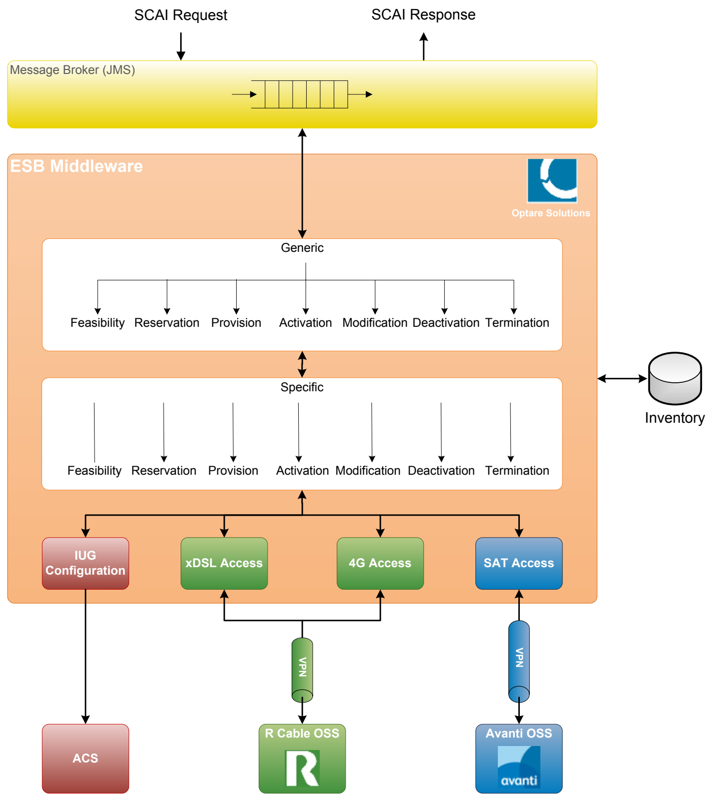


Figure 5-58 MTOSI SCAI and vertical integration

The integration mechanism performs four steps to be done horizontally as long as possible when some system needs to contact with the SCAI implementation:

- Get and process the request for SCAI and offer the response to the invoker
- Selection of the partner/service/operation integration action needed
- Develop a vertical software development converting the SCAI invocations in proprietary actions in the OSS systems of each partner.
- Establish the communications and transformations needed for each case to connect with the OSS systems of each partner. Specific transformation was used to accomplish the SCAI operations

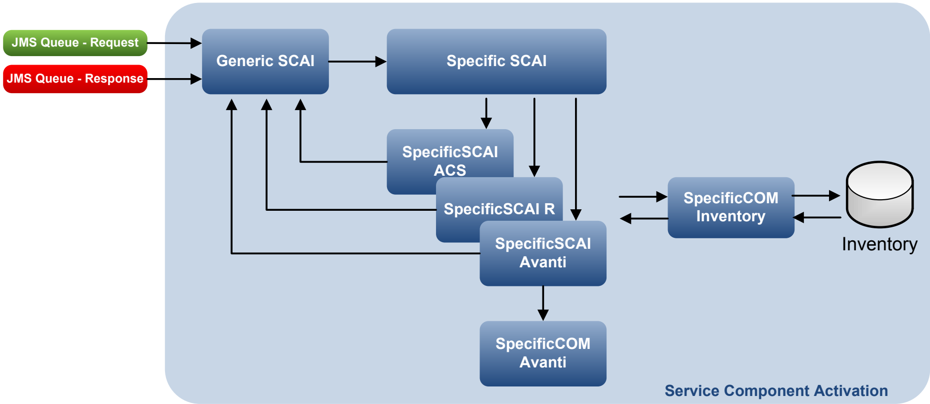


Figure 5-59 Architecture integration layer

There are two main integration components on the ESB:

- Horizontal components (SCAI Common):
- Vertical components (SCAI Vertical): there is a specific module per partner for the different communication mechanisms (integration with custom OSS APIs).

5.5.3.1 SCAI Common (horizontal)

Supports the interface MTOSI SCAI and establishes an asynchronous channel for subsequent monitoring of *genericSCAI* processes. *The specificSCAI* component is responsible for routing the message to the specific module (associate one type of service and / or partner).

GenericSCAI

SCAIRequest:

Consumes requests from the JMS queue and selects the operation to perform in the next component “SCAI Specific”. These are the SCAI operations (feasibilityCheck, reserve, provision, active, deactivate, termination and modify)

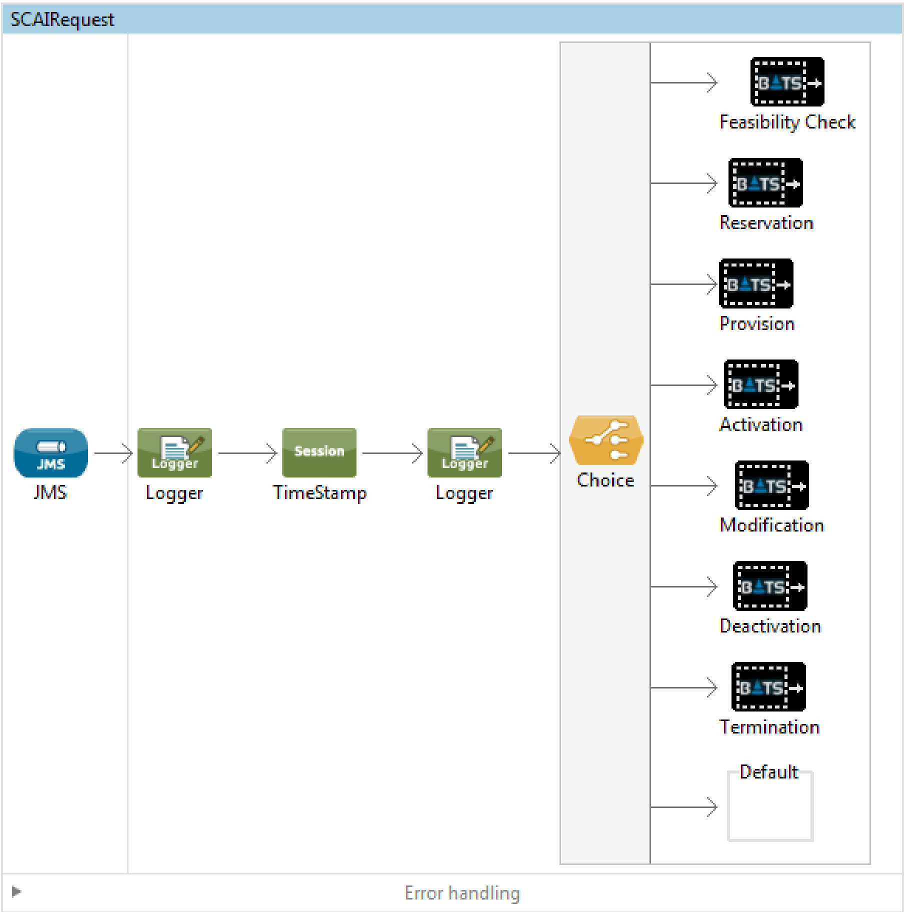


Figure 5-60JMS Workflow

<u>SCAI Response</u>

Constructs the JMS message with the responses of the specific action results and publishes it in the JMS response queue.

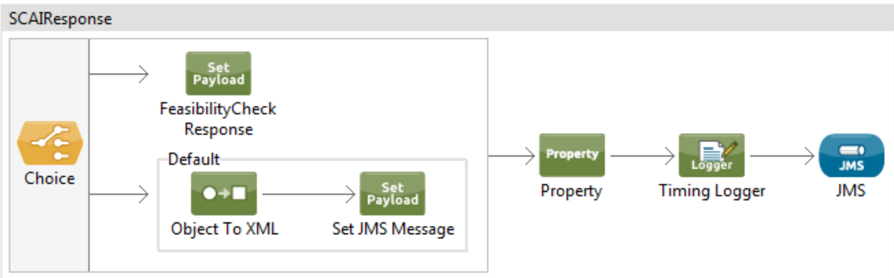


Figure 5-61 JMS Message Responses

<u>SpecificSCAI</u>

For every action (feasibility, reservation, provision, activation, modification, deactivation and termination), a specific flow is invoked to perform the tasks/communications needed for each particular partner.

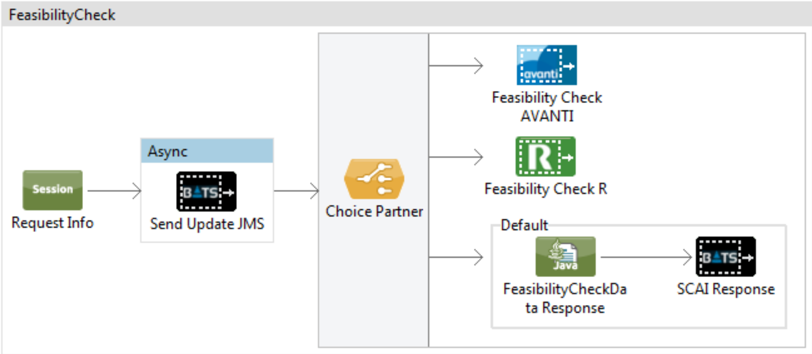


Figure 5-62 Example of a specific operation for SCAI

5.5.4 Conclusions for BATS project

After finalizing the PoC test we can state the following conclusions on use the MTOSI interfaces as basis for service activation processes:

- The set of interfaces is rich and fulfils most of the needs in processes of this type;
- The incorporation of OSS's such as Avanti's cane be implemented via an interface conforming to MTOSI;
- The definition of the interfaces also has a lot of emphasis on the flexibility, the characterization and the use of templates allow the activation of any kind of service
- The benefit on flexibility via a good exercise of abstraction penalizes the running implementations because of an excessive hierarchy to build the access to the information. Some elements could be cached and/or include some shortcuts for complex structures to gain agility without loose flexibility;
- The high number of levels in hierarchy also impact with the persistence resources that need to be ready for support long queries with several deep levels and an intense us of resources;
- The great number of elements defined in MTOSI makes difficult to manage and deploy it without an automated mechanism like the deployment generated in this project (SVN+Maven+Jenkins);
- The MTOSI interface has loose importance on the TMForum and this affects to the quality of the deliverables. Many points of optimization has been detected, the most important maybe the missed update inventory operation and also a review of the integrity of the elements defined;
- The interfaces allows the FCAPS operations and has an excellent degree of abstraction but need to be reviewed to be implementable (e.g. the definition of a complex index for each instance);
- The BATS project could conclude that these interfaces could be used for their initial purpose, the coordinated service activation over different technologies, but it generates some extra work because of it is no well-maintained and in some important aspects is incomplete. Also automation is a must where a rich interface with many items to be considered is used to support a process;
- A detailed explanation of the vertical integrations performed is documented as an annex of this document.

6 References

[1] Lab Trials Planning, BATS Deliverable 6.1.1, issued January 2014.

