New generation satellite broadband Internet services: should ADSL and 3G worry?

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Abstract—**In the context of Internet access technologies, satellite networks have traditionally been considered for specific purposes or as a backup technology for users not reached by traditional access networks, such as 3G, cable or ADSL. In recent years, however, new satellite technologies have been introduced in the market, reopening the debate on the possibilities of having high-performance satellite access networks.**

In this paper, we describe the testbed we set up - in collaboration with one of the main satellite operators in Europe - and the experiments we performed to evaluate and analyze the performance of both *Tooway* and *Tooway on KA-SAT* (or *KA-SAT* for short), two satellite broadband Internet access services. Also, we build a simulator to study the behavior of the traffic shaping mechanism used by the satellite operator. In terms of performance, our results show how new generation Internet satellite services are a promising way to provide broadband Internet connection to users. In terms of traffic shaping, our results shed light on the mechanisms employed by the operator for shaping user traffic and the possibilities left for the users.

I. Introduction

Originally launched for long-distance telephony and for television broadcasting, communication satellites are more and more used for Internet access [1], [2], [3], [4], [5], [6]. In its infancy, due to its poor performance, Internet access via satellite has traditionally been chosen by users not served by other access networks (e.g. 3G, cable or ADSL), having special needs (e.g. bank communications) or as backup and secure links. The first commercial services for residential, satellite Internet access were mono-directional, requiring another technology (e.g. the telephone) for the uplink direction. The poor performance (few hundred kb/s) and the necessity of another Internet access strongly limited their spread. Later on, bidirectional commercial services have been launched (eg, Tooway [7]), but still their performance was poor and the costs high. In the following years, however, a great effort has been put on this technology and several improvements have been achieved. Among the most relevant, we cite the new TCP versions and improved TCP acceleration mechanisms, which highly increased the performance of TCP (and then of the applications relying on it) over the satellite link [8], [9], [10], [11], [12], [13], and the launch of satellites with a set of features specifically designed for Internet access [14]. As a good example, KA-SAT, launched in mid 2011, is primarily targeted to Internet connectivity and promises high individual and aggregated performance, thanks to several improvements such as multi-spot illumination/frequency reuse, TCP accelerators, robust terrestrial network (based on MPLS), etc.. As a consequence, recent commercial services for Internet access via satellite promise tens of Mb/s user data rates and stable performance, and therefore reopen the debate on the possibility to use satellite networks for Internet access at a larger scale. The several advantages of Internet access via satellite (quick and easy installation and deployment of terminals, low environmental impact, etc.) are counterbalanced by a number of disadvantages, including high latency, necessity to employ middleboxes and accelerators, impact of the weather conditions, etc. These aspects and the need of real bounds when referring to operational satellite network were the main motivations of this work. Thanks to a collaboration with one of the main satellite operators in Europe, we set a testbed and we experimentally evaluate and analyze the performance of both *Tooway* and *KA-SAT*. Also, we build a simulator to study the behavior of the FAP (Fair Access Policy), a traffic shaping mechanism used by the satellite operator. Our experimental analyses show how new generation Internet satellite services are a promising way to provide Internet connection to users, while the proposed simulator sheds light on the mechanisms employed by the operator for shaping users traffic.

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II. Broadband Satellite IP Networks

In this section we briefly review the satellite technologies subject of our study: Tooway and KA-SAT. Then, we describe the mechanism to control the volume of traffic allowed to the users (called Fair Access Policy or FAP) employed in both Tooway and KA-SAT.

a) ***Tooway****:* it has been provided by the same operator of KA-SAT for few years and has reached a quite high number of users (in the order of ten/hundred thousands). The connection is bidirectional (as for KA-SAT). However, this technology does not provide for spatial reuse of the frequencies because the satellite has a single spot covering the Europe and some countries in the Mediterranean area. The network operates through wireless links working in the Ku and Ka frequency bands and offers about 3.6 Mb/s of maximum downlink throughput and $384 \rightarrow 512$ kb/s of maximum uplink throughput per user. Three different profiles are offered to the users, mainly differing in terms of maximum volume of traffic allowed (see Sec. II-A).

