Next Generation HTS system using hybrid satellite and terrestrial BB delivery-- BATS

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Abstract
This paper presents the results from the EU FP 7 project BATS aimed at integrated BB access across the EU for 2020 and beyond. The BB access is integrated between DSL, LTE and the satellite and features a broadband intelligent user terminal. The satellite component is a cluster of two multibeam HTS satellites providing lower cost per bit than today's satellites. The system architecture embedding the gateways and user terminals is presented as well as the design for the advanced satellites. The detailed design concepts of the intelligent router are also provided. We present the results of controlled lab tests on an emulated test bed as well as initial results from a field trial in which the intelligent routers were placed in households in Spain and Germany and connected to local; DSL and LTE as well as the Hylas satellite.

1. Introduction
The research project BATS (Broadband Access via integrated Terrestrial & Satellite systems) addresses the delivery of BroadBand (BB) future services in Europe according to the EC Digital Agenda [1] objective to reliably deliver >30Mbps to 100% of European households by 2020.
Next generation BB satellite communication systems will play an important role in the fulfilment of the Digital Agenda objectives. The accelerated deployment of current terrestrial broadband technologies will not be able to satisfy the requirements in the most difficult-to-serve locations, either due to a lack of coverage in areas where the revenue potential for terrestrial service providers is too low (unserved areas) or due to technological limitations which diminish the available end-user throughput in rural environments (underserved areas). The Digital Agenda targets will therefore need to be accomplished by the integration of satellite as a key component of the future broadband communication systems. Market studies such as [2] indicate that in a significant number of regions of Europe, coloured in the lighter and darker grey, more than 50% of premises will lack access to superfast Broadband by 2020.

In order to accommodate the areas of Europe which are 'unserved' and 'underserved' in terms of BB availability, the BATS system will combine the limited capacity of terrestrial BB networks with Ultra High Throughput Satellite Systems to provide an order of magnitude cost/bit reductions and solutions to existing market barriers of bandwidth and latency limitations. BATS proposes a novel architecture

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which combines the flexibility, large coverage and high capacity of future multi-spot beam satellites, the low latency of fixed DSL lines, and the pervasiveness of mobile/wireless access. The BB service will be delivered via an Intelligent User Gateway (IUG), dynamically routing traffic flow according to its service needs through the most appropriate delivery mechanism to optimise the users' Quality of Experience (QoE). To cope with such integrated scenario, BATS will provide a unified network management framework.

The reminder of the paper is organised as follows. Section 2 presents the requirements and demands driving the project. Section 3 presents the design of the HTS satellites. Section 4 details the overall architecture and the intelligent router. Section 5 presents the results of the laboratory trials and section 6 the results from the field trials. Finally, section 7 presents the major conclusions of the project.

2. BB requirements and demands

An analysis that included inputs from two external contractors was employed; the first included a review of the addressable market for BATS; the second provided information on fixed premise LTE service delivery in Germany.

Other inputs were the design decisions that considered the IxGs along with those looking at the satellite and air interface capabilities. The analysis was performed at a NUTS3 level and then totalled per country and across the EU27+Turkey (EU27+T). NUTS3 are "small regions for specific diagnoses" defined by Eurostat [3] and widely used for analyses.

This analysis determined the following:

- The addressable market for BATS and the proportion of households within that market that can afford this for a given monthly price;
- The competition from LTE has been assessed and, given that LTE is relatively costly at twice the cost to deliver 250GB compared with satellite, the impact on BATS is predicted to be fairly low.;
- The data rates required per household in 2020 were extrapolated, the consultant's predicted data rates being twice as high as that calculated from Cisco data [4];
- The satellite supply using the BATS 2020 design was calculated per NUTS3 region. The model uses this data to ensure that dimensioned demand does not exceed supply. This leads to the finding that a further level of satellite optimisation would better serve the BATS target market;
- The model analyses a number of different scenarios and sensitivities. The analysis is critically dependant on the amount of data carried by the satellite in the forward link. The BATS model benefits from optimising pricing per country and by targeting the underserved ahead of the unserved.

Figure 1 show the fulfilled demand per NUTS3 region and per country.