[2] Integrated Network Emulator, BATS Deliverable D6.3 issued November 2014

[3] HTTrack, an offline browser utility, http://www.httrack.com

[4] Ekiga, an open source video conferencing application over the Internet, http://www.ekiga.org

[5] ITU-T Recommendation P.920, Interactive test methods in audiovisual communications, May 2000.

[6] ETSI, ETSI EN 301 545-2:"Digital Video Broadcasting (DVB); Second Generation DVB Interactive Satellite System (DVB-RCS2); Part 2: Lower Layers Satellite standard", 2008.

[7] P. H. Moose, “A technique for orthogonal frequency division multiplexing frequency offset correction," IEEE Trans. Communication, vol. 42, No. 10, October 1994.

[8] U. Mengali, M. Morelli, “Data-aided frequency estimation for burst digital transmission”, IEEE Transactions on Communications, Vol. 45, No. 1, January 1997.

[9] H. Bischl, H. Brandt, and F. Rossetto, “An experimental demonstration of network coding for satellite networks,” CEAS Space Journal ,vol.2, nos. 1–4, pp. 75–83, Dec. 2011.

Annex

A.1 Spanish Field Trial Evaluation Questionnaire

BATS
BROADBAND ACCESS VIA INTEGRATED TERRESTRIAL & SATELLITE SYSTEMS

Gradiant

Final Questionnaire

*Obligatorio

1. Speed test of the BATS service *

Please execute the speed test and record the results (example: 0,57 Mb/s and 5,42 Mp/s 73)

2. Speed of your previous DSL connection *

3. How many Internet users in your household or bussiness? *

(where the BATS system is installed)

4. During the BATS trial, and on a regular week, how much time have you spent on the Internet (any kind of service)?

5. How many times do you use... *

	everyday	several times a week	several times a month	never (or almost never)	DK/NA
...normal web pages (newspaper, Wikipedia, etc.)?					
... content rich browser (Google Maps, etc.) ?					
... e-mail ?					
... social networks (Facebook, twitter)?					
... messaging aplications (skype, Google+ Hangouts)?					
... VoIP (Skype, etc.)?					
... video calls (Skype, etc.)?					
... multimedia content streaming (Youtube, OTT TV etc.)?					
... content download/P2P (bittorrent, emule, etc.)?					
... online gaming (strategy, adventure, casino, etc.)?					
... online banking, e-Gov sites, etc.?					

6. Could you indicate which of the following Internet applications and services are the most important for you? *

8. How would you rate the quality of the following Internet applications and services employing the BATS service? *

	very poor	poor	fair	good	very good	DK/NA
...normal web pages (newspaper, Wikipedia, etc.)						
… content rich browser (Google Maps, etc.)						
... e-mail						
… social networks (Facebook, twitter)						
... messaging aplications (skype, Google+ Hangouts)						
... VoIP (Skype, etc.)						
... video calls (Skype, etc.)						
... multimedia content streaming (Youtube, OTT TV etc.)						
... content download/P2P (bittorrent, emule, etc.)						
... online gaming (strategy, adventure, casino, etc.)						
... online banking, e-Gov sites, etc.						

9. How would you describe the quality of the following Internet applications and services employing the BATS service as compared to your previous DSL connection? *

(example: content download is better with the BATS service as compared to my previous DSL connection)

	much worse	worse	equal	better	much better	DK/NA
...normal web pages (newspaper, Wikipedia, etc.)						
… content rich browser (Google Maps, etc.)						
... e-mail						
… social networks (Facebook, twitter)						
... messaging aplications (skype, Google+ Hangouts)						
... VoIP (Skype, etc.)						
... video calls (Skype, etc.)						
... multimedia content streaming (Youtube, OTT TV etc.)						
... content download/P2P (bittorrent, emule, etc.)						
... online gaming (strategy, adventure, casino, etc.)						
... online banking, e-Gov sites, etc.						

10. How much do you use the following Internet applications and services employing the BATS service as compared to your previous DSL connection? *

(example: I use content download much more with the BATS service as compared to my previous DSL connection)

	much less	less	equal	more	much more	DK/NA
...normal web pages (newspaper, Wikipedia, etc.)						
… content rich browser (Google Maps, etc.)						
… e-mail						
… social networks (Facebook, twitter)						
… messaging aplications (skype, Google+ Hangouts)						
… VoIP (Skype, etc.)						
… video calls (Skype, etc.)						
… multimedia content streaming (Youtube, OTT TV etc.)						
… content download/P2P (bittorrent, emule, etc.)						
… online gaming (strategy, adventure, casino, etc.)						
… online banking, e-Gov sites, etc.						

11. How would you rate the following aspects of the BATS service? *

	very poor	poor	fair	good	very good	DK/NA
download speed						
upload speed						
response time						
stability						

12. How would you describe the following aspects of the BATS service as compared to your previous DSL connection? *

(example: download speed is better with the BATS service as compared to my previous DSL connection)

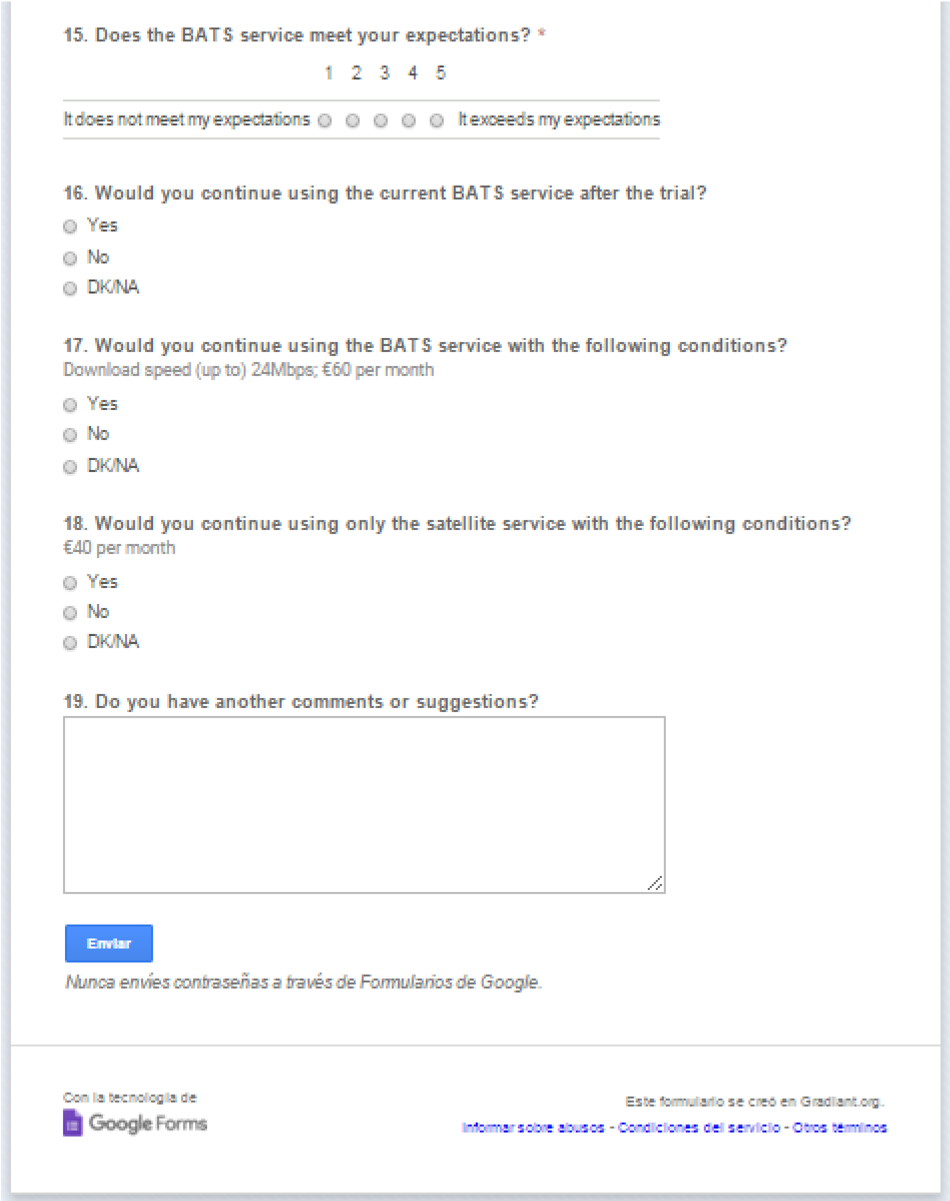
	much worse	worse	equal	better	much better	DK/NA
download speed						
upload speed						
response time						
stability						

13. In general terms, how would you rate the quality of the BATS service compared to your previous DSL connection? *

	1	2	3	4	5	
very poor						very good

14. How would you rate your level of satisfaction regarding the BATS service? *

	1	2	3	4	5	
not satisfied at all						very satisfied



15. Does the BATS service meet your expectations? *

	1	2	3	4	5	
It does not meet my expectations	○	○	○	○	○	It exceeds my expectations

16. Would you continue using the current BATS service after the trial?

- Yes
- No
- DK/NA

17. Would you continue using the BATS service with the following conditions?
Download speed (up to) 24Mbps; €60 per month

- Yes
- No
- DK/NA

18. Would you continue using only the satellite service with the following conditions?
€40 per month

- Yes
- No
- DK/NA

19. Do you have another comments or suggestions?

Enviar

Nunca envíes contraseñas a través de Formularios de Google.

Con la tecnología de Google Forms

Este formulario se creó en Gradiant.org.
Informar sobre abusos - Condiciones del servicio - Otros términos

A.2 German Field Trial Evaluation Questionnaire

1. During the BATS trial, and on a regular week, how much time have you spent on the Internet (any kind of service)?

Wieviel Zeit verbrachten Sie während des BATS Versuches durchschnittlich pro Woche im Internet?

