Efficient network resources utilization for Ka-band high capacity satellite systems

L. Carniato, F. Fongher, M. Luglio, W. Munarini, C. Roseti, F. Zampognaro

***Abstract*— An efficient resource allocation is of paramount importance to guarantee the best performance with a fair distribution of satellite capacity, even for Multi-beam High Throughput Satellites (HTS) platforms. These platforms are recently gaining relevance for broadband Internet access and are nowadays able to provide xDSL like services. Although the available bandwidth for HTS is greater than previous platforms, it is still fundamental to use it wisely and avoiding abuses, which may jeopardize the service performance of the installed user-base. This paper focuses on the commercial system using the KA-SAT platform by Eutelsat, where a Deep Packet Inspection (DPI) solution is adopted to allow multi-dimensional per-user and per-application priority. Simulation and emulation tests have been executed to identify both the optimal DPI configuration and the amount of satellite capacity to procure in order to meet user requirements. Test achievements are then used to provide useful inputs for the real platform configuration in the frame of the Lift Off ESA project.**

***Index Terms*— HTS, DPI, Ka-Sat, Emulation, Simulation**

I. Introduction

THE availability of High Throughput Satellite (HTS) systems [1] has recently allowed the introduction of broadband access commercial offers also to non-business users. Satellite systems allow a quick deployment in remote and rural areas without the need of additional infrastructures and investments from the Satellite Internet Service provider (S-ISP). Nevertheless, to improve on competitiveness, satellite resources shall be optimally shared among a great set of users to compensate investment and management costs (development and construction, launch, orbit maneuvers, asset control, ground station, etc.) which impact the cost to the final user. To reach this aim resource sharing shall be carefully controlled, otherwise a few "greedy" users may catch most of the available capacity approaching saturation and impacting negatively performance of the overall user population. Therefore, it is evident the need of agreed service policies and traffic control procedures. In this framework, the Lift-Off European Space Agency (ESA) project [2] is carrying on a study and developing a pilot satellite network to efficiently support hundreds of users.

This paper summarizes the main project outcomes, which rely on the implementation of a solution based on the Deep Packet Inspection (DPI) [1][3] on a Ka-Sat HTS network [4][5] to identify an accurate resource allocation. Target objective is to carefully control, with different priorities and constraints (volume limit, time limit, etc.), the traffic of different categories of users, so that overall performance is satisfactory in compliance with defined user profiles. In addition, the accurate traffic shaping can enable a virtual "flat" profile (no explicit data volume limitations) in the commercial offer for some user categories (i.e. home users), making satellite appealing much closer to traditional terrestrial xDSL.

Setup of both DPI profiles and policies for application filters has been supported by simulation and emulation activities in order to validate effectiveness of the proposed solution. The simulation campaign and outcomes are presented in the paper, as well as its relation with the operational platform.

II. Reference Scenario

The considered HTS system is based on the Tooway platform operated by Eutelsat [1] exploiting capacity of Ka-Sat multi-spot satellite [4][5]. Ka-Sat offers coverage of Europe and part of Africa and Middle-east countries, as shown in Figure 1. The coverage is achieved with 82 spot beams, each providing a maximum capacity of 475 Mbit/s (combined for up and downlink).

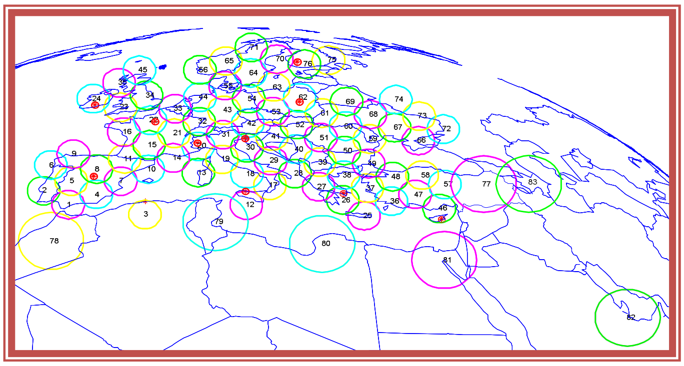

Figure 1: Ka-Sat Beams Coverage

Figure 2 shows the simplified architecture of the considered HTS system. The main elements are: the user equipment at the users' premises (outdoor unit and indoor unit consisting in antenna and Ka band modem), Satellite (Ka-Sat working in Ka-band with a multi-spot setup), a Network management server (Network Operations Center, NOC) and the terrestrial

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connection as backbone to the Internet. Additional support operations are also necessary to monitor the access and usage of the platform, represented by a Radius authentication server with accounting and billing facilities. Several other architectural components are necessary to independently operate as a satellite Virtual Network Operator (VNO), but are not presented herein for simplicity since they are not directly related to the resource allocation.