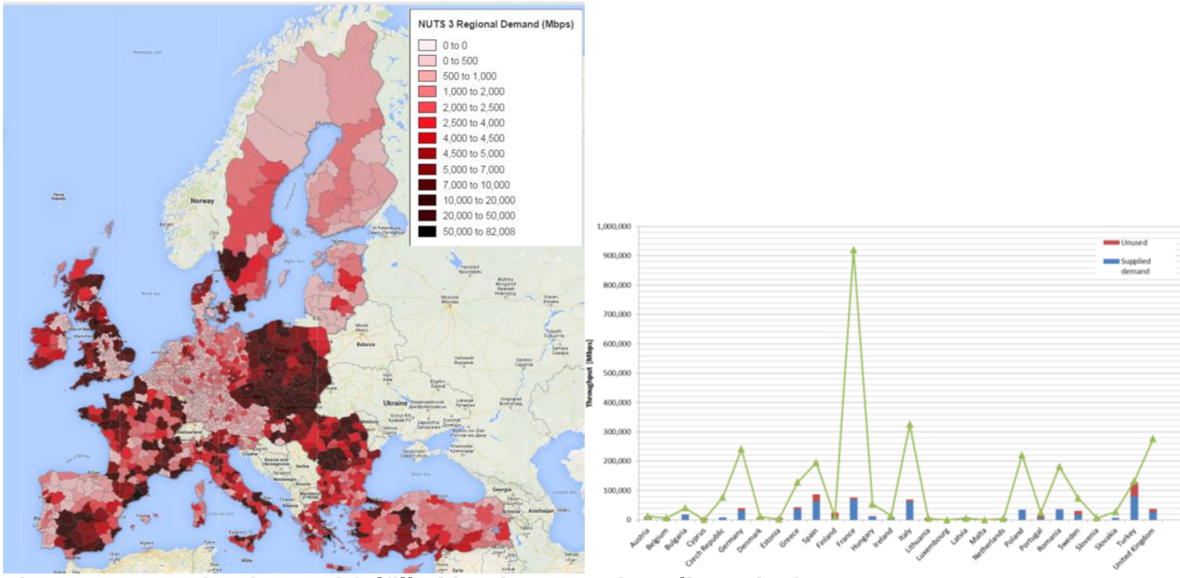

Figure 1: Capacity demand fulfilled by the BATS baseline mission

3. HTS satellite designs

The space segment design involves two co-located GEO satellites handling 151 user beams each, and covering West and East sides of the overall coverage. In order to maximise the overall throughput, the whole FSS civil Ka-band (exclusive + shared bands) has been allocated to the user links, and a four-colour frequency reuse scheme has been considered among the multiple beams. As a consequence, a significant aggregated bandwidth is required for the feeder links. In BATS, two options, one based on Q/V band gateways and one based on optical gateways, have been considered. The Q/V band RF option involves the sharing of the user throughput among multiple gateways. The related system design trade-offs have been presented in [5]. In the alternate version, an innovative free space optical link is considered for a single gateway to take in charge the whole system throughput at a time. An affordable site diversity system based on several optical ground stations (OGSs) and a highly capacitive optical fibre network are considered to overcome cloud obstruction of the feeder link. Further details on this mission can be found in [6].

Link budgets in clear sky conditions result in total satellite capacities of 800 Gbps on the forward link and 249 Gbps on the return link (i.e. both satellites). Even with the baseline large offered capacity (beyond the Tbps), a significant amount of unsatisfied traffic demand is still present in certain zones of the coverage (reaching several tens of Gbps) while in other areas, the demand is fully met, 'wasting' resources on those beams not heavily loaded (illustrated in Figure2).