[▼]

2. How many times do you use... *

Wie oft nutzen Sie ...

	everyday	weekly	monthly	never	DK / NA
Normale Internet Seiten (z.B. Wikipedia)	○	○	○	○	○
Inhalt-reiche Seiten (z.B. Google Maps)	○	○	○	○	○
E-mail	○	○	○	○	○
Soziale Netzwerke (z.B. Facebook)	○	○	○	○	○
Messaging (z.b. Skype)	○	○	○	○	○
VoIP (z.B. Skype)	○	○	○	○	○
Videotelefonie	○	○	○	○	○

(z.B. Skype)	○	○	○	○	○
Streaming (z.B: Youtube)	○	○	○	○	○
Download P2P (z.B: Bittorrent, Emule)	○	○	○	○	○
Online Games (Strategie, Abenteuer, Casino)	○	○	○	○	○
Online Banking, e-Gov Sites	○	○	○	○	○

3. How would you rate the quality of the following Internet applications and services employing the full BATS service? *

Wie bewerten Sie die Qualität folgender Internet Services mit dem vollen BATS - Service?

	very poor	poor	fair	good	very good	DK / NA
Normale Internet Seiten (z.B. Wikipedia)	○	○	○	○	○	○
Inhalt-reiche Seiten (z.B. Google Maps)	○	○	○	○	○	○
E-mail	○	○	○	○	○	○
Soziale Netzwerke (z.B. Facebook)	○	○	○	○	○	○
Messaging (z.b. Skype)	○	○	○	○	○	○
VoIP (z.B. Skype)	○	○	○	○	○	○
Videotelefonie (z.B. Skype)	○	○	○	○	○	○
Streaming (z.B: Youtube)	○	○	○	○	○	○
Download P2P (z.B: Bittorrent, Emule)	○	○	○	○	○	○
Online Games (Strategie, Abenteuer, Casino)	○	○	○	○	○	○
Online Banking, e-Gov Sites	○	○	○	○	○	○

4. How would you describe the quality of the following Internet applications and services employing the full BATS service compared to your previous (DSL) connection? *

Wie würden Sie die folgenden Internet Services mit dem BATS System bewerten im Vergleich zu ihrer bisherigen Verbindung?

	much worse	worse	equal	better	much better	DK / NA
Normale Internet Seiten (z.B. Wikipedia)	○	○	○	○	○	○
Inhalt-reiche						

Seiten (z.B. Google Maps)						
E-mail						
Soziale Netzwerke (z.B. Facebook)						
Messaging (z.b. Skype)						
VoIP (z.B. Skype)						
Videotelefonie (z.B. Skype)						
Streaming (z.B: Youtube)						
Download P2P (z.B: Bittorrent, Emule)						
Online Games (Strategie, Abenteuer, Casino)						
Online Banking, e-Gov Sites						

5. How much do you use the following Internet applications and services employing the full BATS service compared to your previous (DSL) connection? *

Wie oft nutzen Sie die Folgenden Internet Services mit dem BATS Service verglichen mit ihrer bisherigen Verbindung?

	much less	less	equal	more	much more	DK / NA
Normale Internet Seiten (z.B. Wikipedia)						
Inhalt-reiche Seiten (z.B. Google Maps)						
E-mail						
Soziale Netzwerke (z.B. Facebook)						
Messaging (z.b. Skype)						
VoIP (z.B. Skype)						
Videotelefonie (z.B. Skype)						
Streaming (z.B: Youtube)						
Download P2P (z.B: Bittorrent, Emule)						
Online Games (Strategie, Abenteuer, Casino)						
Online Banking, e-Gov Sites						

6. How would you rate the following aspects of the BATS service? *
Wie würden Sie die folgenden Aspekte des BATS Services bewerten?

	very poor	poor	fair	good	very good	DK / NA
download speed	○	○	○	○	○	○
upload speed	○	○	○	○	○	○
repsonse time	○	○	○	○	○	○
stability	○	○	○	○	○	○

7. How would you rate the following aspects of the BATS service compared to your previsous (DSL) connection? *
Wie würden Sie die folgenden Aspekte des BATS Services bewerten im Vergleich zu Ihrer bisherigen (DSL) Verbindung?

	much worse	worse	equal	better	much better	DK / NA
download speed	○	○	○	○	○	○
upload speed	○	○	○	○	○	○
repsonse time	○	○	○	○	○	○
stability	○	○	○	○	○	○

8. In general terms, how yould you rate the quality of the BATS service compared to your previous (DSL) connection? *
Allgemein, wie würden Sie die Qualität des BATS-Services bewerten im Vergleich zu Ihrer bisherigen DSL Verbindung

	1	2	3	4	5	
very poor	○	○	○	○	○	very good

9. Do you have any comment about the quality of the BATS service?
Haben Sie irgendwelche Anmerkungen über die Qualität des BATS Services?

10. How would you rate your level of satisfaction regarding the BATS service? *
Wie Zufrieden sind Sie mit dem BATS Service?

	1	2	3	4	5	
not satisfied at all	○	○	○	○	○	very satisfied

11. Does the BATS service meet your expectations? *
Hat der BATS Service Ihre Erwartungen erfüllt?

	1	2	3	4	5	
It does not meet my expectations	○	○	○	○	○	It exceeds my expectations

12. Would you continue using the service after the trial? *
Würden Sie weiterhin den Service in Anspruch nehmen nach dem Feldversuch?

- ○ Yes
- ○ No
- ○ DK / NA

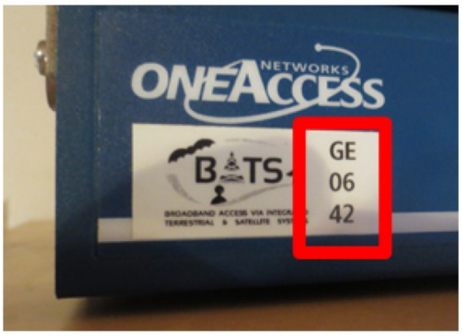
13. Dou you have any other comments or suggestions?
Haben Sie irgendwelche Kommentare?

14. Dou you want to end the trials immediately? If yes, please state reason?
Möchten Sie den Test sofort beenden? Falls ja, bitte teilen Sie uns mit warum.

How is your actual Internet connection? Please test and share the results as explained in the images below.
Bitte testen Sie Ihre aktuelle Verbindungsgeschwindigkeit unter www.speedtest.net und fügen sie den Link wie unten beschrieben ins Textfeld ein.

Wie lautet Ihre IUG Nummer? *

Siehe Bild



Senden

Geben Sie niemals Passwörter über Google Formulare weiter.

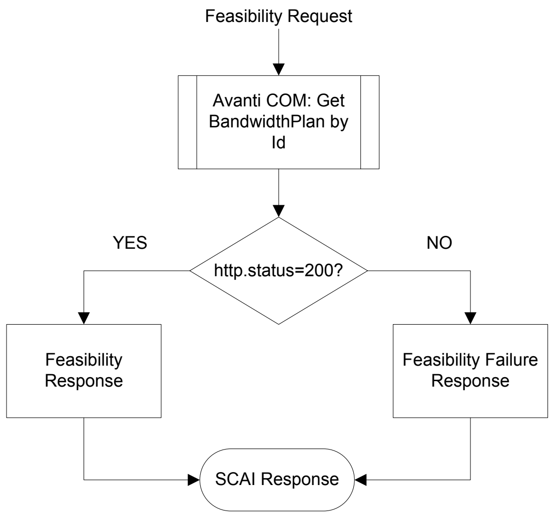
A.3 Detailed vertical MTOSI operations and components

Avanti

The SpecificSCAI-Avanti flow contains the specific actions to manage orchestration processes of the Avanti's SAT connection product (also known as SIT):

- Feasibility

  This process checks if request's bandwidth plan Id exists in partner's catalog:



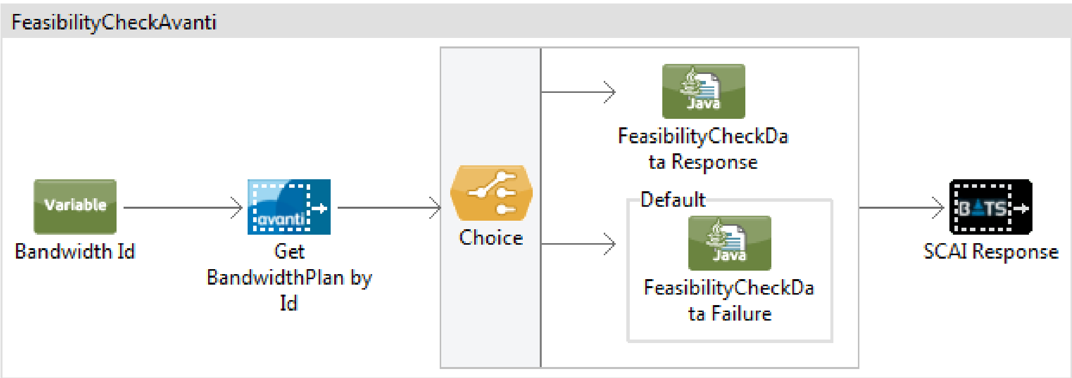


Figure A-1 Feasibility process and ESB implementation

- Reservation

  The reservation process creates a Sit Installation:

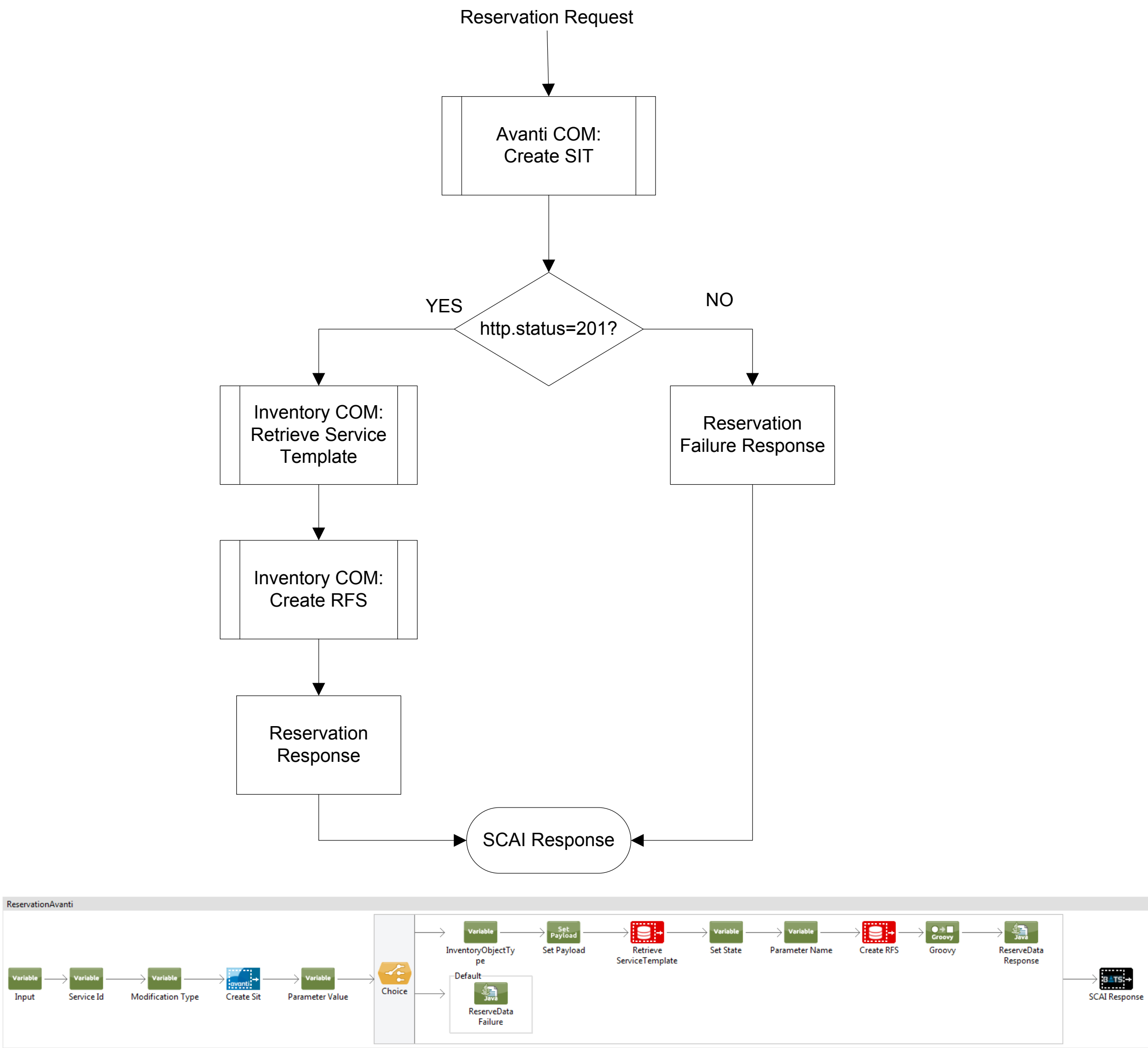


Figure A-2 Reserve process and ESB implementation

- Provision

  Avanti's provision executes sequentially the next steps:

  - Add Location to SIT
  - Link Customer to SIT
  - Create a job order associated to SIT
  - Get the job order's etag field
  - Schedule the job order

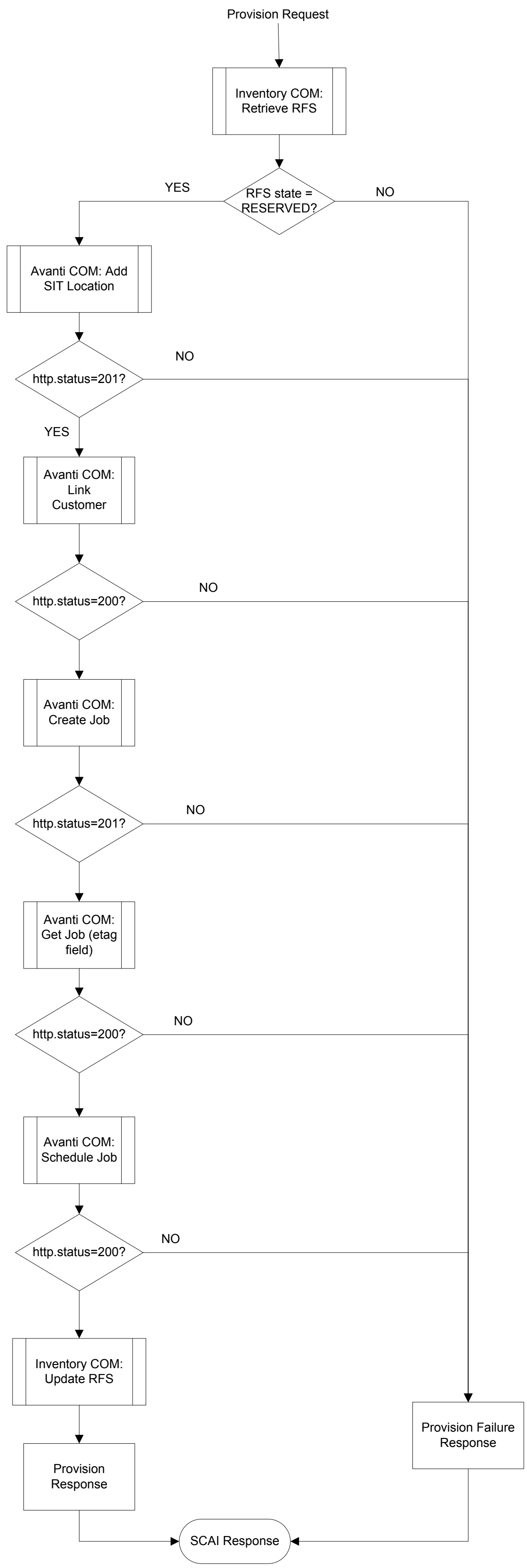


Figure A-3 Provision process and ESB implementation

- Activation

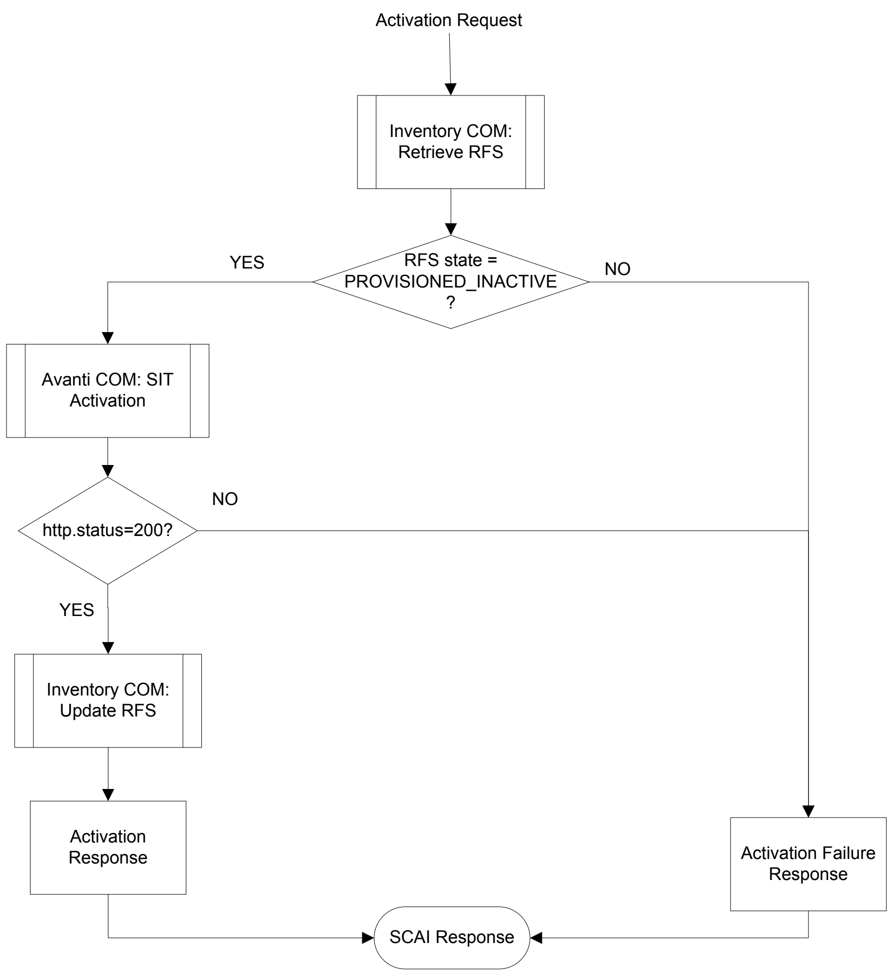


Figure A-4 Activation process and ESB implementation

- Modification

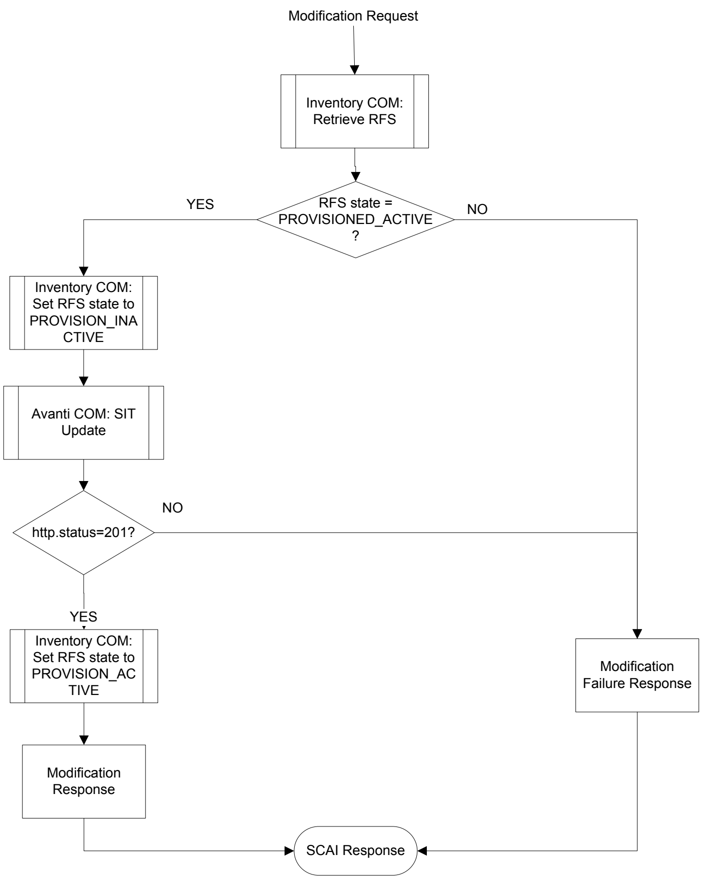


Figure A-5 Activate process and ESB implementation

- Deactivation

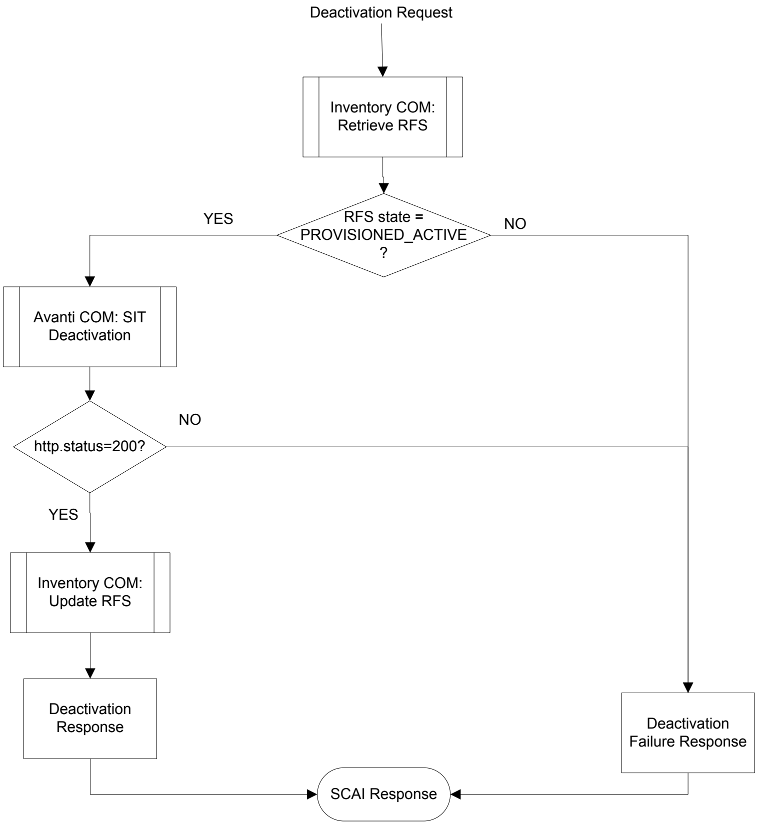


Figure A-6 Deactivate process and ESB implementation

- Termination

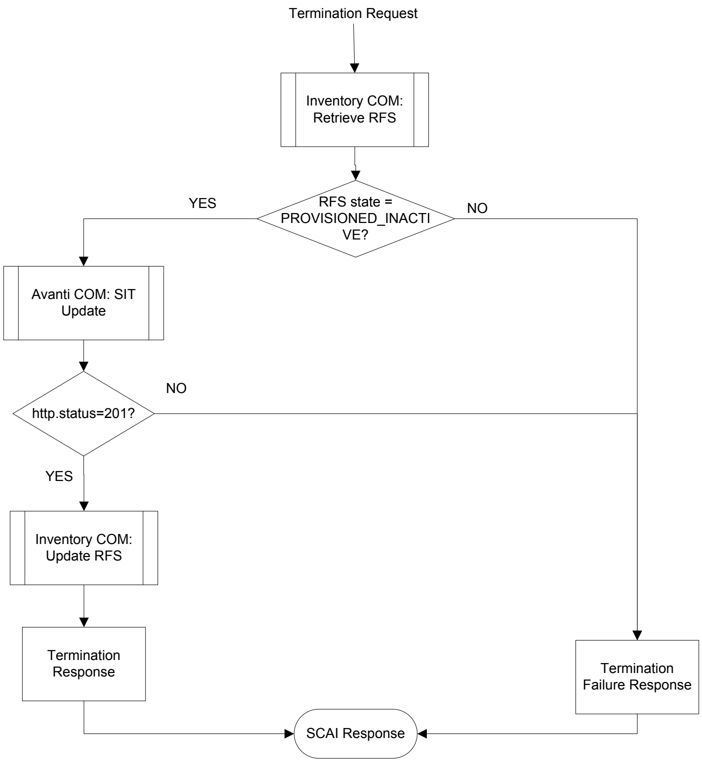


Figure A-7 Terminate process and ESB implementation

SpecificCOM-Avanti

Avanti offers a sandbox of their OSS systems that uses a REST interface for publishing its functionalities.

REST API

<< back to list of versions

Service URL	operation	HTTP method	Description
Partner			
services/rest/default/Partner	list	GET	Lists Partners. Accepts extra parameters.
services/rest/default/Partner/[id]	read	GET	Reads the details of an item of Partner resource identified by [id].
services/rest/default/Partner/fields	fields *	GET	Describes the Partner resource
services/rest/default/Partner/[id]/installation_companies	installation_companies *	GET	Lists all installation companies associated to a Partner.
services/rest/default/Partner/[id]/usage_report	usage_report *	GET	Report data usage for a VNO resource identified by [id].
User			
services/rest/default/User	list	GET	Lists Search for users. Accepts extra parameters.
services/rest/default/User/[id]	read	GET	Reads the details of an item of User resource identified by [id].