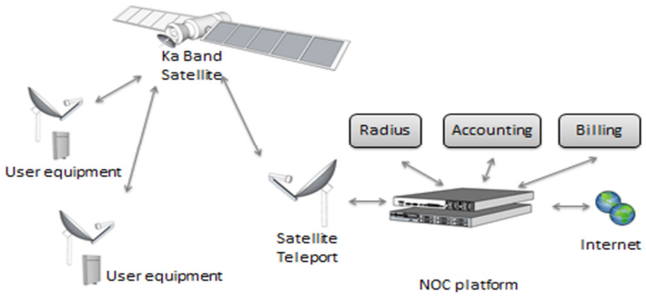


Figure 2: System architecture

Despite the frequency reusing on physically separated spotbeams, the bandwidth offered to Satellite VNO can be aggregated transparently at IP level, in a "beamless" mode. This means that it is not required to buy a separate portion of physical capacity on all spotbeams of interest, but only agree with the Satellite Operator (Eutelsat) the spotbeams of interest and the total bandwidth required. In this way, the HTS operator realizes a virtual single spot beam specifically tailored to the target area (typically a country), increasing the flexibility of the platform. Eutelsat is in charge to dynamically map on-demand the beamless IP resources of several VNOs to the physical medium.

For the service envisaged in the Lift Off project, the 10 Ka-Sat spotbeams covering Italy were selected in a "beamless" setup with a total of about 30 Mbit/s.

III. Scope of the DPI solution

In general, terrestrial broadband access is provided with a contention ratio of *1:N*. It means that the same capacity (assuming for instance C Mbit/s) is contended by N users. At a given time, the sum of all the capacity in use by the N users must always be less than or equal to C. In realistic conditions, since the traffic generated by each user is time-independent and can be approximated through On-Off models (e.g., content downloads followed by idle intervals), all the N users can statistically achieve the maximum capacity C because they will use actively the system at different times. Of course, in the worst case when all N users are simultaneously accessing web contents at a sustained rate, each one will only achieve C/N Mbit/s. To avoid this performance degradation, N is kept as low as economically possible, with a general overprovision of capacity C (which is possible if considering ADSL2+ standards allowing up to 20 Mbit/s). Typical values for N in ADSL, range from 20 (good quality) to 50 (lower quality).

When considering the broadband access through the Tooway Ka-Sat platform, although allowing a much higher throughput compared to older satellite platforms, the cost per Mbit is still much higher than in terrestrial cases. Therefore, with the aim to preserve a competitive commercial offer (compared to terrestrial ADSL), it is not possible to reduce the contention ratio below a certain threshold or further increase the maximum per-user capacity (overprovision). In other words, satellite operator can keep its market competitiveness only if efficiently manages a very high contention ratio and maximizes utilization of the available capacity. As a drawback, working in a high-contention approach can severely impact on experienced performance. The only viable solution to provide good performance while guaranteeing 100% satellite resource utilization, is to perform a detailed control on traffic and to adopt traffic shaping techniques, in order to allow a fair provision of services as agreed in the Service Level Agreements (SLAs). In this way, potential resource consuming applications (e.g., peer-to-peer during the day, data upload), which are out of SLA, can be controlled and kept under defined thresholds, in order to have marginal impact on applications considered in the definition of the user profile.

For this reason, a Deep Packet Inspection (DPI) block has been added in the target architecture so that priority and per-application constraints can be applied, optimizing users' experience.