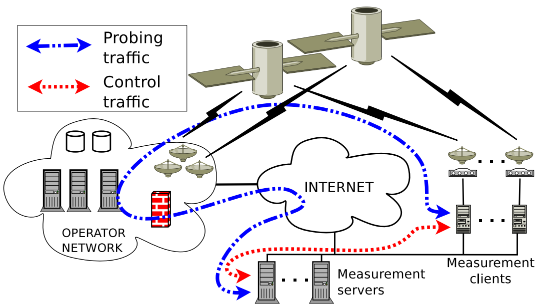

Figure 1. Testbed used for the experiments.

*b) **KA-SAT**:* it is based on a new geostationary satellite deployed recently (mid 2011). The satellite operates in Ka band and it is equipped with very directional antennas, with spot size in the order of a few hundred kilometers. Thanks to this feature, the satellite is able to cover a large part of Europe using about a hundred spots. The concept of spatial reuse of the frequencies (as done in the cellular network) has been used, reaching an aggregated satellite throughput in the order of a hundred Gb/s. The commercial service for bidirectional Internet access, launched in the late 2011, offers different profiles, with downlink throughput ranging in $6 \rightarrow 10$ Mb/s and uplink throughput ranging in $1 \rightarrow 4$ Mb/s. The different profiles are also characterized by a different volume of traffic allowed. Being the satellite geostationary, the one way delay of this access technology is in the order of 300 ms. Both Tooway and KA-SAT employ Performance Enhancement Proxies (PEPs) to speed-up TCP traffic [13]. This aspect has been taken into particular consideration when performing performance measurements, as detailed in a previous paper [17].

A. The FAP

To carefully share the aggregated satellite bandwidth among the users, both Tooway and KA-SAT limit the maximum traffic volume allowed to the users. The technique used is called Fair Access Policy (FAP for short). It operates as follows: it periodically checks the volume of traffic produced by the user in different sliding time windows (1 hour, 4 hours, 1 day, etc.), if one of these volumes exceeds a threshold (that is larger for larger time windows), the maximum allowed throughput is limited (the limitation is more sever for larger time windows, e.g. the maximum allowed throughput is about 250 kb/s if the user exceeds the 1-h threshold, it is about 150 kb/s if the user exceeds the 4-h threshold, and so on). The limitation is removed when the volume in the time window becomes smaller than the threshold. In Sec. V we present a methodology and a simulator we devised to study the FAP behavior.

III. The Testbed

The testbed was set up in collaboration with one of the main satellite operators in Europe. As shown in Fig. 1, it is composed of linux servers connected to the Internet both through our University network and the different access network technologies under test: Tooway (the first-generation bidirectional satellite connection), KA-SAT (the new-generation bidirectional satellite connection), ADSL, and 3G. All these connections are provided by commercial providers, while the University network is connected to the Internet through GARR [18]. Being Tooway and KA-SAT based on different technologies, the testbed comprises different kinds of antennas and modems for these two connections. For Tooway the testbed is equipped with parabolic antennas having offset Gregorian design and diameter of the main dish of 65 cm. These antennas are connected to ViaSat SurfBeam modems laying in our server room and connected to the Tooway measurement clients. For KA-SAT we have front-feed parabolic antennas with diameter of 77 cm. These antennas are connected to ViaSat SurfBeam 2 modems laying in our server room and connected to the KA-SAT measurement clients. The testbed comprises satellite clients that are both subjected to the FAP and not (i.e. with no limits on the volume of traffic). The clients not subjected to the FAP have been used for measuring the performance of the satellite connections (Sec. IV). The FAP-limited clients have been used to study the shaping mechanism (Sec. V). We believe this satellite networking testbed has unique characteristics and allows both to deeply characterize these connections, and experimenting the same conditions of the standard users.

As illustrated in Fig. 1, we generated traffic through the connections under test, from a host using this connection to another host in our University. We used D-ITG [15] for traffic generation and performance measurement, with different traffic profiles (VBR and CBR), rates (from about 5 kb/s to 12 Mb/s), and protocols (TCP and UDP), and we collected statistics mainly related to the throughput, delay (both one way and round trip), jitter and loss [26]. The experimental campaigns have been performed between February 2010 and July 2012, involving a few thousands minutes-long measurement experiments and collecting about 1 TByte of measurement data. Traces collected during these campaigns have been made publicly available at [25].