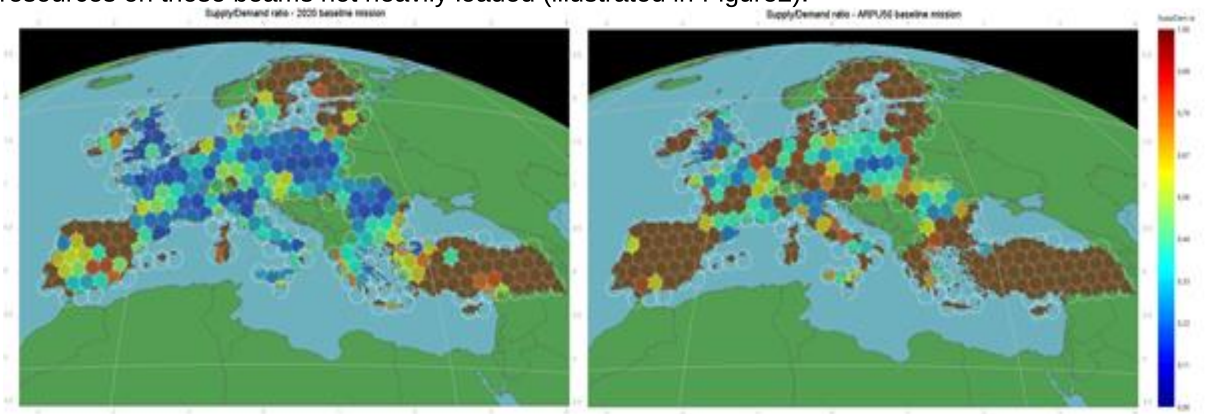

Figure 2: Capacity supply/demand ratio in the coverage with BATS baseline mission (left) and Capacity supply/demand ratio in the coverage with BATS baseline + Enhanced missions (right)

In order to cope with the remaining traffic demands the BATS strategy considers a space segment development for the 2025 timeframe with a view to offer an enhanced complementary satellite transmission capacity to the baseline satellite system. From Figure 2, it seems reasonable to think that enhanced mission design must cope with a certain degree of flexibility in terms of resource allocation (i.e. with respect to the baseline mission where homogeneous resource allocation was considered) but, above all, needs to be still a capacitive solution in order to cope with the high ratio of unsatisfied user demand. For that purpose, a complementary design has been addressed; the new design has kept the same user beam definition and power envelope as the baseline scenario to minimize the non-recurring costs. However, a more aggressive frequency reuse scheme combined with the implementation of interference mitigation techniques (i.e. on-ground Precoding for the FWD link) have been assumed, only in a certain subset of beams in the target coverage. Essentially, to add a certain level of resource allocation flexibility, not all beams are 'switched-on' permanently (nominally the case in 2020 baseline) but only a certain subset (i.e. 50%) presenting the highest unsatisfied traffic demand (which in turn can be re-configured on the fly by means of an on-board switching beam selector system).

Globally, a beam satisfaction ratio[2] improvement w.r.t. baseline design has been obtained, going from 37% (baseline) up to 53% with the traffic estimation considered[3]. In terms of total throughput, considering a more aggressive FR scheme combined with precoding, greater total capacities are obtained (i.e. ~1.1Tbps) w.r.t. baseline mission considering only 50% of the beams in an active mode, thus proving the potential of interference mitigation techniques in future HTS systems. With both

[2] In a beam to beam basis, i.e. (X) of beam traffic demands are fully met, while (1-X) of beams present still some remaining unmet demand

[3] It should be noted that these percentages depend directly on the traffic demand estimation from which the design was based on. More information on this assumptions can be found in [4]

missions (baseline + enhanced - Figure 2) more than 2 Tbps are provided to the BATS integrated system.