services/rest/default/User/fields	fields *	GET	Describes the User resource
Vendor			
services/rest/default/Vendor/[id]	read	GET	Reads the details of an item of Vendor resource identified by [id].
services/rest/default/Vendor/fields	fields *	GET	Describes the Vendor resource
Customer			
services/rest/default/Customer	list	GET	Lists Customers. Accepts extra parameters.
services/rest/default/Customer/[id]	read	GET	Reads the details of an item of Customer resource identified by [id].
services/rest/default/Customer	create	POST	Create an item of Customer resource.
services/rest/default/Customer/[id]	update	PUT	Updates a item of Customer resource identified by [id]

In the SpecificCOM-Avanti all the invocation methods to the Avanti's REST API were developed to perform the product lifecycle management.

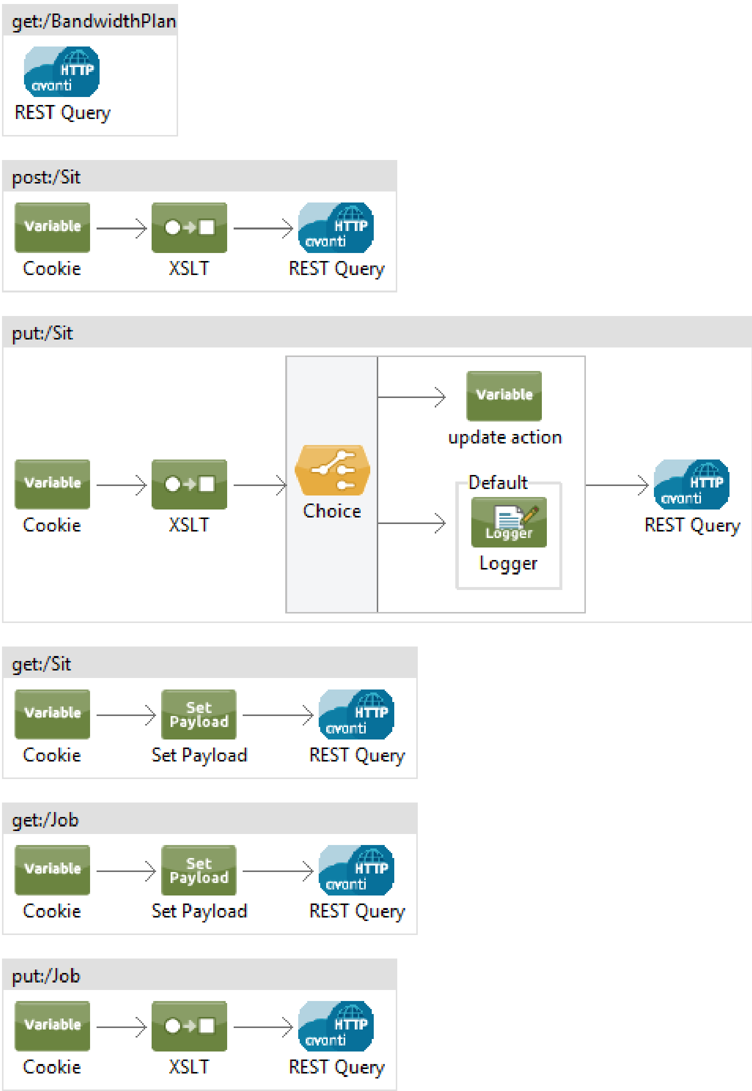


Figure A-8 SCAI Specific provision for Avanti

R Cable

The SpecificSCAI-R flow contains the specific actions to manage orchestration processes of the xDSL and 4G products:

- Feasibility

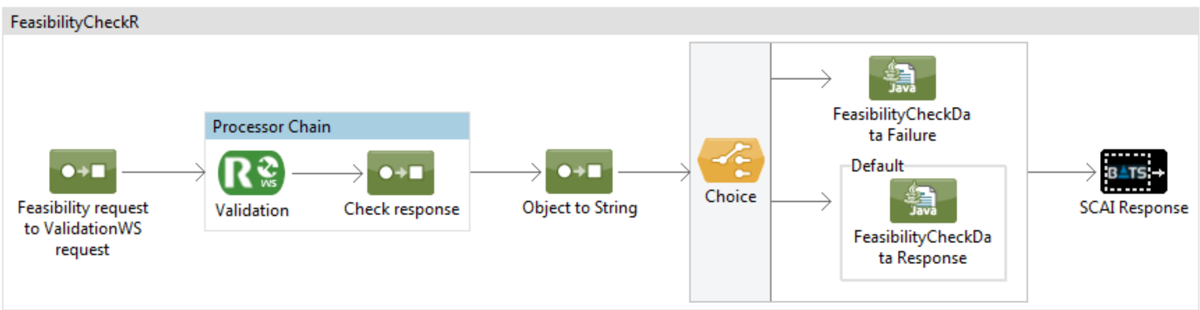
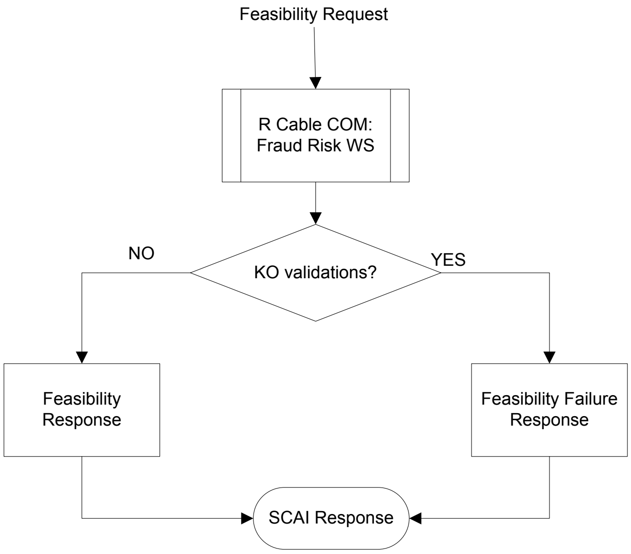


Figure A-9 SCAI feasibility specifics for R Cable

This flow uses a web service published by R Cable to check the customer's fraud risk:



- Provision

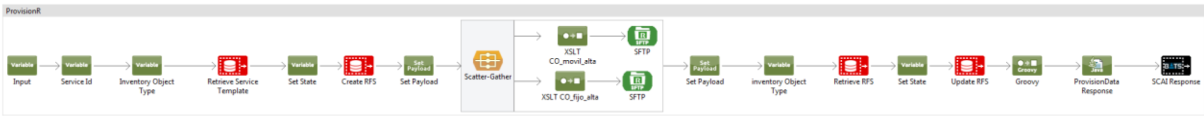
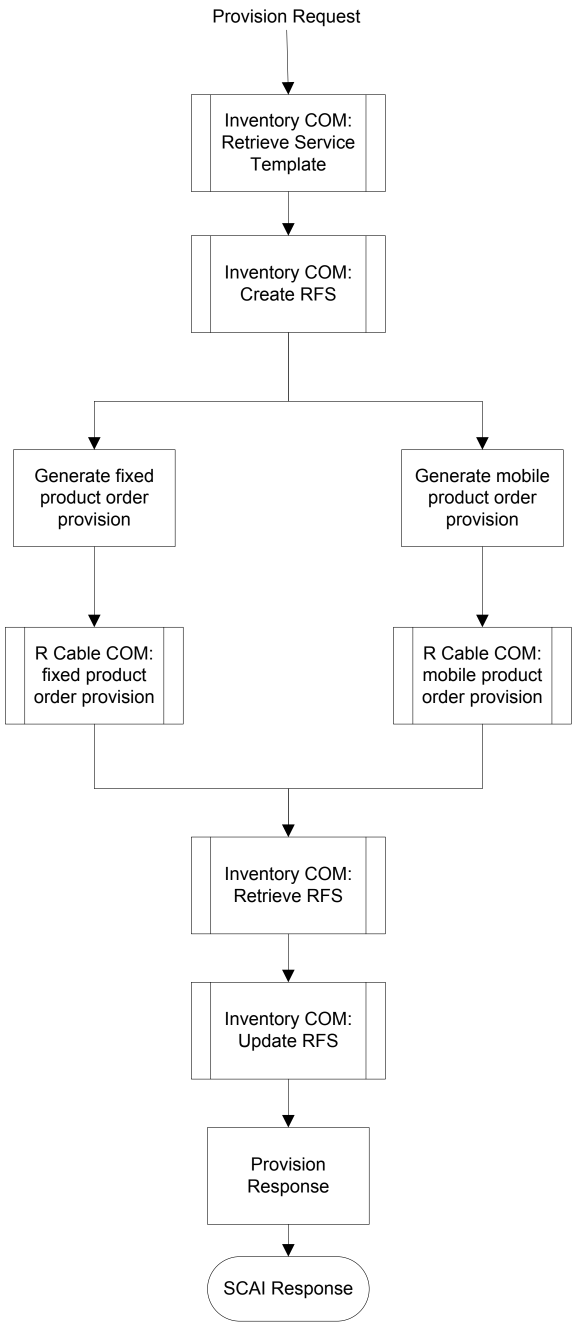


Figure A-10 SCAI provision specifics for R Cable

The provision process generates the fixed product order provision and the mobile product order provision and sends them to R Cable that publishes an ftp mailbox for receiving the orders.



