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Abstract: In the not so distant future we envisage an Internet where the biggest share of capacity is used by streaming applications, with no QoS reservations in the network core. Such traffic calls for a robust and ubiquitous end-to-end multimedia congestion control mechanism such as TCP Friendly Rate Control (TFRC), that provides fair sharing with the other Internet traffic. We also suggest satellite links will be more common than today, utilising Demand Allocation Multiple Access (DAMA) to maximise satellite transponder utilisation when providing triple-play services. The interaction of TFRC with DAMA therefore needs to be investigated. Simulations show that DAMA slows down the start-up phase of TFRC, causing non-negligible delays. To mitigate this problem, we propose judicious use of the experimental Quick-Start (QS) mechanism.

Improving TCP Friendly Rate Control Behaviour in DVB Satellite Networks¹

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Abstract

In the not so distant future we envisage an Internet where the biggest share of capacity is used by streaming applications, with no QoS reservations in the network core. Such traffic calls for a robust and ubiquitous end-to-end multimedia congestion control mechanism such as TCP Friendly Rate Control (TFRC), that provides fair sharing with the other Internet traffic. We also suggest satellite links will be more common than today, utilising Demand Allocation Multiple Access (DAMA) to maximise satellite transponder utilisation when providing triple-play services. The interaction of TFRC with DAMA therefore needs to be investigated. Simulations show that DAMA slows down the start-up phase of TFRC, causing non-negligible delays. To mitigate this problem, we propose judicious use of the experimental Quick-Start (QS) mechanism.

Keywords: multimedia; TFRC; satellites; DAMA; Quick Start

Introduction

The advent of popular services like YouTube and Google Video, are evidence of a strong push towards Internet television, and the momentum that streaming p2p is gaining [1] makes us envision a future where the majority of Internet traffic is produced by streaming applications. Currently, these streaming applications have limited impact on the Internet infrastructure. They do not need a Quality of Service (QoS) reservation infrastructure, and do not yet pose a congestion problem, whereas the emerging commercial TV over IP (TVoIP) have been typically provided using strong QoS within a single Internet service provider network. We expect video streaming to become the most bandwidth demanding Internet application, with high-quality video streaming gaining a significant place in the next generation Internet. In this future network we suggest that hard QoS reservation will continue to be absent in the network core. In such a scenario, network over-provisioning will be a requirement – as streaming without reservations can only work in the absence of congestion – but nonetheless congestion control will be mandatory for granting overall network stability. Consequently, it is likely that congestion control will become important for streaming applications. One appropriate congestion control method for use in the general Internet is TFRC (TCP Friendly Rate Control), an equation-based