DPI in terrestrial wireless networks [6] is typically adopted for similar reason, but with less critical conditions (higher bandwidth, smaller delay, smaller contention ratio etc.) and not simultaneously on all user base. Effectiveness and actions of DPI increases with higher contention ratio: possible traffic spikes are smoothed over a higher number of users. Accordingly, the considered Ka-Sat scenario, with hundreds of users sharing the virtually unique "beamless" capacity, represents an optimal field of applicability for DPI. In this case, it is possible to group together a huge community of users, also belonging to different traffic profiles. For instance, business users will access network at most during business hours/days, while home users will likely need more traffic during the evening and weekends. Then, also within the same macro-category, there will be statistically independent usage patterns, so that access to web pages or email will not be simultaneous for all but rather distributed as a random process. In this context, the aggregation of traffic of different types of users, and a keen shaping (taking into account the most critical and interactive ones) on a broad set of users will allow to simultaneously achieve the full channel utilization while keeping the target quality.

DPI technology, through real time header and connections analysis, can discriminate the different protocols/applications associated and handle them according to a set of rules. DPI actions do not aim to limit the activity of the customers, but rather to improve their Quality of Experience (QoE), for instance prioritizing the real time protocols with respect to the ones associated with delay-tolerant services. The correct dimensioning of DPI rules and parameters is the key to the presented service success and represents a step-ahead compared to terrestrial wireless networks.

IV. Setup of the Commercial offer

The work described herein is carried on as a support activity in the frame of the ESA Lift-Off project [2], aimed to define and implement a HTS-based competitive service. The main goal of the project is to verify if and how, with the use of a proper DPI setup, it is possible to achieve a high contention ratio while keeping good applications performance. This goal shall be pursued, as far as possible, without explicit limitations on the users' contract, such as maximum volume (introducing a de-facto "flat" access), with the final aim to get prices for final users comparable to a terrestrial xDSL offer. The main actions will be designed to both control and mitigate resources abuse and system misuse (e.g., use of business applications in a home contract), which may impair the performance of the whole user community. Then, DPI parameters must be fine-tuned taking into account the different categories of users.

In [7] the authors already presented the initial simulation and emulation activities in relation to this system, mainly focused to validate the overall DPI idea and support the initial real pilot system deployment. The users were initially classified according to different requirements (and cost brackets) as Business (Small Office Home Office - SOHO), CCTV (close circuit security cams), Backup (link only used in case of emergency) and Telecontrol (remote symmetric telemetry). Later on, Home Users and a Asymmetry Telecontrol categories have been added. The DPI configuration identified shall support different priorities for user categories, and then for applications classified within. As a simplified model of the real DPI in use in the Pilot system, the following rules are adopted, with priority indexes going form 7 (highest) to 1 (lowest):

- User cluster (category) are sorted by priority in descending order: Telecontrol (highest priority = 7) – Business (high priority = 6) – CCTV – Volume (mid priority = 4) – Home (low priority = 3);
- Within the same cluster, in general the following applications are treated in priority descending order: Web and VoIP (maximum priority = 7); Email – telemetry data (high priority = 6) – VPN – Video streaming (medium priority = 4 with high guaranteed minimum rate); File transfer, other common applications without realtime constraints (low priority = 2); peer-to-peer only if spare capacity is available (lowest priority = 1)
- Additional constraints:
  - 1 Youtube video streaming per user at each time;
  - Web/VoIP priority for telecontrol is set to low priority = 2, because this cluster (category) shall not be used for this kind of traffic. Same for CCTV.

As an exemplification, Email (with priority 6) for Business has priority on File transfer (priority 2) for business, but Email of Business (priority 6) has priority on Email service for home users (cluster with lower priority). How this multi-dimensional priority algorithm is enforced by the DPI hardware is a commercial issue and not fully disclosed.

Since target pilot network envisages 300 users, divided in the above traffic categories, a preliminary simulation activity aimed to assess overall bandwidth requirement for such a user population was already performed in the previous work. In addition, some emulation activities were executed, involving real user software implementations, aimed to provide an initial assessment of QoE of some key applications (in particular Web browsing performance) with or without a DPI shaper. As an output, presented in [7], an assessment of average data rates per-user/per-category was outlined, together with the initial priority setup of a commercial DPI hardware. With these preliminary results, the commercial service was successfully started.