4. Integrated satellite and terrestrial delivery

The overall network architecture, as illustrated in Figure 3, comprises the three broadband access segments previously mentioned: xDSL, cellular and satellite, whose connections are terminated at the BATS CPE or IUG on the end-user side and at its reciprocal unit on the central/operator side, the ING.
The IUG is the routing entity located at the end-user premises serving as the focal point for the integration of the terrestrial and satellite connections. As the counterpart of the IUG on the network side, the ING has the functionalities of both managing a set of associated IUGs and acting as a single connection interface to the public internet. Note that in the upstream, connections routed by the IUG across the different networks are merged back together at the ING before accessing the Internet. For the downstream traffic, an ING has equivalent building blocks and routing functionalities to the IUG. The main functionality of IUG and ING is to route the outgoing traffic towards the most suitable access network segment considering the QoE requirements of each particular traffic flow and the real-time status of each of the links. Based on this, the ING is to be located as close as possible to the Point of Presence (PoP) of the terrestrial operators involved in the integrated BB delivery system, in order not to increase the latency of the services routed over terrestrial network, which are meant to be the most delay sensitive.
Due to the high Bandwidth-Delay product in GEO satellite links, Performance Enhancement Proxies (PEPs) are currently used to mitigate the associated TCP PEP performance degradiation. Given the number of gateways in the BATS satellite segment, it has been decided that the best compromise between performance, impact and complexity is to locate a high capacity PEP in a central point of the network near to the PoP or at the same ING, alleviating the internal re-routing and synchronization issues compared to a case where the PEP is located at the nominal satellite gateway and traffic needs to be re-routed to one of the redundant gateways to avoid service interruption due to fading or failure at the nominal one.
An inherent characteristic of the BATS system is the heterogeneity of the various technologies that are involved; satellite broadband offers high bandwidth but higher latency as opposed to narrow-band xDSL low latency links. In such a scenario, randomly distributing packets among the different connections despite the characteristic of both traffic and networks could in turn affect negatively the end-user QoE. More sophisticated methods are hence required to allow the simultaneous use of satellite and terrestrial links in a seamless manner fully exploiting their specific strengths.

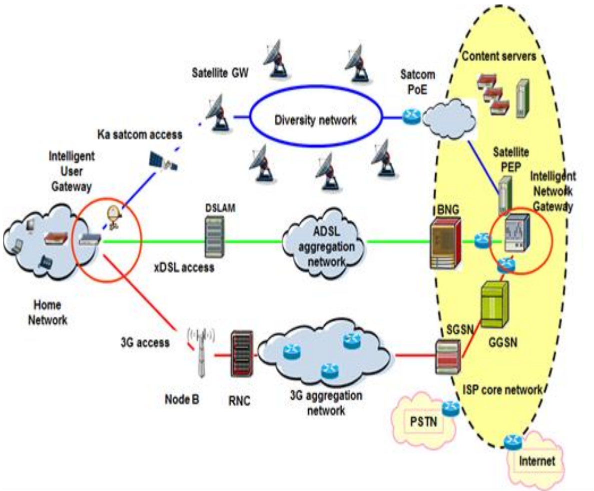

Figure 3: BATS Integrated Satellite and Terrestrial Network Architecture

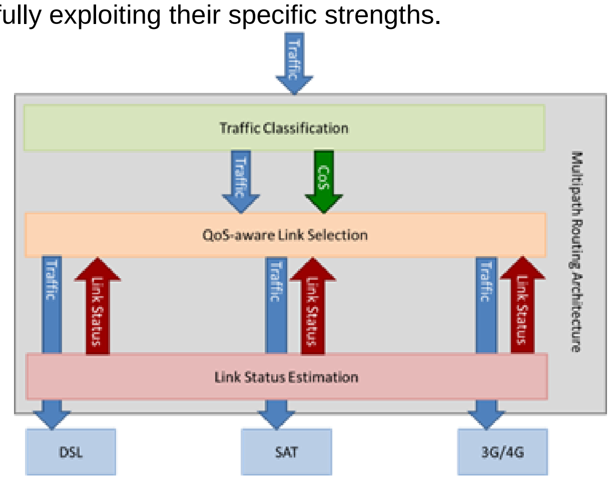

Figure 4: Key Design Modules of both IUG and ING

In BATS, the IUG and ING have been conceived with a modular approach and well-defined connecting interfaces between the different components which allow for specific improvements on individual modules without modifying the entire system. Figure 4 illustrates the key building blocks of both IUG and ING, namely being the Traffic Classifier, QoS-aware Link Selection module and the module for Link Status Estimation.
TCP (and HTTP) are now the protocols dominating up to about the 80% of Internet traffic [7]. Based on this, the routing strategy in the IUG and ING has been designed with a focus on optimizing the routing of TCP traffic, managing UDP via Policy Based Routing (e.g., route traffic over terrestrial links

when available). Given the integrated satellite and terrestrial architecture, MPTCP [8] has been identified as an appropriate instantiation to base the core of the multipath routing architecture, as it aims at using multiple paths between a source and a destination host while providing the same interface to both the application and the network layer as in conventional TCP. As in regular TCP, MPTCP is also designed to be an end-to-end transport layer protocol. Hence, in order to exploit the multipath features of MPTCP only between intermediate routers such as IUG and ING, MPTCP proxies need to be used at those routers. In the BATS design, the implementation of MPTCP proxies at both IUG and ING allows the definition of a completely integrated architecture based on a common set of mechanisms independent from the heterogeneity of the access networks. Details on the IUG and ING design are provided in [[9].