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4 algorithm that is designed to be fair to streaming applications running over it and to concurrent TCP flows traversing
5 the same routers [15]. TFRC is also supported as congestion control in the newly standardised Datagram Congestion
6 Control Protocol) (DCCP) [14].
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10 At the same time, we envisage that the current success and the continued development of the DVB (Digital Video
11 Broadcasting) standard for packet communications over satellite [16,18] will make satellite equipment interoperability a
12 reality, and the deployment of small and large satellite networks cheaper and consequently more common than it is
13 now. DVB-RCS (DVB with Return Channel by Satellite) [17] or other bidirectional satellite communication standards
14 will make both private and public satellite networks affordable for generic Internet access, through the use of dynamic
15 bandwidth allocation schemes on the satellite segments. DAMA (Demand Allocation Multiple Access) will be
16 necessary both for better exploitation of the expensive shared satellite bandwidth and as a means of implementing BoD
17 (Bandwidth on Demand) schemes on satellite networks. This mix of technologies is the basis for the provision of triple-
18 play services on satellite networks [21].
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24 Prediction is difficult, especially about the future, for this reason we do not mean to make forecasts, but only to analyse
25 a possible future scenario where unreserved streaming traffic on the Internet is common. In such a scenario, it is
26 important to assess the performance of TFRC-controlled streaming applications traversing a path with links whose
27 bandwidth is varying under the control of a DAMA dynamic bandwidth allocation scheme. The start-up phase of TCP
28 is significantly slowed when the TCP connection uses a satellite link controlled by DAMA, with respect to a satellite
29 link with a fixed bandwidth allocation [3]. The problem is caused by the interaction of DAMA with the slow-start
30 algorithm. Since this algorithm is also used by TFRC, we expect a degradation in the performance of TFRC streaming
31 applications during the start-up phase on DAMA satellite links. The QS (Quick-Start) mechanism [7,10] significantly
32 mitigates the problem when running TFRC over a fixed allocation satellite link [4].
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39 In this paper we couple the QS mechanism with a satellite DAMA system and show that careful integration of QS with
40 DAMA can offset the performance degradation caused by the interaction of TFRC with DAMA. We first consider the
41 performance of a TFRC streaming application over a satellite link that does not deploy DAMA, with and without use of
42 QS. This is what a TFRC-enabled streaming flow would experience today when traversing a satellite link. We then
43 show that managing the satellite link with DAMA significantly worsens the streaming application performance, but a
44 careful implementation of QS can almost completely offset this performance loss. We consider the usage of TFRC as
45 implemented by the sending application directly, that is, without the use of DCCP. Extension of this work to consider
46 the implications of using DCCP may be the subject of further research.
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51 Performance of streaming applications is measured in terms of median and maximum one-way delay [9], measured
52 from the sending host to the receiving host. While variable one-way delay is absorbed at the receiver using a de-jitter
53 buffer, completely absorbing this delay implies a total delay at the decoder that is greater than the maximum one-way
54 delay. It is possible to trade total delay at the decoder with packet loss, thus reducing the delay in exchange for a small
55 packet loss rate. However, TFRC-enabled streaming applications running on DAMA experience the maximum delay
56 only during the first few seconds of transmission, exactly the most important ones for content zapping, so reducing
57 delay by sacrificing video quality in terms of packet loss may not be an option: our opinion is that minimising the
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4 maximum delay during start-up is highly desirable for the application.
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7 In Section 2 we describe and comment on the technologies in our scenario: DVB, DVB-RCS, DAMA, Skyplex Data,
8 TFRC and QS. In Section 3 we compare by simulation how TFRC over a fixed-allocation satellite network fares with
9 respect to TFRC on a DAMA system. This comparison considers cases with and without QS, for a single TFRC
10 streaming flow. Section 4 presents the scenario, where several TFRC flows of different types traverse a DAMA system.
11 We analyse different methods of interaction between DAMA and QS and compare their relative merits. The
12 conclusions describe the implications of our work and identify possible future developments of this analysis.
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15 16 **Technology overview** 17

18 This section presents a brief overview of the main technologies involved in the scenario described in the introduction.
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20 21 **DVB Architecture overview** 22

23 DVB (Digital Video Broadcasting) is a mature technology used to send packet data over wireless media, which is
24 particularly popular in the DVB-S (DVB for satellite) format. IP packets are first encapsulated by MPE (Multi Protocol
25 Encapsulation) [12] or using ULE (Unidirectional Lightweight Encapsulation) [13]. This encapsulation also adds the
26 MAC address of the destination satellite earth terminal. The encapsulated data is then delivered using a transport stream
27 of 188-bytes MPEG-2 cells.
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30 31 32 **Network Architecture** 33