Initial assumptions for the simulation and emulation were adjusted according to real measurements on the evolving pilot, so that the system performance can be controlled and corrective actions can be adopted. The novel contribution of this paper regards the report and the analysis of the tailoring of DPI applied to the completed pilot network (300 active users) and a forecast of a future system evolution up to 750 users. In order to achieve these new results, the simulation setup was extended and actualized to real users traffic patterns and the emulation platform is hosting a dedicated DPI platform following the overall rules summarized before.

V. SIMULATION AND EMULATION SETUP

The simulation and emulation activities were performed to support the deployment of the initial pilot of 300 users and to provide an estimation of resources used if the number of users is increased to 750. The simulator makes use of a customized NS2 installation [8][9], while the Emulation platform is built in a virtual environment using a cluster of Linux VMs [10].

The preliminary bandwidth patterns forecast, confirmed by initial real users, was adjusted to match at best the real patterns with pilot real user number increase. At the same time, a new DPI setup has been included in the emulation platform, with background traffic loaders actualized as well to match the running pilot.

A. Simulation detailed setup

Compared with preliminary results already presented in [7], real observations have shown a much higher uplink usage. Then, all the NS2 cluster traffic profiles have been updated accordingly, as shown in Table 1. The biggest difference is the much higher symmetry of Business Flat (BF) traffic, and a lower average rate for CCTV flows.

Table 1: average traffic per user category

Cluster	Pre-pilot setup – Avg per user	New Setup– Avg per user
BF (BusinessFlat)		
forward:	36.2 kbit/s	37.5 kbit/s
return:	16.7 kbit/s	32.2 kbit/s
C2B (Home)		
forward:	13.0 kbit/s	33.9 kbit/s
return:	5.6 kbit/s	8.0 kbit/s
Tele 256 – sym.		
forward:	1.0 kbit/s	1.5 kbit/s
return:	30.3 kbit/s	22.4 kbit/s
Tele 512		
forward:	*	2.0 kbit/s
return:	*	22.6 kbit/s
Volume/Backup		
forward:	8.9 kbit/s	6.1 kbit/s
return:	1.6 kbit/s	1.1 kbit/s
CCTV		
forward:	0.0 kbit/s	0.0 kbit/s
return:	177.0 kbit/s	52.7 kbit/s

* Cluster not included at the first run, introduced later.

B. Emulation detailed setup and DPI

The emulation platform described in [10] has been updated to reproduce a satellite network compliant with target system, for both actual conditions (300 users) and the required forecast (750 users). The platform allows to reproduce the characteristic of satellite access similar to the real Ka-Sat scenario, in a controlled laboratory environment. It is possible to attach to the edges of the emulator real operating systems and protocols, or use pre-configured Virtual Machines (VMs) for an accurate realtime network emulation.

In addition, a simplified model of DPI software as the one used in the real pilot system was included in the platform. The software identified for DPI simulation is called MasterShaper [11] (GPL free software) and was installed in the Gateway node of the platform. It offers GUI for configuration and basic reporting graphical tools. MasterShaper allows all the main shaping functionalities required, and was configured similarly to the hardware DPI included in the pilot. It has strong limitations compared to the real commercial equipment in use in the pilot, but allowed to perform the main classification and prioritization tasks useful to assess the application performance and quality of experience.

The setup of MasterShaper was done with the idea of shaping the traffic of the overall 300 users pilot originally foreseen, with an initial value for the beamless channel of 11-4 Mbit/s. This configuration setup was built from scratch and is represented in Figure 3, following the simple DPI priority guidelines identified in section IV.

Through the different priorities defined (user category and traffic), different IP traffic loaders are reproducing the aggregate traffic similar to the one of the real pilot. On top of this background load, some reference applications (mainly web browsing and Youtube streaming) can be executed on endpoints Virtual Machines (VM) to evaluate their performance. To this aim, a set of automated scripts were realized and executed on a reference VM, part of the Business category of users and competing with other traffic (generated by loaders) belonging to this category.