5. Laboratory trials

In order to evaluate the subjective performance of the developed intelligent broadband aggregation sysem in a controlled environment, a test bed has been set up in University of Surrey. The test bed involves three different access network emulators working in parallel, combined together with the developed Intelligent User and Network Gateways (IxG). Besides, in order to facilitate subjective tests, an application server and several client terminals have been integrated into the test bed. Figure 5 shows the high-level diagram of the test bed.

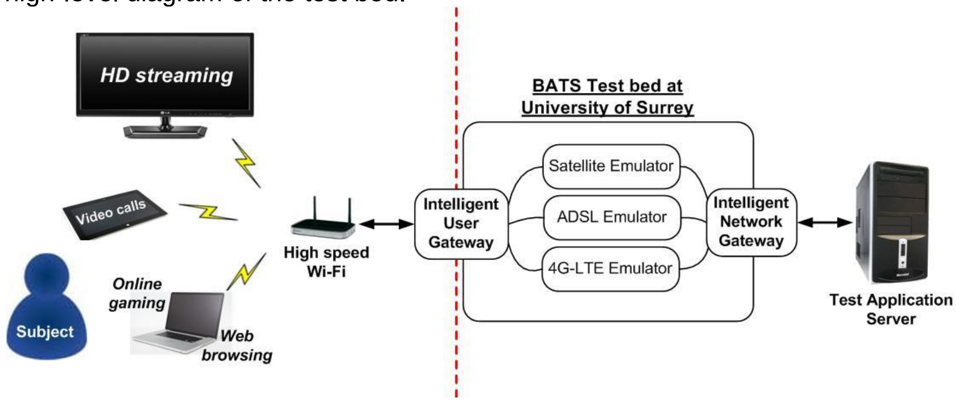

Figure 5: Overview of the test bed used for the subjective experiments

The satellite emulator is based on the OpenSAND platform [10], a Level-3 detailed DVB-S and DVB-RCS full up emulator. The ADSL and 4G-LTE emulators are based on the Netemu platform [11], which is a Level-2 emulator. The individual emulators can be accurately configured with pre-defined performance characteristics, yielding a reproducible environment. For each of the three network emulators, three distinct states have been defined to be used during the experiments as *Good* (G), *Marginal* (M) and *Poor* (P). Those pre-defined states are in line with typical real life conditions, as depicted in Table 1.

Table 1: Network emulator parameter settings

	Downlink Bandwidth	Uplink Bandwidth	Latency (one way)	Jitter	Packet Loss Ratio (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}

Subjective test applications

Four different applications have been deployed to measure the QoE of subjects. These 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 5. 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 a web server. For *web browsing*, the contents of ten different web sites have been copied into the same web server. The web server is accessible by the test clients through the network emulators. The web browser in the test clients have been pre-configured to bookmark these web pages and to delete all cookies and cache after each test. For the *video conferencing* scenario, an application called Ekiga [12] is installed on both the test client and the test application server. During the tests, subjects can 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 [13]. 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.

Subjective test conditions and results

Sixteen subjects with different backgrounds and Internet usage habits have participated in the tests. The test involves accessing a single application at a time through the emulated networks. The IxG devices are expected to optimally route the traffic through the most suitable link based on the application requirements. In order to measure the QoE gain by IxG, each test application has also been accessed through individual emulators with their specific settings (i.e., without the IxG in Figure 5). The purpose is to measure the maximum and minimum levels of achievable QoE associated with each application. Figure 6 shows the QoE levels achieved for each application using different emulators in terms of Mean Opinion Scores (MOS). For each application, only those emulator settings are used, which provide us with a range from the possible minimum to the possible maximum QoE. Except for the online gaming scenario, which most subjects were not experienced in, the MOS vary in a wide range. The online gaming scenario has shown the least variation.