34 Figure 1 shows the main elements of a DVB-RCS multi-spot mesh network based on the Skyplex system. The network
35 is divided into regions, corresponding to the geographic areas covered by a satellite spot beam. The group of traffic
36 terminals (TT) that belong to a specific region are monitored and controlled by a centralised authority, called the
37 Regional Network Control Centre (RNCC), which is connected through a terrestrial line with the Network Control
38 Centre, a higher-level network management system. A Time Division Multiple Access (TDMA) scheme [17] is used to
39 share the satellite uplink capacity, possibly on multiple frequencies (MF-TDMA). In a TDMA system, a *time slot* is the
40 time granularity defined for access to the shared medium. Each *terminal* gets the right to transmit on one or more slots
41 (an assignment) from a *master terminal* or Network Control Center (NCC). The NCC terminal periodically broadcasts a
42 BTP (*burst time plan*) detailing the assignments for a *frame*, that is, a periodically repeating group of slots for which a
43 BTP is valid. This design resembles, but is subtly different to most other deployed DVB-RCS networks.
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49 In Figure 1, the RNCC assumes the role of master terminal for the terminals served by a spot. Several methods exist for
50 deciding how to allocate assignments to the terminals. The simplest uses fixed assignments for each terminal, decided
51 by a human operator. More complex, dynamic assignments are described under the umbrella of DAMA (demand
52 assignment multiple access) methods. DVB-RCS defines the following terms:
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- 57 • *Constant Rate Assignment (CRA)*: fixed allocation scheme.
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- 59 • *Rate Based Dynamic Capacity (RBDC)*: capacity requests from the terminals to the NCC equal to the incoming
60 traffic rate seen by the terminal from the terrestrial network. Every explicit request overrides the previous one and
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4 new requests are submitted only when needed.
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- 6 • *Volume Based Dynamic Capacity (VBDC)*: capacity requests from the terminals to the NCC equal the length of the
7 local uplink queue from the terrestrial network. This method is more stable than RBDC, because it inherently
8 compensates for any assignment mismatch, but is slower to react to traffic changes.
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- 10 • *Free Capacity Assignment (FCA)*: allows the unassigned capacity to be redistributed among the terminals without
11 any explicit request.
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15 Any combination of the above is allowed. For example, when combining all four methods, the request is computed as:
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$$17 \quad R_{req(t)} = R(t) + \frac{q(t)}{T_s} + C + F, \quad (1)$$

18 where $R(t)$, which accounts for RBDC, is the mean traffic rate entering the terminal from the terrestrial network over a
19 time interval $[t - Tr, t]$ and where Tr is equal to the super-frame duration; $q(t)$, which accounts for VBDC, is the uplink
20 queue length at time t , T_s is a time, C is a constant term accounting for CRA. F is the FCA volume allocated to the
21 terminal. The logic behind T_s is that once the requested bandwidth is allocated, the terminal is able to empty its uplink
22 queue in a time equal to T_s , while serving the traffic arriving at the terminal..
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30 **The Skyplex Data platform**

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32 The Skyplex Data system [5] was the first commercial system to implement a satellite mesh IP network for point-to-
33 point or multicast transmission. It operates in the Ka band, and implements the DVB standard on the direct channel
34 (downlink) and some features of DVB-RCS on the return channel (uplink). An On-Board Processor (OBP), performs
35 stream multiplexing, allowing a fully meshed network without the need for a double-hop satellite network.
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39 The HotBird6 satellite carries four Ka band transponders, each equipped with a Skyplex unit. Each manages several
40 channels configurable in either a Low Rate (LR, 2.112 Mbps) or High Rate (HR, 6.226 Mbps) mode. SCPC (Single
41 Channel Per Carrier) is possible, while TDMA mode is used for DAMA access. The total number of channels is
42 between 6 (all HR channels) and 18 (all LR channels).
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46 The time domain on the return channel is organised in a hierarchical structure, which consists of super-frames (the
47 largest containers), multi-frames and frames. The BTP is sent once each super-frame, and is valid for each multi-frame
48 contained in a super-frame. Each frame is composed of 6 time slots that are filled by bursts of 8 MPEG packets, for a
49 total of 48 packets per frame. Since a slot can be assigned to a single terminal, the TDMA mode allows a maximum
50 number of 6 users, with a bandwidth assignment granularity of 352 kb/s for both LR and HR. The number of users can
51 be extended by grouping together 8 LR frames or 24 HR frames in a multi-frame. In this case, the number of users per
52 channel becomes 6×8 in LR and 6×24 in HR, with a bandwidth assignment granularity of 44 kb/s for both LR and HR.
53 Finally, 3 multi-frames are grouped into an 820 ms long super-frame.
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59 Bandwidth assignment can be either static or dynamic. In the static case a fixed number of time slots are assigned to
60 each terminal (CRA, [17]). In the dynamic case (RBDC, [17]), each terminal sends a request to the NCC, which builds
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4 the BTP, thus assigning a time slot to a terminal. The assignment does not guarantee any priority between terminals nor
5 any service quality. The request and assignment is computed as follows:
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- 8 1. Each terminal computes a bandwidth request ($BWreq$) based on the traffic arriving at the terminal from the
9 terrestrial network, computed in a Tr period equal to the super-frame duration, and sends it to the RNCC. As
10 far as we were able to measure with our equipment [3], Skyplex Data terminals use RBDC mode, so the
11 request is computed on the base of the input data rate only.
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- 14 2. The RNCC computes the bandwidth to be assigned based on the information received with the $BWreq$, by
15 assigning bandwidth proportional to each request, with a minimum equal to the allocation granularity. If the
16 sum of the requests exceeds the availability, it is normalized to the maximum capacity.
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21 When a request arrives that is less than the previous one, the allocation is reduced exponentially. If $N_B(t_n)$ is the
22 number of bursts allocated with the n -th BTP at the instant t_n and the local traffic detected in the Tr interval (t_n, t_{n+1})
23 correspond to a number $N_L(t_n)$ of traffic bursts, then at the $(n+1)$ -th BTP the bursts allocated are:
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$$25 N_B(t_{n+1}) = aN_B(t_n) + b[N_L(t_n) - N_B(t_n)].$$