IV. The analysis

A. Tooway Performance

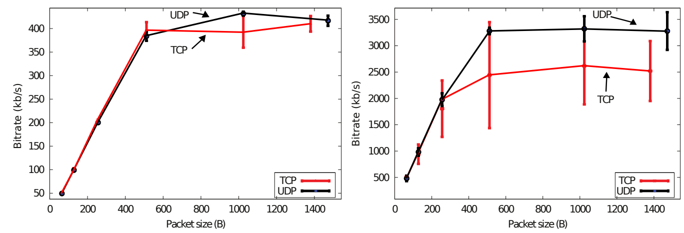

Figure 2. TCP/UDP throughput on Tooway uplink (left)/downlink (right).

Fig. 2 reports the throughput obtained in uplink and downlink on Tooway with both UDP and TCP as a function of the packet size (each point represents the average of 10 experiments, and the standard deviation is reported with the vertical segment). For the downlink, we report the results obtained with a packet rate of 1000 pps, while for the uplink we report those obtained with a packet rate of 100 pps: with these packet rates we saturated the downlink and the uplink

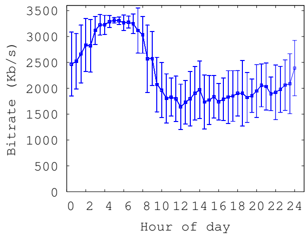

Figure 3. TCP downlink (left)/uplink (right) throughput during the day.

of Tooway respectively. We report the results obtained in saturation because we want to show the maximum throughput. Looking at Fig. 2, we can see that Tooway is able to achieve about 300 kb/s of throughput in uplink with both TCP and UDP. In downlink, **Tooway is able to achieve about** 3.5 **Mb/s with UDP and about** 2.5 **Mb/s with TCP, with the latter having also larger variance**. This is due to the sensitivity of TCP to competing traffic: the high number of users of Tooway, and consequently, the high volume of traffic competing for resources cause the TCP throughput to be lower than that of UDP in average and also more variable. This important result will be considered in the analysis of the FAP in Sec. V.

Fig. 3 shows the throughput behavior during the day. The plot is obtained measuring the maximum throughput in both uplink and downlink with TCP every half hour for two entire weeks. The results have then been grouped and averaged for each hour of the day (i.e. the result related to each of the hours reported on the x axes is obtained averaging the results obtained in that particular hour in all the fourteen days). The left plot of Fig. 3 shows that **the throughput in downlink is characterized by a very strong diurnal pattern**, with average values that range from 1.6 Mb/s during the day to 3.2 Mb/s during the night. The right plot of Fig. 3 shows that this behavior is less marked in uplink. The main reason at the base of this behavior is that Tooway - based on Viasat SurfBeam technology - uses multi-carrier TDMA in the uplink, which allows to isolate the uplink channels of the users [7]. Moreover, the total volume of downlink traffic of all the users is much larger than the uplink one and this can cause congestion also in the terrestrial network of the operator.

An important aspect to consider in this scenario is the presence of the PEP, which can severely impact measurement results. Fig. 4 shows the RTT estimated with three different approaches: ICMP, TCP on port 80 (*syn-ack time*, TCP80 in the following), and TCP on port 81 (*syn-reset time*, TCP81 in the following). The effect of the PEP is notable: **the RTT with TCP80 is in the order of** 10^0 **ms, while with the other two approaches it is in the order of** $10^2/10^3$ **ms**. The reason is that the PEP operates only on TCP traffic on port 80, and the RTT estimated with TCP80 only regards the network path between the user and the PEP (i.e. the LAN connecting the measurement client and the satellite modem). This aspect has been investigated in more details in [17].

B. KA-SAT Performance

Throughput. Fig. 5 shows the results obtained in the uplink and downlink on KA-SAT, using the same format of Fig. 2.