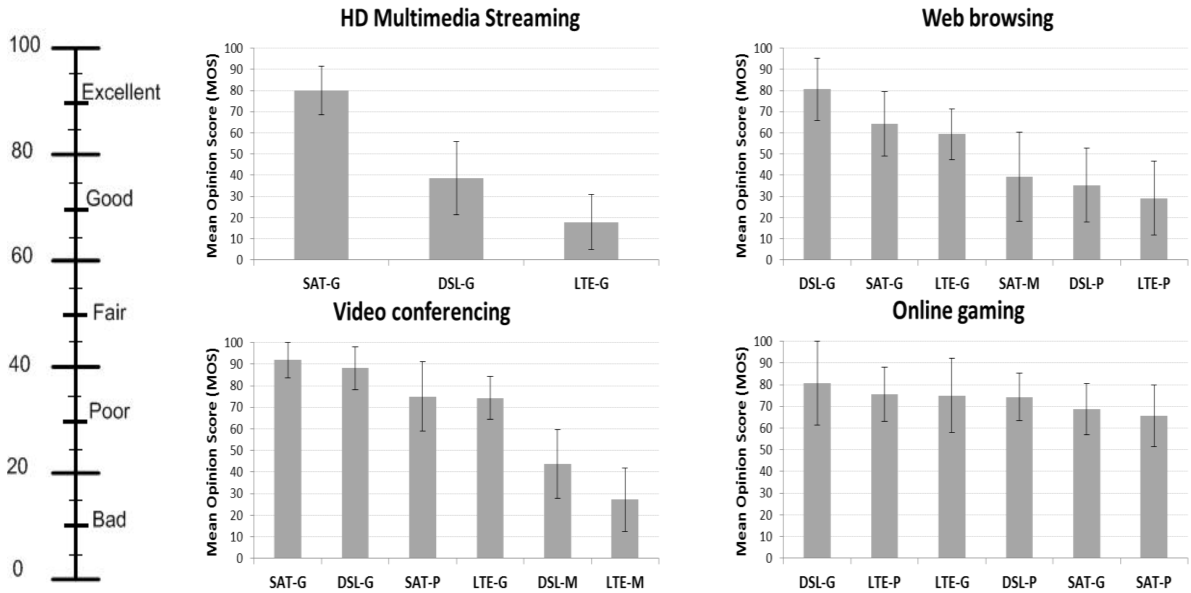

Figure 6: QoE results for single application at a time (over individual network emulators)

Figure 7 shows the results when IxG is integrated into the system. The emulator configurations are presented in the format of [Satellite condition, DSL condition, LTE condition] (e.g., GMM, PMG, MGG, etc.). Note that in 80% of the network combinations shown in Figure 7, at least two of the networks are in Poor or Marginal condition. This is to ensure an unbiased measurement. According to Figure 7, for 79% of all test cases, the MOS are over or close to 80 (70 for Web browsing), which indicates good - excellent quality. Hence, the IxG is broadly successful in identifying the application traffic and correctly route it. It can be seen, however, in Figure 6 that depending on the network condition, the MOS can drop easily to bad – poor quality region (0-40) when the IxG is not active.