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27 This behaviour is described in [17], but no detail is given on the values of a and b . We assumed $a = 0.5$, $b = 0.5$, thus
28 obtaining an exponential decay with a time constant of 2 super-frames.
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34 Messages for bandwidth request and assignment

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37 Figure 2 shows the sequence of messages exchanged between a terminal and the RNCC for the bandwidth assignment.

- 38 a. The terminal evaluates the rate of the incoming traffic for a time span of Tr , equal to the super-frame period.
- 39 b. In the next multi-frame after receiving the request the terminal sends a capacity request $BWreq$.
- 40 c. The RNCC receives the request messages from all terminals, computes the value of the bandwidth to be
41 allocated and multicasts the BTP.
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- 44 d. The terminal uses the received BTP for the next 3 multi-frames.
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47 The *allocation delay* is the delay between the moment a request is ready, at the end of the Tr period, and the availability
48 of the desired bandwidth in the BTP, which for Skyplex Data is equal to two super-frames. During the allocation delay,
49 the terminal uses its uplink queue to absorb exceeding incoming traffic waiting for delivery.
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53 **TCP Friendly Rate Control algorithm**

54 TFRC operates above the IP layer and was designed to provide multimedia applications with congestion control
55 capabilities when using UDP across the Internet. TFRC is a rate-paced equation-based congestion control mechanism
56 that requires both the sender and receiver to participate in determining the allowed sending rate [2]. In TFRC, the
57 receiver periodically sends a feedback report informing the recent loss event rate that has been witnessed by a
58 multimedia flow. The sender uses an equation that models the equivalent throughput that would have been obtained by
59 a TCP flow to calculate the allowed sending rate for the next path RTT period. This includes sum of all link RTTs along
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4 the path between the sender and the receiver. The equation calculates the throughput that a TCP connection would
5 receive under steady-state conditions given the loss event rate and the RTT of the connection:
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$$7 \quad M = \frac{s}{8 \quad RTT \sqrt{\frac{2bp}{3}} + 3T_{RTO} \sqrt{\frac{3bp}{8}} p(1 + 32p^2)},$$