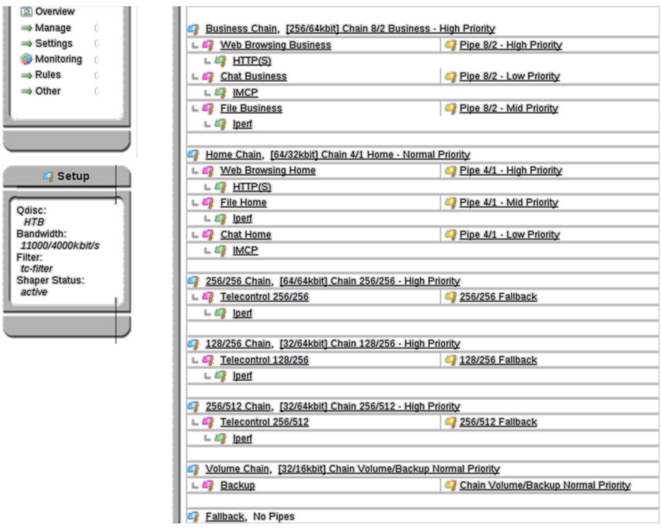


Figure 3: 11-4 Mbit/s MasterShaper Chains/pipes configuration

VI. Simulation and Emulation Results

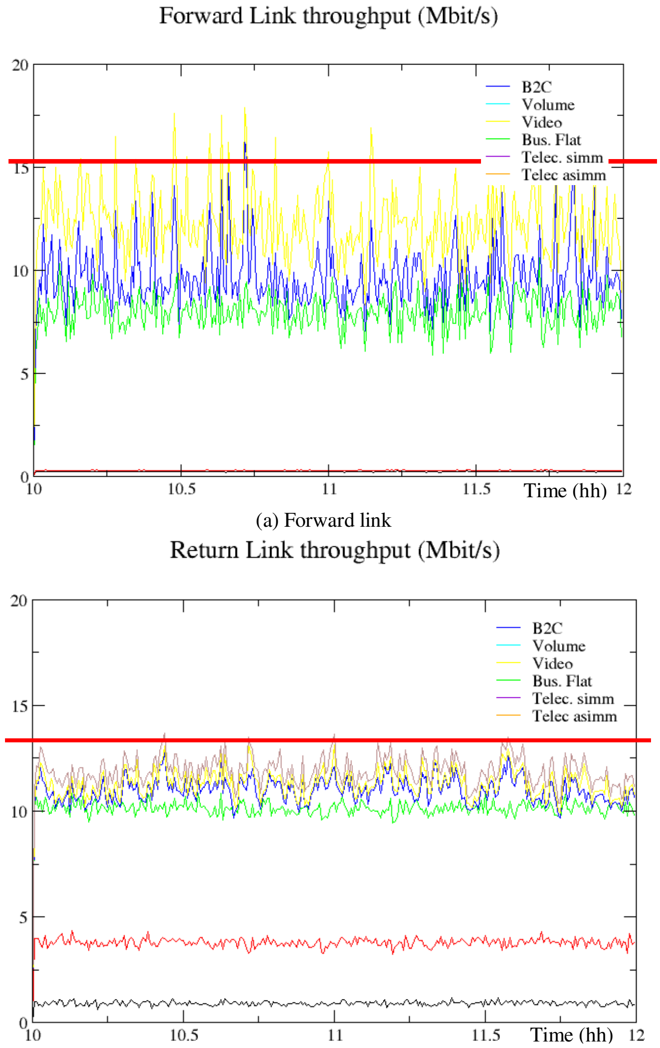
A. Current pilot analysis

The results presented in this subsection are related to the real pilot of 300 users, showing the overall "beamless" channel use (and partition within different flows) for both simulation and emulation activities.

1) Simulation

In Figure 4 the overall forward (a) and return link (b) channel utilization during a 2 hours time-frame (day time of a working day) is reported, when the system is loaded with 300 users behaving in average as reported in the real pilot.

The system capacity is always close to the maximum capacity in use, 15 and 13 Mbit/s for forward and return link respectively, with a few events in which the two identified thresholds are exceeded. In these cases the DPI software will enforce its priority rules. It is important that the system at the same time works close to saturation and avoids a heavy use of DPI. In both plots the upmost line represents the total capacity in use, partitioned into clusters.