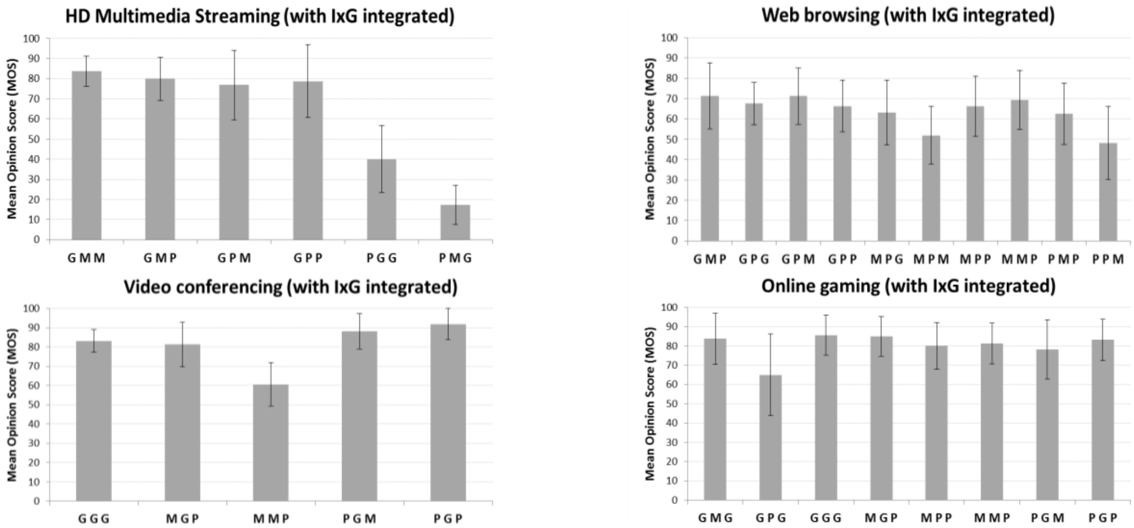

Figure 7: QoE results for single application at a time (IUG and ING integrated)

6. Field trials

Alongside the Laboratory Trials, prototypes of the IUG have been installed in up to 50 end-user households across both Spain and Germany. For the prototypes, the BATS IUG and ING implementations, as described in Section 4, have been embedded in the existing OneAccess routing and WAN optimisation platforms. The IUG is actually composed of 3 physical devices with Ethernet interconnections: a One540 AVDSL/4G router [14] a WXB360 Gateway [15] that provides the BATS MPTCP proxy implementation and the Hughes HN9600 [16] as Ka-band satellite router for the broadband service over the Hylas 1 satellite. This multi-box solution has been proposed given the available state of the art technology and to avoid additional external devices for WAN access networks and LAN+WIFI (built-in the One540) and to provide all necessary computational power to run the BATS algorithms. The IUG relies on the One540 for most IP routing features while having the BATS MPTCP implementation in the WXB360 to limit risks on negative side-effects and provide a way to reach the target multi-link performances. Besides the LAN interfaces, the One540 provides internal DSL and the 3G&4G modems. The prototype IUG for the field trials is illustrated in Figure 8. In addition, it is worth noting that the BATS solution also comes with the outdoor unit for the satellite broadband service which includes in this case either a 74cm or 98cm satellite dish.

Figure 8: IUG implementation for the Field Trials.

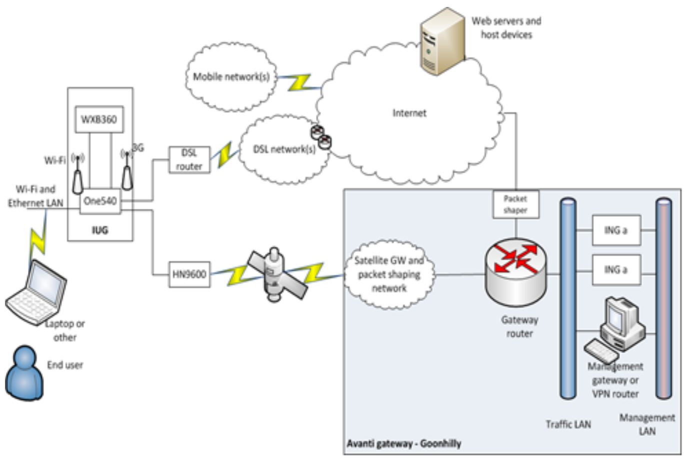

Figure 9: Network Architecture for Field Trials in Germany.