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11 where M is the sending rate in byte/s, s is the packet size in bytes, RTT is the round-trip time, p is the steady state loss
12 event rate, T_{RTO} is the TCP retransmission timeout, and b is the number of packets acknowledged by a single TCP
13 acknowledgement, which in TFRC is set to 1. TFRC can be used by the application itself as a standalone protocol, or it
14 can be one of several allowed mechanisms used by DCCP [15], a new IETF transport-level protocol. The simulations
15 in this paper consider usage of TFRC as a standalone protocol.
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19
20 TFRC exhibits a much lower variation of throughput over time compared to TCP, making it suitable for multimedia
21 applications such as (TVoIP) and Voice over IP (VoIP) since it allows the sending rate to vary more smoothly by
22 decreasing and increasing the sending rate gradually, while ensuring that it competes fairly with TCP. However, this
23 makes TFRC respond slower to changes in available bandwidth compared to TCP. TFRC can be used for both unicast
24 and multicast traffic.
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29 TFRC was designed to be reasonably fair when competing for bandwidth with TCP connections using the same packet
30 size, and does not perform well when a low-bandwidth TFRC flow using small packets shares a bottleneck with high
31 bandwidth TCP flows using large packets, because the TFRC flow is unfairly slowed down. To solve this problem,
32 TFRC-SP [6], a Small-Packet (SP) variant of TFRC was designed for applications such as VoIP that send small packets.
33 TFRC-SP seeks to achieve the same bandwidth as a TCP flow using packets of up to 1500 bytes. TFRC-SP also
34 enforces a minimum interval of 10 ms between packets, to prevent a single flow from sending small packets arbitrarily
35 frequently.
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40 Streaming applications use *transmit buffers*, possibly provided by the underlying network stack, to queue the encoded
41 packets while the transport protocol dequeues the packets from the transmit buffer based on its sending rate. Streaming
42 audio (e.g. Radio over IP) requires large transmit buffers, whereas for VoIP applications (e.g. telephony) the size of
43 transmit buffer is usually very small. A mismatch of the encoding rate and the sending rate could lead to packets being
44 queued in the transmit buffer and eventual buffer overflow. Similarly, the receiver uses a *dejitter buffer* to remove the
45 effects of jitter before play out.
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50 When traversing a satellite link, the path RTT is an important factor in determining the performance of a TFRC flow,
51 because the sending rate is inversely proportional to RTT. Satellite networks have a high RTT: a minimum of about
52 500 ms for geostationary satellites, plus processing and framing delays. Some problems of using TFRC or TFRC-SP on
53 satellite networks are:
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57 • *Initial slow-start*: the time duration of slow-start phase is proportional to the RTT, and can be very long for
58 applications with large encoding rates. While TFRC sends 4 packets at the beginning of the slow-start phase,
59 this may not be enough.
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- *Slow-start after an idle period*: during an idle period the sending rate may be reduced to a minimum of 4 packets per RTT, after which slow-start is again needed to return to full rate, taking longer than the initial slow-start.
- *Sending rate limit*: TFRC's sending rate can be at most twice the current receiver rate. This growth rate may not be sufficient to keep up with the encoding rate when an application oscillates between silence and talk periods.

The first two problems can be overcome with the help of Quick-Start.

The Quick-Start protocol

Quick-Start (QS) is an IETF experimental protocol designed to provide lightweight signalling of the level of congestion (specifically available capacity) between routers and a pair of communicating end hosts [7, 10]. QS was originally conceived to improve the performance of TCP bulk transfers over lightly-loaded network paths, but it may be useful in the case of multimedia flows, where it can mitigate the effect of slow starting to the encoding rate, both initially and after an idle period [11].

The sending end host sends a QS-Request for its desired sending rate (measured in bytes per second) using a Quick-Start option placed in the IP header. Each router along the path, either approves the requested rate, reduces the requested rate, or indicates that the QS-Request is not approved. Quick-Start is not a reservation protocol: routers do not reserve bandwidth, nor do they specially treat subsequent packets from the same flow; when a router approves a request, it is only asserting that at the moment there is sufficient free capacity for the requester to send at the requested rate without risking congestion. If the QS-Request is approved by all routers along the path, then the sender receives a transport-level QS-Response, after which it can send at up to the approved rate for an entire path RTT. In fact, QS only temporarily affects the flow, speeding it up, then releases control to the default congestion mechanism. If the request is not accepted, QS does nothing, and the start-up algorithm of the default congestion mechanism is used.

QS is not an end to end mechanism. To approve a QS-Request therefore requires that all routers along the path are QS enabled. While this is not necessarily an issue with equipment directly connected to a satellite terminal or connected via a (private) network that implements QS, there is less incentive to implement QS within the general Internet.

In this paper we explore the use of QS with TFRC to mitigate the effects of slow-start over a DAMA-enabled satellite link. The receiver generally sends a feedback report as soon as the first packet is received during the start of a connection [2]. Hence the QS sender ignores the first feedback report from the receiver, thus streaming at the accepted QS rate until the sender exits the QS validation phase [11]. The satellite terminal takes the role of a QS-enabled router and uses QS as a mechanism to probe the satellite sub-network about available capacity and possibly to allocate resources. This may involve some cross-layer communication, as discussed later in section 3.4.