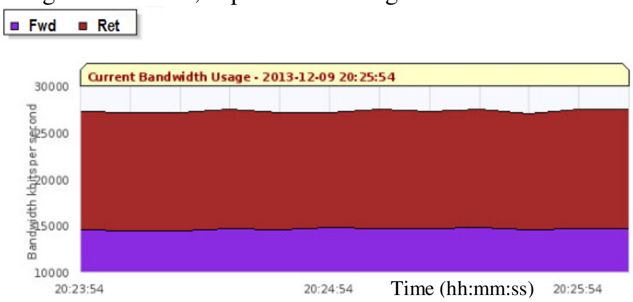
(a) Forward link

(b) Return link

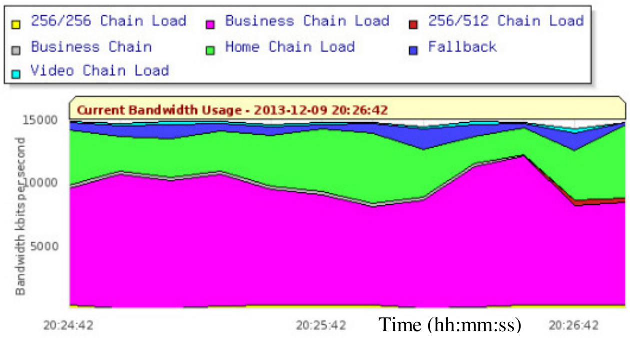
Figure 4: Simulated 300 users channel usage

2) Emulation

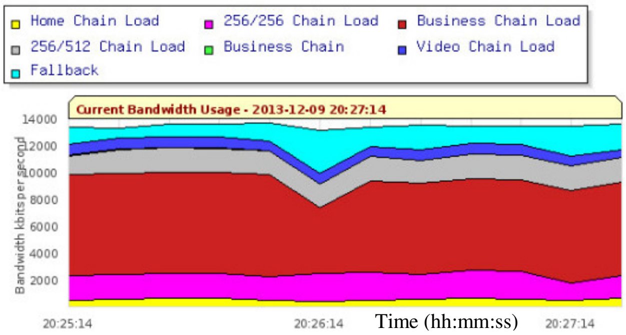
Concerning the emulation platform, a set of Virtual Machines was equipped with IP traffic generators, similar in transport protocol and average values as the one measured on the real pilot. Iperf [12], curl-loader [1], ping, ftp, etc. were used within a set of bash scripts to recreate similar conditions, including temporal values of the statistical distribution of real traffic, for 300 users. Each application is going to the right priority pipe, as configured in the MasterShaper, with an increase to 15-13 Mbit/s channel limits. In addition, some lower priority background traffic is generated on all terminals, to fill completely the channel and evaluate in realistic conditions the user performance. The background loading conditions, and how traffic is shared among different categories of users, is presented in Figure 5.



(a) Total 15Mbit/s Fwd + 13 Mbit/s ret



(b) 15 Mbit/s forward partitioning



(c) 13 Mbit/s return partitioning

Figure 5: 15-13 Mbit/s loaders traffic through the shaper with approx. 100% channel use

On the basis of these channel load conditions, measurements using Firefox browser were executed on a target VM both in person, to evaluate the quality of experience of browsing subjectively, and with the support of automatic scripts. The results presented here are the outcomes of several days testing, with a run each hour of the day. The two most significant tests were web browsing, where the average time to render a set of 12 web pages is measured, and Youtube streaming.

In order to assess in brief a long emulation session, some post-processing scripts were built to summarize results from several run. They can represent at best the snapshot of the system performance. The following results are related to a reference Business users, but are available for all clusters.

The web HTTP browsing tests gave the following result, which is in line with the timing of an unloaded satellite network and confirms the correct implementation of DPI rules with a good user quality of experience:

HTTP test
Runs: 62 (1 every hour)
Pages per run: 12 (total 744 renderings)
Average rendering time: 16.126 s

While for HTTP a summary value can be simply the average rendering time, for Youtube a more complex script was built, to measure several performance indicators. In particular, the buffering events (video play which stops for lack of data) are considered a bad service indicator, especially if they last for long time. The following output obtained provides a simple performance indicator of several Youtube plays, specifying how many runs suffered of at least one buffering event, and of which average duration. In this case, ~90% of videos played without additional buffering and it is considered an acceptable value:

YOUTUBE test
Total plays: 141 (1 every hour)
Plays with one or more buffering: 15 (~10 %)
Average buffering recovery time 4.5 s

With wrong configuration of the DPI or in presence of excessive traffic, the buffering events value of Youtube increased to 100% with an average of about 30 s of buffering recovery time.