The network setup and location of ING are different for the deployments in Spain and in Germany. In Spain, BATS provides a more integrated framework thanks to having both DSL/3G and satellite operators in tight collaboration. In this case, the ING has been located in Spain within the core network of the terrestrial operator as recommended in Section 4. On the other hand, in Germany, the BATS network is fully managed by the satellite operator without collaboration with the terrestrial players. In this case, the IUG is externally connected via an Ethernet cable to the DSL router from a non-BATS

operator. For the German configuration, the ING has been located in UK within the core network of the satellite operator. In both cases, however, the ING is based on the WXD2450 high-end optimization device from OneAccess. Two INGs have been installed in both Spain and Germany that will share the workload and be able to support traffic from/to 20 IUGs each. As an example, the network setup for the German configuration is illustrated in Figure 9.
In addition, the prototype IUG and ING also leverage the existing OneAccess features in order to provide the required broadband services (i.e. tunnel management, routing, monitoring, troubleshooting, remote SW update, etc.).
The 50 households have been strategically selected to provide a range of users differing in:

- Type of household (age and gender of the main test candidate, total number and age of all other inhabitants in the home).
- Activities on the Internet (frequency and place of use of Internet, type of applications and services used).
- User level (self-evaluation of the user, experience in the use of different applications and services).
- End-user devices (desktop and laptop computers, smartphones, tablets, gaming consoles, streaming devices, etc.).

In addition, the operators and IxG manufacturer involved in the trials are taking objective measurements of the different connections to analyse in-depth the performance of the BATS system and specific technology. At the time of preparing this publication, the field trials are still on-going hence results from them are not yet available and their analysis is still left as future work.

7. Conclusions

The BATS project has produced a new design for an HTS satellite to cover Europe which optimises the space and ground segment costs to reduce the overall cost per bit to the user. An intelligent user router has been designed to route BB traffic over the most appropriate of three routes. It has been shown in the lab trials that this system improves the QoE to the users for a variety of applications. A wider field trial is in progress.

8. Acknowledgements

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References

[1] European Commission, *A digital Agenda for Europe*, COM(2010)245, 26 August 2010.
[2] Point Topic, *Mapping is vital to broadband investment*, ITU Telecom World, 2011.
[3] Eurostat NUTS overview http://ec.europa.eu/eurostat/web/nuts/overview
[4] Cisco Visual Networking Index, "Forecast and Methodology, 2013-2018" Cisco, 2014.
[5] J.Perez-Trufero, B.Evans, A.Kyrgiazos, M.Dervin, B.Garnier, C.Baudoin "HTS system with Q/V band gateways and its integration with terrestrial BB communication networks" ICSSC conference 2014, San Diego Cal USA.
[6] O.Vidal, B.Roy,S.Dimitrov,R.Barrios, D.Giggenbach et A.Le-Kernec, "Next Generation high Throuhgput Satellite System based on optical feeder links", In Proc. of 21st Ka-conference, Bologna, Italy, 2015.
[7] D. Lee, B. Carpenter, and N. Brownlee, *Observations of udp to tcp ratio and port numbers,* in Internet Monitoring and Protection (ICIMP) 2010, May 2010, pp. 99-104.
[8] A. Ford, C. Raiciu, M. Handley, and O. Bonaventure, *TCP Extensions for Multipath Operation with Multiple Addresses*, *RFC 6824 (Experimental)*, Internet Engineering Task Force, January 2013.
[9] L. Ottavj, E. Duros, J. Webert, F. Gamberini, C. Niephaus and J. Perez-Trufero, *Intelligent Gateways Enabling Broadband Access via integrated Terrestrial and Satellite Systems*, In Proc. of Wireless and Satellite Systems Conference 2015, July 2015.
[10] The OpenSand platform, http://www.opensand.org
[11] NetEmulator, http://www.openchannelfoundation.org/projects/NetEmulator/
[12] Ekiga, an open source video conferencing application over the Internet, http://www.ekiga.org
[13] ITU-T Recommendation P.920, *Interactive test methods in audiovisual communications*, May 2000.
[14] OneAccess Networks, "One540: Cloud Services Gateway & Multi-Service Access Router", Datasheet available at: http://www.oneaccess-net.com/products/multi-service-data-routers-and-eads/medium-business-regional-offices/item/69-one540
[15] OneAccess Networks, "WXB360: WAN Optimziation for Medium and Small-Scale Offices".
[16] Hughes public information on the HN9600, http://www.hughes.com/resources/hn9600-satellite-router