Performance of TFRC over DAMA

To highlight the main characteristics of a TFRC flow we consider a simple case, where a single TFRC connection is

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4 analysed over a geostationary link managed either with constant allocation or DAMA.
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6 **Simulation scenario**

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8 Simulations were performed using the ns-2.28 TDMA-DAMA module [8]. We consider a geostationary satellite
9 network with a HotBird6 satellite seen from Pisa (IT), with a propagation delay $T_p = 250$ ms. We define two
10 configurations, both compliant with the Skyplex OBP, which we will refer to respectively as the *small-frame*
11 *configuration* (24 slots per frame) and *large-frame configuration* (144 slots per frame); only the latter is compliant with
12 Skyplex data modems. Each slot is 1504 bytes and contains 8 MPEG cells. Once per super-frame each traffic terminal
13 generates a bandwidth request and the RNCC broadcasts the BTP containing the bandwidth allocation for all satellite
14 terminals. The capacity of the shared satellite channel is 6.336 Mb/s, so the allocation period, i.e., the multi-frame, is
15 45.6 ms and 273 ms in the small- and large-frame configurations respectively, while the BTP period, i.e., the super-
16 frame, is 3 times longer. The allocation delay is computed differently in the two configurations, because in one case the
17 propagation delay is greater than the BTP period, while it is smaller in the other case.
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24 Table I. SYMBOL DEFINITIONS
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27 The satellite network consists of 5 traffic terminals (including the master terminal) with directly connected end hosts.
28 The allocation scheme is the one used in the Skyplex network, that is, it uses a rate-based allocation scheme (RBDA),
29 each terminal is assigned at least one slot per multi-frame, the allocated rate reduces exponentially following a
30 reduction in the requested rate, and no FCA is used.
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34 The slow-start behaviour of TFRC leads to significant increase in delay during the start-up phase. To illustrate this
35 phenomenon, we consider the *one way delay* (OWD) and the *end-to-end delay* (E2ED) of packets of a single TFRC
36 flow initiating a connection over an idle satellite link (Figure 3). The OWD [9] is the delay between the wire-time
37 transmission of the packet and its wire-time reception, which accounts for the queuing delays in router buffers and the
38 propagation delays. The E2ED is the difference between the time the sending application generates the packet and the
39 time the packet is delivered to receiving application's dejitter buffer. The difference between the two delays is the time
40 spent in the transmit buffer of the sending host.
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45 46 47 One-way delay (OWD) and end-to-end delay (E2ED)

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49 The size of the uplink queue is set to 1000 packets, as in the Skyplex platform, while the transmit buffer is unlimited in
50 the simulations described in this section, because we are interested in the dynamics of interaction of a single connection
51 with DAMA. The uplink buffer is set to realistic sizes in the next section, where a complex scenario with multiple
52 connections is considered.
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55 **The TFRC start-up problem**