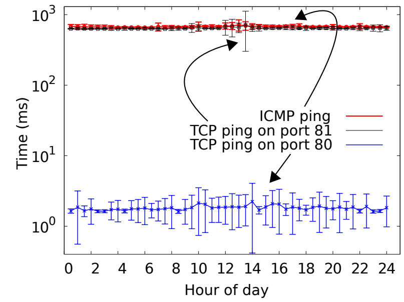

Figure 4. Ping times with ICMP and TCP.

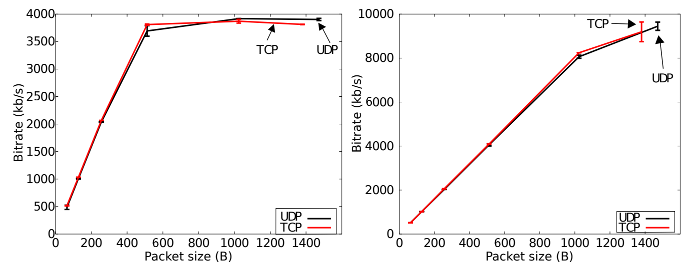

Figure 5. TCP/UDP throughput on KA-SAT uplink (left)/downlink (right).

The difference with figure Fig. 2 is that for the uplink we report the results obtained with a packet rate of 1000 pps because at 100 pps the KA-SAT uplink was not saturated. Fig. 5 shows that **KA-SAT is able to achieve much higher and more stable performance than Tooway**. In particular, the uplink throughput is about 3.9 Mb/s with both TCP and UDP, and the downlink throughput is about 9.5 Mb/s with both transport protocols. The much more stable performance is mainly due to two causes: (i) KA-SAT employs state-of-the-art TCP performance accelerators that help TCP traffic to cope with the peculiar characteristics of the satellite link; (ii) being very new, KA-SAT has much less users and the network, also thanks to the high aggregated throughput available, is far from being congested by the user traffic.

One Way Delay. An important performance parameter for long-distance wireless networks is the packet latency (or delay). This is often evaluated through the round trip time (RTT) to overcome the difficulty of synchronizing the clocks of the hosts. The RTT, however, is influenced by both uplink and downlink directions of the connection, which can be an issue on asymmetrical network connections such as the satellite ones. In this paper, we instead perform an experimental analysis of the one way delay (OWD) of KA-SAT. To solve the clock synchronization issues, we set up the testbed to receive the packets on the same hosts that generated them, as reported in Fig. 6 (see measurement clients/servers). These measurement hosts are therefore both senders and receivers of measurement traffic in these tests. To make the traffic travel through the satellite network we added a host acting as a NAT (i.e. the NAT host in Fig. 6). The packets are sent by the measurement client/server towards a fake IP that is changed by the NAT to that of the same measurement client/server. We experimentally verified that the impact of such operation is

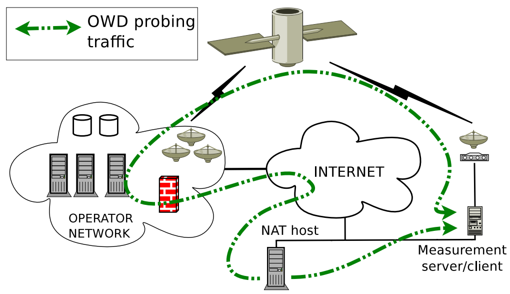

Figure 6. Mechanism used to evaluate the OWD.

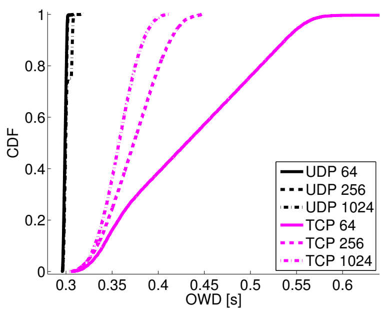

Figure 7. OWD with TCP and UDP on KA-SAT.

negligible with respect to the OWD of the link under test.