B. Forecast of 750 users service

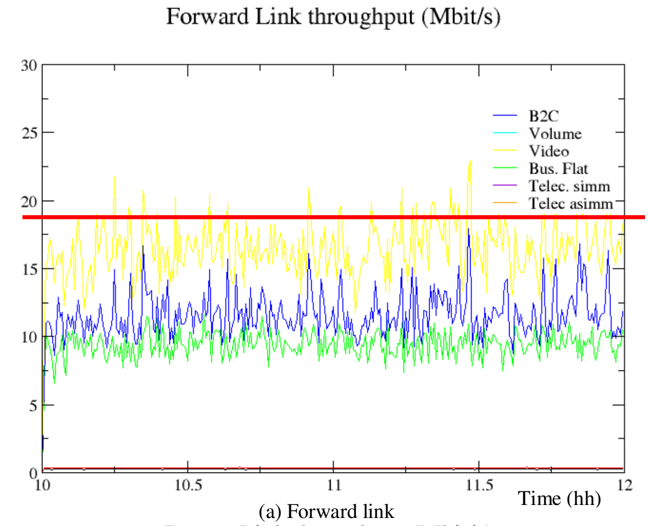
With the previous load per user as reference, the number of Users in the simulation were increased up to a total of 750 users (possible forecast for Q1 2014). The user increase was applied proportionally to the real users already active in the system, following realistic market trends.

It was in fact necessary to obtain a new value for the beamless capacity able to keep such performance, in a likely increase of all the cluster users, for business and economical assessments.

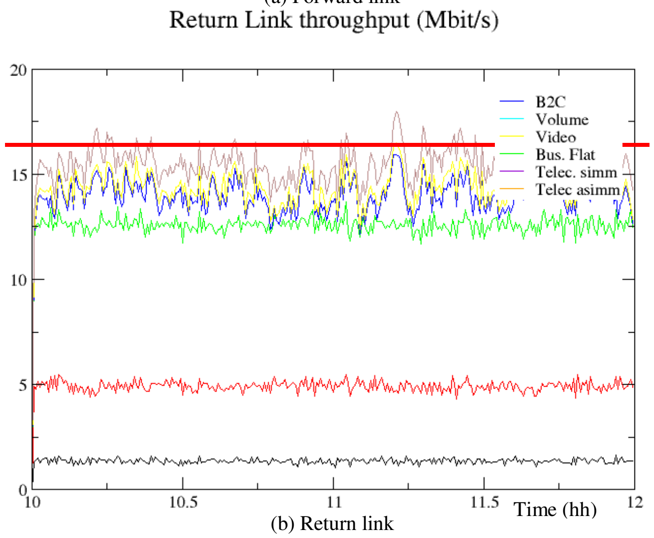
1) Simulation

A first estimation of new limit for bandwidth required using NS2 and is represented in the following figure. The increase in users distribution is based on current growth conditions and a simple forecast. The total number of users in these simulations have reached 750, with, in a first instance, a merge of users making use of seasonal and daily recently introduced cluster profiles to existing B2C users.

The estimation of final bandwidth to be procured to serve 750 users is then 19-16 Mbit/s (total 35 Mbit/s), as a new threshold (red horizontal line) to handle most of the traffic.



(a) Forward link



(b) Return link

Figure 6: Simulated 750 users forecast bandwidth use

This new value is then set as new capacity thresholds (for both forward and return link) to the Emulation platform to evaluate users performance of Web and Youtube, which must be in line with previous accepted values.

Simulation outcomes also highlighted that a doubling of users do not require a doubling of bandwidth. This result is fundamental to support the economy of scale of the platform for the Satellite-ISP and encourage the use of DPI solutions in these high contention ratio conditions ($N > 100$).