- Activation/Modification/Deactivation/Termination

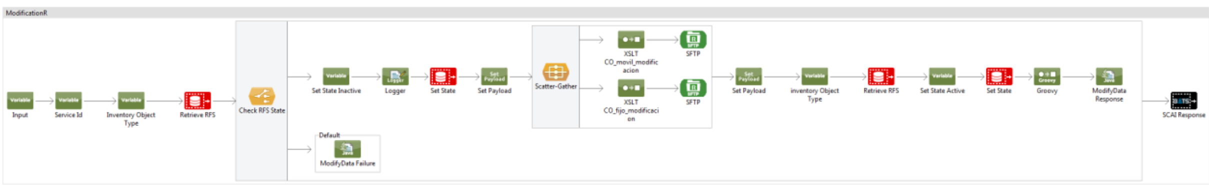


Figure A-11 SCAI activation specifics for R Cable

Activation, Modification, Deactivation and Termination processes follow a similar logic:

- Check RFS state
- Generate fixed and mobile process orders
- Update RFS state

The difference is the transformation that generates the process orders for each activity.

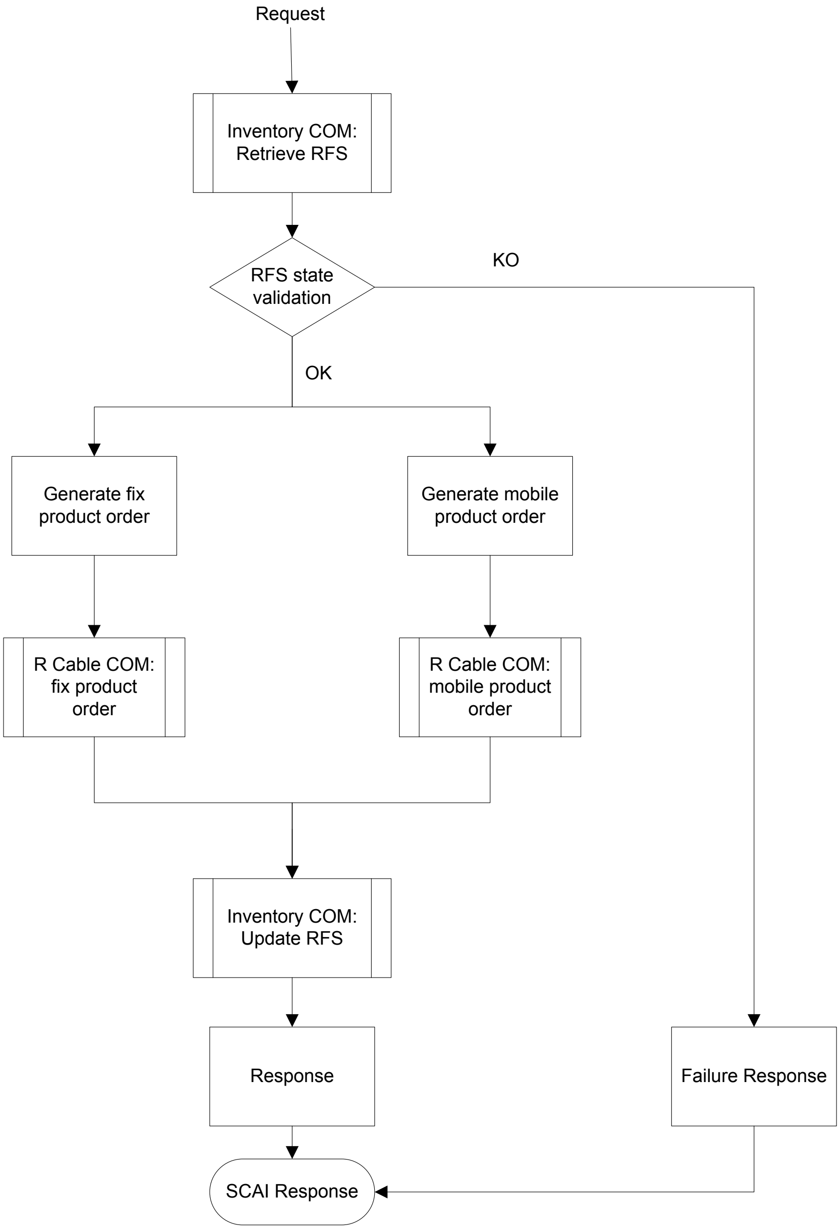


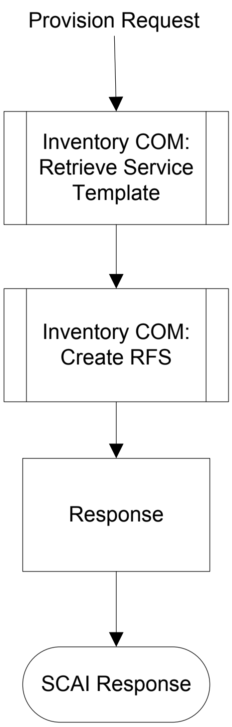
Figure A-12 SCAI modification specifics for R Cable

ACS

The SpecificSCAI-ACS flow contains the specific actions to manage remotely the intelligent user and network gateways with TR-069, using an auto configuration Server (ACS):

Provision, Activation, Deactivation and Termination sub flows only have interactions with inventory creating/updating the RFS' state. Only the Modification sub flow contains invocations to the Auto configuration Server:

- Provision



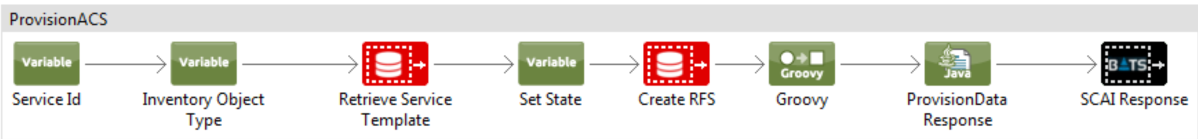
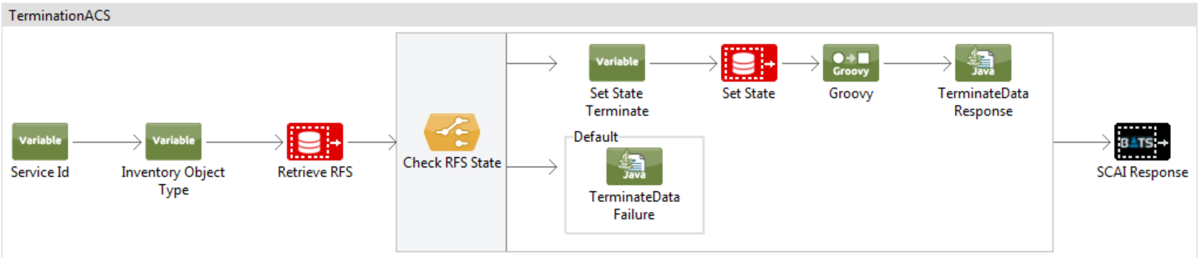


Figure A-13 SCAI provision specifics for ACS

- Activation/Deactivation/Termination



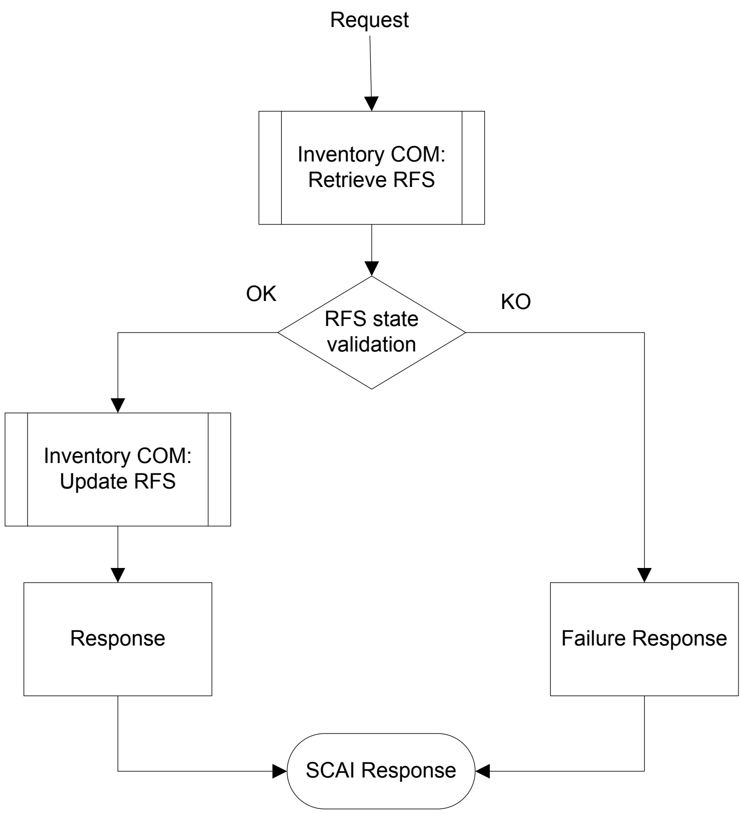
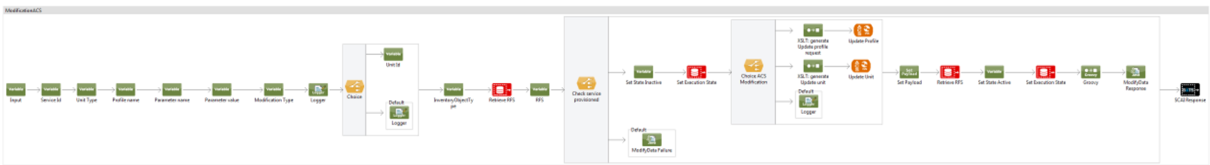


Figure A-14 SCAI activation specifics for ACS

- Modification



Two types of modifications are available:

  - UIG profile modifications
  - UIG unit modifications

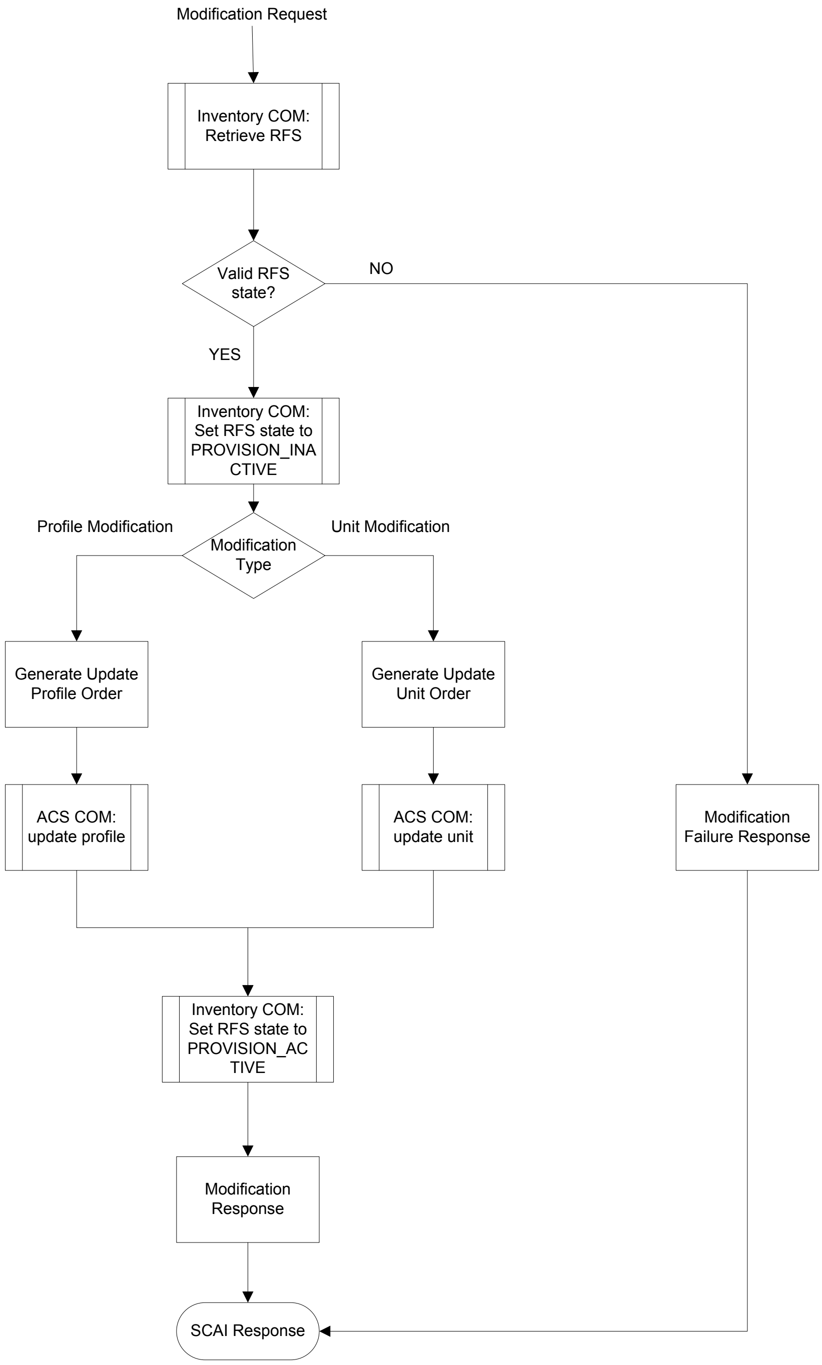


Figure A-15 SCAI modification specifics for ACS

Inventory

This component is used by all specific orchestration flows to invoke inventory that publishes a web service to make possible the next operations:

- Retrieve Service Templates and RFS entities from inventory
- Update/create the RFS entities in inventory

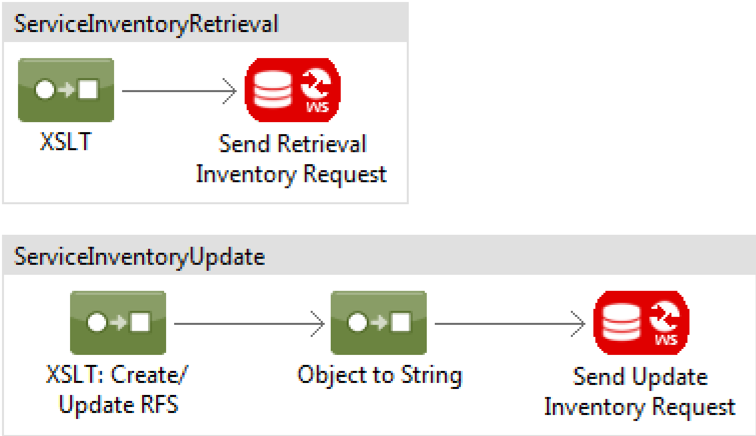
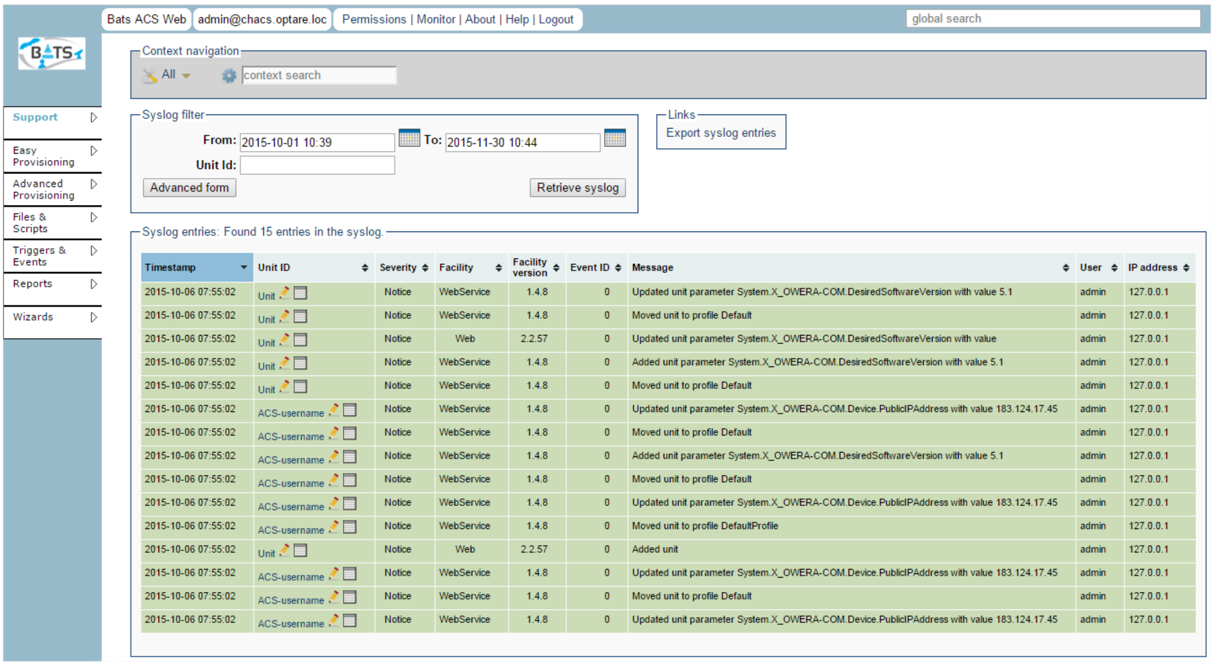


Figure A-16 Service inventory processes

BATS ACS

It was deployed a BATS ACS based on FreeACS (www.freeacs.org), an open source TR-069-enabled device management system. It can provision firmware and configuration, run scripts and take out reports, collect error messages and backup configuration.



Timestamp	Unit ID	Severity	Facility	Facility version	Event ID	Message	User	IP address
2015-10-06 07:55:02	Unit	Notice	WebService	1.4.8	0	Updated unit parameter System.X_OWERA-COM.DesiredSoftwareVersion with value 5.1	admin	127.0.0.1
2015-10-06 07:55:02	Unit	Notice	WebService	1.4.8	0	Moved unit to profile Default	admin	127.0.0.1
2015-10-06 07:55:02	Unit	Notice	Web	2.2.57	0	Updated unit parameter System.X_OWERA-COM.DesiredSoftwareVersion with value	admin	127.0.0.1
2015-10-06 07:55:02	Unit	Notice	WebService	1.4.8	0	Added unit parameter System.X_OWERA-COM.DesiredSoftwareVersion with value 5.1	admin	127.0.0.1
2015-10-06 07:55:02	Unit	Notice	WebService	1.4.8	0	Moved unit to profile Default	admin	127.0.0.1
2015-10-06 07:55:02	ACS-username	Notice	WebService	1.4.8	0	Updated unit parameter System.X_OWERA-COM.Device.PublicIPAddress with value 183.124.17.45	admin	127.0.0.1
2015-10-06 07:55:02	ACS-username	Notice	WebService	1.4.8	0	Moved unit to profile Default	admin	127.0.0.1
2015-10-06 07:55:02	ACS-username	Notice	WebService	1.4.8	0	Added unit parameter System.X_OWERA-COM.DesiredSoftwareVersion with value 5.1	admin	127.0.0.1
2015-10-06 07:55:02	ACS-username	Notice	WebService	1.4.8	0	Moved unit to profile Default	admin	127.0.0.1
2015-10-06 07:55:02	ACS-username	Notice	WebService	1.4.8	0	Updated unit parameter System.X_OWERA-COM.Device.PublicIPAddress with value 183.124.17.45	admin	127.0.0.1
2015-10-06 07:55:02	ACS-username	Notice	WebService	1.4.8	0	Moved unit to profile DefaultProfile	admin	127.0.0.1
2015-10-06 07:55:02	Unit	Notice	Web	2.2.57	0	Added unit	admin	127.0.0.1
2015-10-06 07:55:02	ACS-username	Notice	WebService	1.4.8	0	Updated unit parameter System.X_OWERA-COM.Device.PublicIPAddress with value 183.124.17.45	admin	127.0.0.1
2015-10-06 07:55:02	ACS-username	Notice	WebService	1.4.8	0	Moved unit to profile Default	admin	127.0.0.1
2015-10-06 07:55:02	ACS-username	Notice	WebService	1.4.8	0	Updated unit parameter System.X_OWERA-COM.Device.PublicIPAddress with value 183.124.17.45	admin	127.0.0.1

Figure 0-17 ACS management view

TR069 Client

To simulate the communication between real CPEs and Bats ACS it was executed a TR069 test client.