Fig. 7 shows the cumulative distribution function of the OWD samples collected with TCP and UDP, using a packet rate of 100 pps and three different packet sizes. Counter intuitively, **with TCP, the OWD decreases with the packet size: the larger the packet size, the smaller the OWD**. We verified that this behavior is due to a buffer in the satellite network that operates on TCP traffic (very likely being the PEP). Such buffer operates on bytes rather than on packets, which justifies the larger OWD values obtained with smaller packet sizes. This is also confirmed by the fact that with UDP we did not observe this behavior, and the OWD is always very concentrated around 0.3 s. Such buffer causes the OWD with TCP and small packet sizes to increase up to 0.6 s.

TCP Versions. KA-SAT is characterized by high bandwidth-delay product, and there are various TCP versions optimized for these kinds of networks. Moreover, as previously anticipated, KA-SAT employs a PEP that terminates the TCP connection of the clients just before the satellite network and opens a new TCP connections, very likely using one of such optimized TCP versions. Furthermore, general Internet users have different TCP version, that may behave differently in this particular network scenario due to the interaction with the PEP. Driven by these considerations, we performed an analysis of the performance of various TCP versions on KA-SAT to understand what is the impact of the various congestion control algorithms on throughput, jitter and delay. In particular, following the suggestion of the satellite operator, we used the TCP versions supported by the latest Linux kernel client that are more indicated for this connection (*westwood*, *illinois*, *highspeed*, *hybla*, and *cubic*). With each of them, we generated CBR and VBR traffic in uplink and downlink at different

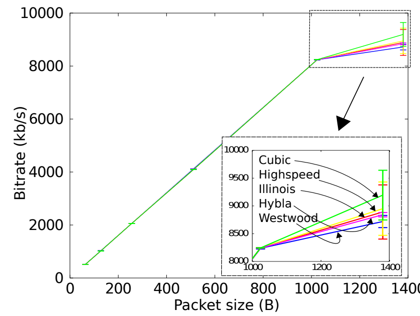

Figure 8. Different versions of TCP on KA-SAT.

rates and with different packet size and we measured the throughput, jitter and delay. For space constraints, in Fig. 8 we show only the throughput (average and standard deviation over 10 experiments) obtained with the considered TCP versions: minor differences are only notable in saturation (see the zoom in Fig. 8). This means that the PEP is actually able to decouple the satellite connection from the LAN of the client so that its TCP version does not impact the performance. Among the minor differences, we can note that **cubic, the default TCP version of Linux, obtains in average the best performance**.

Voice, Videos and Games. We verified also the performance achieved by KA-SAT with other applications. In particular, we verified what performance video, game and VoIP applications can expect from this network. Using D-ITG we generated traffic emulating these applications and we measured the OWD, jitter and losses. The top plot of Fig. 9 shows the average values (over 10 measurements) of these parameters obtained with video and game traffic in uplink. For video traffic (VBR in the figure), we used the methodology presented in [20], [16], based on the model presented in [21]: packet rate equal to 720 pkt/s and random packet size with Normal distribution.With this traffic on KA-SAT we measured about 80 ms of jitter, about 1.3s of delay and about 25% of packet loss, which may severely impact the quality of the video and therefore the Quality of Experience. For game traffic, we used the parameters from the models presented in [22], [23]: bimodal packet size and Student inter-packet times for Counter Strike (CSA in the figure) and Normal packet size and Exponential packet rate for Quake3. With these applications we obtained better performance with respect to the video: the jitter is about 16 ms for Counter Strike and 12 ms for Quake3, the delay is about 400 ms and the packet loss is 0 for both games. The performance of VoIP in downlink are reported in the bottom plot of Fig. 9. For this application we tested different codecs, according to the VoIP models of D-ITG. In the tri-dimensional plot, we also report the planes related to the Mean Opinion Score (MOS) using the simple model from [24], based on the ITU E-model. As shown, with all the codecs we obtain a MOS between 2 and 3. However, with codec 723.1 we observe a small packet loss of about 0.2%. Therefore, **as for video, voice and games, the QoS of satellite IP services seems to be still far from the one of other broadband access networks**.