2) Emulation

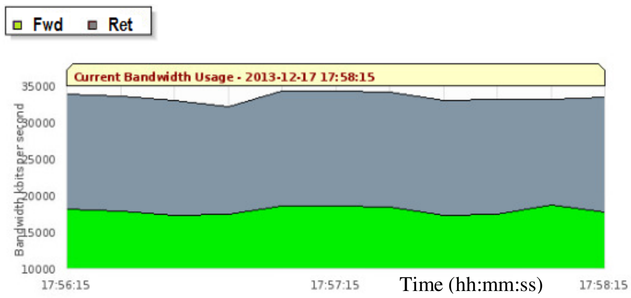
To assess the final setup of 750 users, the same increments in users number of the Simulation have been applied to the emulation. The same percentage of increment has been applied to each of the traffic generators of the Emulator.

The resulting background load conditions are represented in Figure 7, where the channel capacity has been increased to the 19/16 Mbit/s predicted thanks to the simulations. In such conditions, the user experience must be evaluated in order to finally validate this new channel configuration. In this final setup, the additional "fallback" traffic was kept, so that the realistic conditions of about 100% capacity usage is represented, with low-priority filling traffic. With such conditions, a Business user on the reference VM run the same script as described in the previous sections.

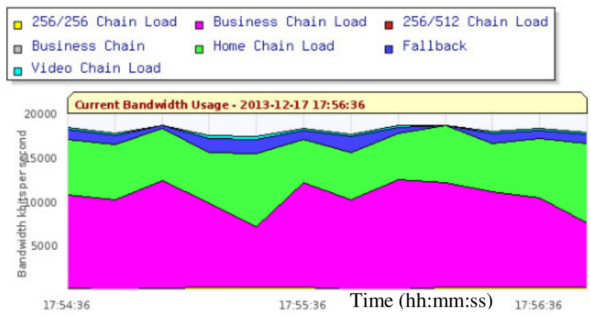
The results obtained are the following, also verified by navigation performed in person using a testing external PC with satisfactory rendering times. Nevertheless, the web HTTP performance is slightly impaired. Also Youtube performance suffered of a slightly higher buffering rate, but with a lower average time to recover. For this reason, the additional purchase for the forward link capacity of additional 2-4 Mbit/s shall be evaluated when the actual pilot will serve 750 users.

<u>HTTP test</u>
Runs: 50 (1 every hour)
Pages per run: 12 (total 600 renderings)
Average rendering time: 18.432 s

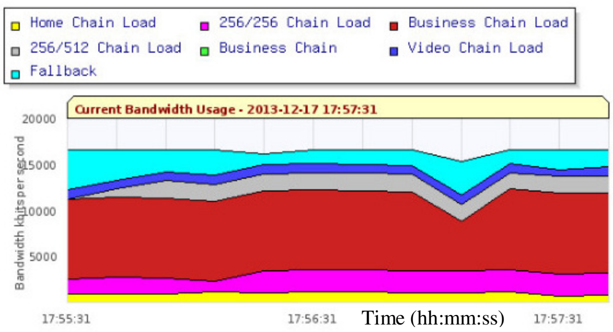
<u>YOUTUBE test</u>
Total plays: 56 (1 every hour)
Plays with one or more buffering: 8 (~14 %)
Average buffering recovery time 2.6 s



(a) Total 19+16 Mbit/s Fwd/Ret



(b) Forward 19Mbit/s partitioning



(c) Return 16Mbit/s partitioning

Figure 7: 19-16 Mbit/s loaders traffic through the shaper with approx. 100% channel use

VII. CONCLUSION

To optimally utilize HTS channel capacity available, it is important to adopt traffic management policies based on DPI, to dynamically allocate capacity per application. At the same time, it is extremely useful to perform traffic analysis as well as to evaluate user satisfaction to tune and dimension the specific system parameters ensuring a good quality product. In this frame, this objective is supported by extensive simulation and emulation activities, which represents a very innovative approach, allowing to perform detailed analysis (in laboratory controlled environment close to the real system) without affecting the real system operations. Simulations and emulations also allow performing projections and traffic forecasts for the increase of users in the future of the pilot, where the relation between number of users and bandwidth required is not trivial. Thus, while the pilot system for broadband services using Ka-Sat was in use, forecast in incremental addition of new users were done, controlling the capacity required and keeping the quality of service and user experience.

The general DPI concept and resource contention, allowing to introduce attractive commercial offer with adequate service quality, the simulator and emulator configuration, their use and results, have been presented in details in the paper.

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