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57 In this section we consider a deterministic simulation scenario, where a single terminal transmits a single flow at
58 256 kb/s with a packet length of 1316 B. To have a complete picture of the dynamics of delay during the start-up
59 period, we repeated the simulation starting the flow with all possible offsets with respect to the super-frame, in 1.9 ms
60 steps. Where vertical bars are depicted, the plots show the minimum, maximum and median of the OWD and E2ED
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4 versus the time elapsed distance from the beginning of connection; other plots show only the median value.
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7 Figure 4 shows the simulated OWD and E2ED in both the small- and large-frame configurations with TFRC and
8 DAMA.
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12 Performance of a single 256 kb/s flow with DAMA.
13 (a) large-frame configuration, (b) small-frame configuration.
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16 In Figure. 4 the minimum delay is equal to the propagation delay T_p . The difference between the top curve (E2ED) and
17 the bottom curve (OWD) is the time packets are queued at the transmit buffer used by TFRC. The difference between
18 OWD and the minimum delay, which is visible in the large-frame configuration, is due to queuing at the uplink terminal
19 waiting for DAMA to assign the requested allocation. The OWD oscillates during start-up because TFRC increases its
20 throughput exponentially using a slow-start algorithm. Once the sending rate exceeds the allocated rate, a new DAMA
21 request is issued, and packets are queued at the uplink queue until the request is honoured one allocation delay later
22 (1.6 s for the long-frame configuration and 0.8 s for the short-term one). During this time, the queue keeps growing and
23 the rate keeps growing slowly following the slow-start algorithm. The effect is that slow-start is much slower on
24 DAMA than on a channel with preallocated bandwidth having the same round-trip time [3]. Since during slow-start the
25 sending application keeps encoding at a fixed rate, there is a mismatch between the encoding rate and the transmit rate
26 governed by TFRC, which translates into queuing at the transmit buffer and the observed E2ED. This is the main effect
27 that significantly slows TFRC on a DAMA link.
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35 E2ED exhibits a large variability; for example, in the large-frame configuration, after 15 s from the beginning of
36 transmission, packet delay can have any value in the range between 5 and 9 s, approximately. Specifically, small delay
37 variations at the beginning of the connection cause large variations in E2ED. This is due to the way the receiver
38 estimates the rate: since the flow rate is estimated as the number of packets seen by the TFRC receiver in a RTT, the
39 estimator suffers from a quantization effect when the number of packets transmitted is small. Both the E2ED and its
40 variability are significantly reduced in the small-frame configuration. This is an important observation for designers of
41 DAMA systems.
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46 This, and subsequent sections, assume a constant media rate for the data sent using TFRC. Actual application dynamics
47 depend upon the codec design, application behavior and encoded media content. Future applications may employ
48 variable rate codecs to tune performance to available capacity. Such codecs result in traffic bursts. We note that
49 although TFRC is a rate paced protocol, the packets that arrive at the terminal uplink are not necessarily evenly paced
50 due to implementation constraints and buffering in the network (these effects are not considered in this work). This
51 depends on the way the time slots are allocated and could result in Quick-Start packets to be sent as bursts which could
52 aggravate the level of congestion.
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57 **QS improves TFRC start-up performance**

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59 Section 3.2 identified the start-up delay problem as the interaction of slow-start in TFRC with DAMA, this section
60 seeks to mitigate this problem. We analyse how much DAMA makes things worse with respect to a constant rate
61 allocation (CRA) on the satellite link, and we analyse how well QS helps at start-up. We assume that the uplink traffic
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4 terminal implements a QS agent that receives QS requests, evaluates how much free capacity is available on the shared
5 satellite channel and forwards the QS-Request accordingly. More details on the evaluation process are given in
6 Appendix A.
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9 Figure 5 summarises these comparisons. The simulation scenarios are the same as described above, with and without
10 DAMA, with and without QS. Only the median of E2ED is shown, for clarity.
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15 Single 256 kb/s flow with and without DAMA, with and without QS.

16 (a) large-frame configuration, (b) small-frame configuration.
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19 In the CRA case the preassigned bandwidth is 1.2 Mb/s, more than 4 times than that needed by the flow. As expected,
20 performance with CRA is better than with DAMA, because the DAMA effect of slowing slow-start disappears [3]. As
21 expected, QS brings a clear improvement, by eliminating the slow-start phase after an RTT. This effect is observed in
22 the case of no-DAMA, QS performance: after an initial increasing delay due to traffic accumulating in the transmit
23 buffer during the first RTT (as a result of slow-start), the QS-Request is accepted and TFRC starts to transmit at faster
24 than the full rate, thus emptying the transmit buffer. The same happens with DAMA QS, but this time the traffic from
25 the transmit buffer accumulates in the uplink queue, until the DAMA request is granted to the requesting terminal.
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30 The bandwidth allocation flexibility brought by DAMA comes at a cost. There is a much slower start-up phase for
31 protocols using slow-start ,such as TCP [3] and TFRC, especially when there is a large DAMA allocation delay is big.
32 This cost is significantly reduced by the use of QS, but remains non negligible for large allocation delays. This latter
33 case is analysed in greater detail below.
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38 Single 256 kb/s flow with DAMA and QS, large-frame configuration.
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40 Figure 6 separates the E2ED into the time spent in the TFRC transmit buffer — represented by the difference between
41 the E2ED curve and the OWD curve — and the OWD itself, due to the fixed propagation delay plus the time spent in
42 the DAMA uplink queue. As in all figures in this section, the line is the median value over all possible time offsets of
43 the start of the flow with respect to the super-frame, and the vertical bars show the variability between minimum and
44 maximum values. In the following analysis, all times are mean times: exact times are dependent on the phase of the
45 satellite frame at beginning of transmission.
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50 The application starts sending at a full rate of 256 kb/s. A QS-Request of 320 kb/s is generated for this rate and TFRC
51 starts its slow-start phase, resulting in packets queued at the transmit buffer, while the uplink queue stays empty because
52 of the minimum DAMA allocation. After one RTT_m (0.8s), TFRC receives the QS-Response and starts sending at the
53 full rate. Since DAMA allocation is still at its minimum of 44 kb/s, packets are queued in the uplink queue. In the
54 meantime, a DAMA request is issued for the current rate (generally less than the full rate) every Tr (0.8 s), the exact
55 timing of the first request depending on the phasing of the request with respect to the start of an allocation frame.
56 Packets are still queued at the uplink queue and the delay increases linearly for one allocation delay after which, at time
57 2.5 s, the allocation is received and the queues begin to empty. During this time, TFRC receives the first feedback
58 report after the QS-Response, and ignores it [11]. The second feedback report arrives at $3RTT_m$, that is 2.3 s, but reports
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4 a rate that is much less than the full rate, so TFRC throttles the sending rate: the uplink queue empties, DAMA makes a
5 request for a lower rate and the transmit buffer starts filling. From this point on, the interaction between the DAMA
6 closed loop and the TFRC closed loop generates an oscillating behaviour whose exact dynamics depend on their
7 relative phase (*phase effect*), leading to wide variability, as shown by the vertical bars. In-depth discussion can be found
8 in Appendix B.
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10 11 **Improving QS performance in a satellite networks: QSD**