KA-SAT vs others. Jitter and throughput are of paramount

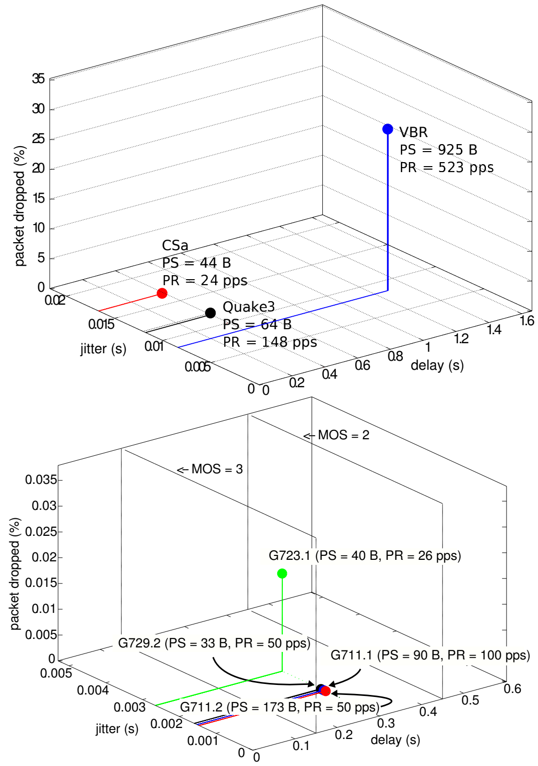

Figure 9. Voice, Video and Games over KA-SAT.

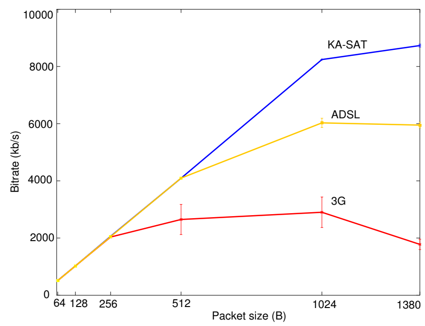

Figure 10. TCP throughput on KA-SAT, ADSL and 3G.

importance in multimedia applications. Fig. 10 reports a comparison of the throughput measured using TCP with different packet sizes on KA-SAT and the one on ADSL and 3G. Interestingly, KA-SAT shows larger throughput values than ADSL and 3G: 9 Mb/s, 6 Mb/s and 2.5 Mb/s respectively. Fig. 11 reports a comparison of the jitter measured using UDP on KA-SAT and the one on ADSL and 3G, obtained with different packet sizes. As shown, even if the satellite connection is based on a very-long-distance wireless link, its jitter is smaller than that of the other two connections, being about 1 ms in average. While these results are not general, as they comprise example 3G and ADSL connections, they still suggest that **KA-SAT is mature enough to be considered together with both ADSL and 3G**.

V. Analysis of the FAP

As introduced in Sec. II-A, both Tooway and KA-SAT employ a bitrate limiter (called FAP), which starts operating when the user exceeds certain thresholds on the volume of traffic produced. In this section, we report some results of our

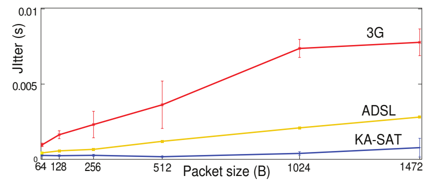

Figure 11. UDP jitter on KA-SAT, ADSL and 3G.

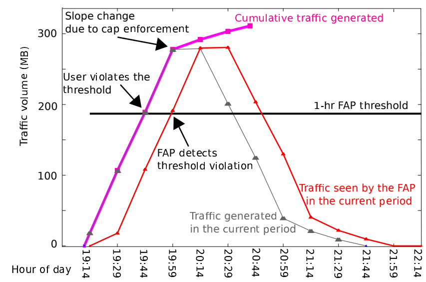

Figure 12. Characterization of the FAP behavior.

analysis to: (1) understand how the FAP accounts the volumes of user traffic; (2) understand how the FAP limits the bitrate allowed to the user; (3) explore possible ways for the user to best use the available traffic volume.