Here is an example of the input used for the test:

```
java -jar /home/ubuntu/tr069client.jar -t 1 -m 1 -s 1 -u
http://chacs.optare.loc/tr069/ -r 0-2 -b unlim -i 1
```

Here is an output from a test:

```
TIME(s)## THREADS ##          TOTAL           ##      LAST PERIOD       ##
       ##         ##    OK   | FAILED | SPEED  ## OK  |FAIL|RETRY| SPEED  ## RETRY PTS.
     10 ##         1 ##    224 |       0 | 1343.3 ## 224|    0|     0| 1343.6 ##
     20 ##         1 ##    507 |       0 | 1520.0 ## 283|    0|     0| 1696.5 ##
     30 ##         1 ##    801 |       0 | 1601.2 ## 294|    0|     0| 1763.5 ##
     40 ##         1 ##   1086 |       0 | 1628.1 ## 285|    0|     0| 1709.0 ##
     50 ##         1 ##   1372 |       0 | 1645.5 ## 286|    0|     0| 1715.1 ##
     60 ##         1 ##   1625 |       0 | 1624.1 ## 253|    0|     0| 1517.1 ##
     70 ##         1 ##   1875 |       0 | 1606.2 ## 250|    0|     0| 1499.1 ##
     80 ##         1 ##   2101 |       0 | 1574.9 ## 226|    0|     0| 1355.2 ##
     90 ##         1 ##   2308 |       0 | 1537.8 ## 207|    0|     0| 1241.3 ##
    100 ##         1 ##   2515 |       0 | 1508.2 ## 207|    0|     0| 1241.4 ##
    110 ##         1 ##   2719 |       0 | 1482.3 ## 204|    0|     0| 1223.3 ##
    120 ##         1 ##   2919 |       0 | 1458.6 ## 200|    0|     0| 1198.8 ##
    130 ##         1 ##   3115 |       0 | 1436.8 ## 196|    0|     0| 1174.8 ##
    140 ##         1 ##   3369 |       0 | 1443.0 ## 254|    0|     0| 1523.2 ##
    150 ##         1 ##   3667 |       0 | 1465.9 ## 298|    0|     0| 1786.9 ##
    160 ##         1 ##   3966 |       0 | 1486.3 ## 299|    0|     0| 1792.9 ##
    170 ##         1 ##   4260 |       0 | 1502.6 ## 294|    0|     0| 1762.9 ##
    […]
```

JMS

The queuing mechanism is supported by Apache Active MQ, an open source messaging server developed by the Apache Software Foundation. The queues are defined on 5 elements per interface (SAI/SCAI) to store requests, responses, and generated orders, associated:

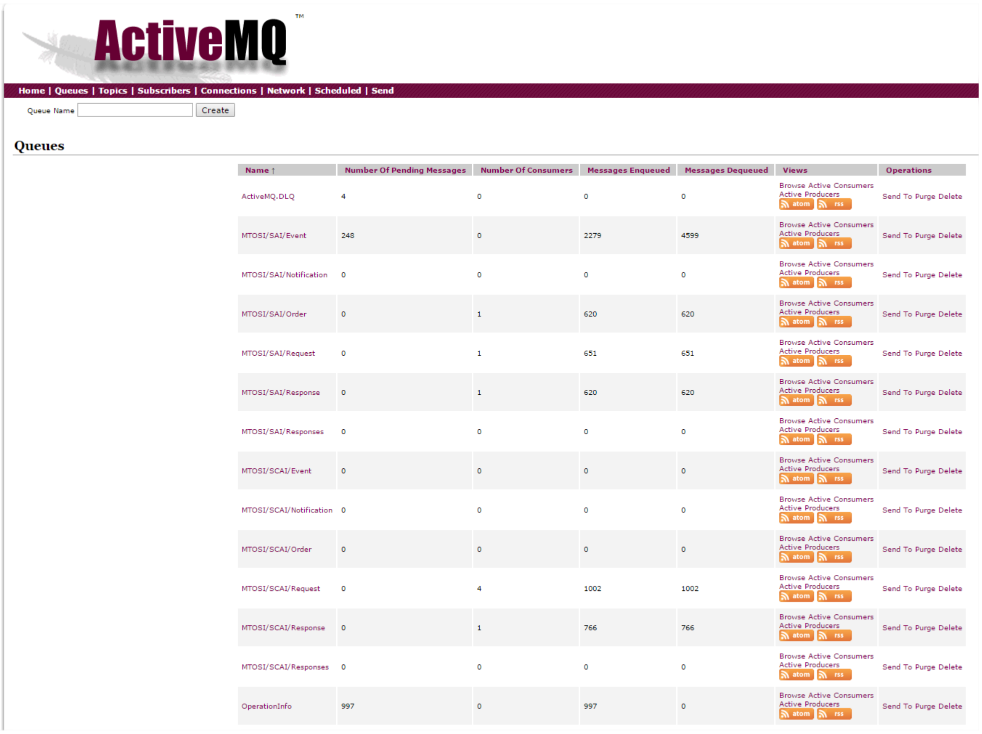


Figure A-18 JMS Message broker

JBOSS wildfly

The inventory module and the set of MTOSI interfaces were deployed in an environment of a JBOSS application server in its Final version 8.1.0 Wildfly.

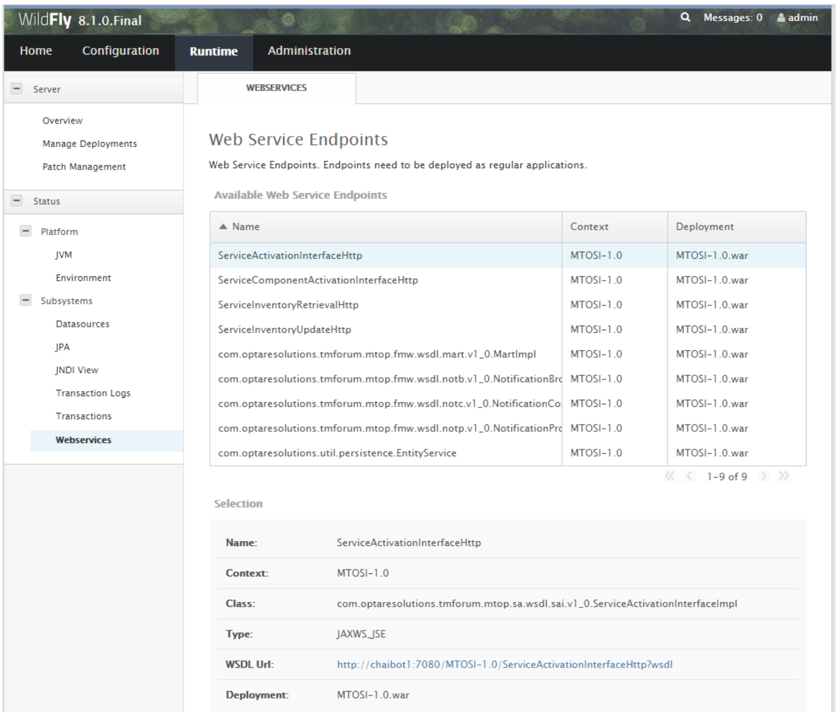


Figure A-19 MTOSI Interfaces deployed on application server

Continuous integration and Continuous delivery (CI/CD)

Merging development work and continual delivery of code to an environment was configured in Jenkins (an open source continuous integration tool) using a SVN repository and the maven build tool.

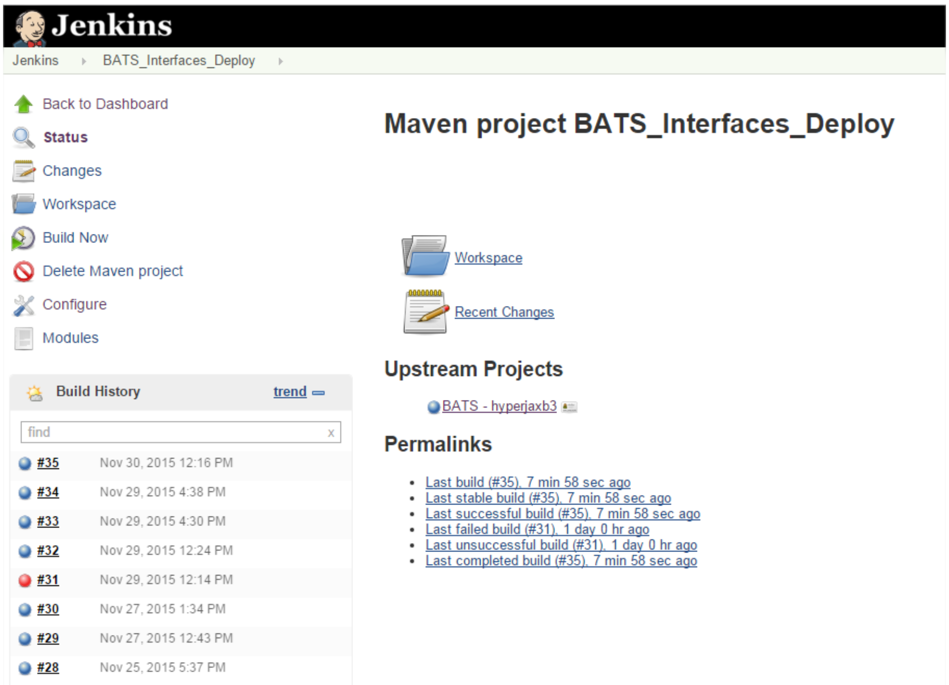


Figure A-20 Deployment of MTOSI interfaces with continuous integration

Intalio BPMS

A Lifecycle process was developed in Intalio BPMS (an open business process management system) to control the CFS lifecycle of BATS provision instances.

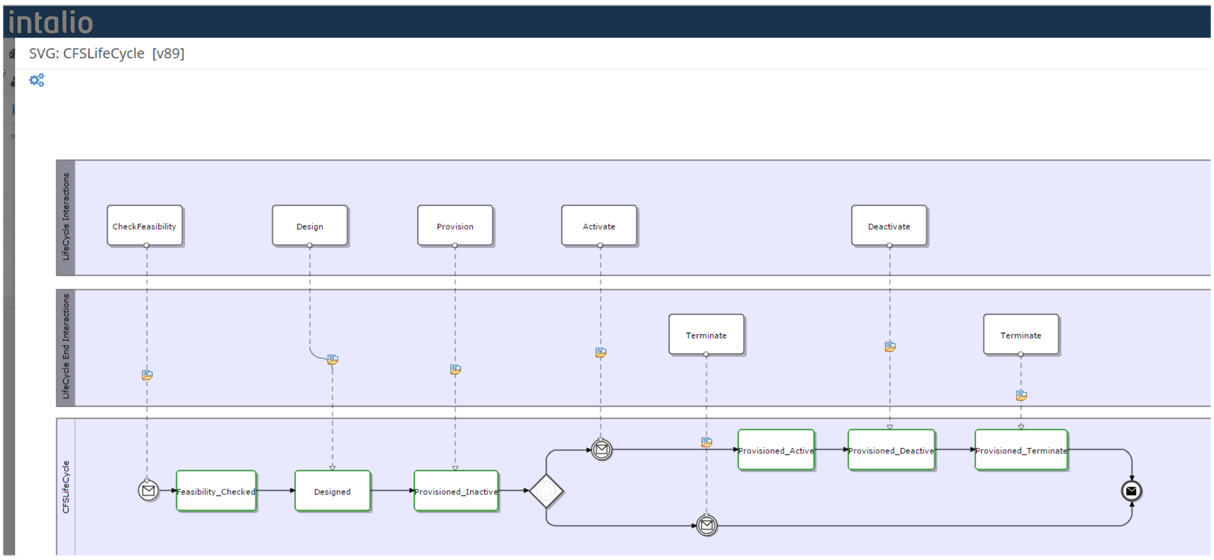


Figure A-21: BPM process lifecycle