To answer the first two questions, we performed a six-month experimental campaign using a measurement client with the FAP enabled. Fig. 12 reports the volume of the traffic generated with D-ITG and the volume of the traffic seen by the FAP (accessible through the OSS of the satellite operator). As shown, the FAP operates on 15-minutes sliding time windows and has a 15-minutes delay with respect to when the actual volume has been produced (i.e. if x MB have been produced up to time t_i, such volume will be seen by the FAP at time $t_i + 15min$). This means that (i) the user can actually exceed the traffic volume for 15 minutes before being capped by the FAP, and (ii) the FAP requires 15 minutes of additional time before removing the cap from the user. Other important considerations have also been drawn from these experiments. Firstly, the FAP considers the volume of traffic at network level (i.e. it looks at the size of the layer-2 payload). Secondly, and more important, **the cap introduced by the FAP operates as a drop-tail queue with packet granularity**. This causes bursty losses, which can severely impact the performance of TCP [19] of capped users.

Having characterized the behavior of the FAP through the

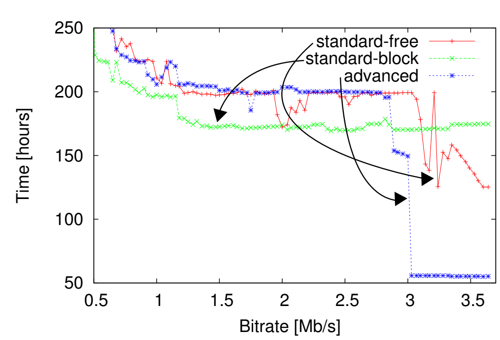

Figure 13. FAP simulation of different traffic consumption strategies.

experimental analysis, we developed a simulator in which we implemented a FAP, to investigate on the possible ways for the user to best use the available traffic volume and to find an answer to the third question. The simulator is written in Matlab and allows to reproduce the behavior of a user that has to download/upload a certain volume of traffic and that of the FAP that accounts the volume every 15 minutes and limits the throughput in case of threshold violation. Adopting the point of view of the user, we then performed a set of experiments aimed at exploring how the user can best use its available volume of traffic. For studying such interesting case, we use values consistent with those of a typical contract from the satellite operator and we refer to a particular working real example. Our simulator is able to provide the answer to questions such the following: given that the user has a maximum allowed volume of 15 GB of traffic per month before being severely capped, how can he/she download[1] such volume in the shortest time?

Fig. 13 reports the time required to download 15 GB on Tooway using different approaches: the first one (called *standard-free*) consists in downloading always at the maximum allowed rate and such rate depends on the cap imposed by the FAP due to exceeding of the intermediate thresholds; the second one (called *standard-block*) consists in downloading only when not capped; the third one (called *advanced*) consists in downloading in each 15-minutes time slot at the maximum data rate that allows the user not to be capped in the following time slot. We performed this analysis instrumenting the simulator for considering different values of the maximum download rate allowed by the network when not capped (the available bandwidth of the connection). The reason is that we verified that the available bandwidth of Tooway is often below the nominal bandwidth of 3.6 Mb/s (see Section IV-A). As shown in Fig. 13, the *advanced* approach allows to reduce the download time down to about 55 hours, while with the other two approaches the minimum time is about 170 with the *standard-block* and 125 hours with the *standard-free*. However, if the network does not provide more than 2.75 Mb/s of available bandwidth, the *standard-block* approach allows to obtain minimum download times. Summarizing, **smart download approaches can help to cope with the FAP if the available bandwidth is higher than 2.75 Mb/s**.

VI. Conclusion

In this paper, we have reported our experience and experimental analysis of the performance of new generation Internet access services based on satellite technologies. We have set up a tesbed and a simulator in collaboration with a European provider and we have performed a study comprising real users. The obtained results show that the new generation satellite access technologies (i.e., KA-SAT) achieve high performance and, despite some limitations especially for isochronous applications, they are a good candidate for competing with the other access networks, thus the provocative title of our paper. In our ongoing work, we are performing experiments aimed at evaluating the performance of KA-SAT with bursty traffic as well as with real streaming and real-time applications.

[1] The analysis can easily be extended to the case of upload or mixed download/upload.

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