12 A major problem of the sequence of events visible in Figure 6 is that the requested DAMA allocation arrives too late
13 with respect to the QS Response. This causes TFRC at the receiver to issue a feedback report with a low perceived rate
14 and in turn causes the TFRC sender to throttle its sending rate just when the requested bandwidth is going to be
15 available on the satellite channel, causing bandwidth oscillation and an increased overall delay.
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20 To improve the performance of TFRC over DAMA using QS, we describe a method that accelerates the availability of
21 satellite bandwidth for the transmitter, and additionally evaluate the possibility of delaying the QS-Request so that the
22 QS-Response and the DAMA bandwidth availability are synchronised at the transmitter. This is obtained through a
23 cross-layer signalling method that we name QSD, short for QS-DAMA. Once the QS agent at the uplink traffic terminal
24 receives a QS-Request and decides there is enough free capacity on the shared satellite channel (see Appendix A for
25 details), it adds the QS-Request to the next DAMA bandwidth allocation request. More precisely, for each T_r interval,
26 the request is computed as defined in (1) plus the sum of the QS Requests received during the T_r interval that can be
27 satisfied by the currently unused shared satellite bandwidth.
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33 To align the arrival of QS-Response at the requester with the availability of the DAMA request on the BTP, the QS
34 agent may delay the QS-Request by a short time that we call the *QSD delay* T_q , before forwarding it along the data
35 path. This choice has the disadvantage that the first data packet, which transports the QS request, is also delayed,
36 leading to an initial delay increase equal to T_q .
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39 All in all, QSD consists of two mechanisms:
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42 • *Immediate DAMA request*: the QS agent at the terminal adds the requested QS rate to the next DAMA request .
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44 • *Optional QS request delay*: the QS agent at the terminal waits for a QSD delay T_q before forwarding the QS-
45 Request to the next hop in the network.
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51 Single 256 kb/s flow with DAMA and various QS strategies, large-frame configuration.

52 Figure 7 compares E2ED using DAMA with different QS strategies. The worst performer (largest E2ED) is the case
53 without QS, the same depicted in Fig. 5a. The next worst is QS without any interaction with DAMA, depicted in Figure
54 6. The behaviour of the proposed QSD implementation without an added delay is represented by the line marked with
55 $T_q = 0$, indicating that the QS request is forwarded immediately: the delay profile of QSD is similar to that of QS. The
56 time elapsed from the issue of a QS Request by the transmitter to the moment it obtains an allocation on the satellite
57 channel is equal on average to $T_r/2 + T_a$, which is 2051 ms. The time that elapses between the issue of the QS-Request
58 and the reception of a QS-Response, assuming that delays due to the terrestrial networks are negligible, is equal to the
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4 mean RTT, which is 777 ms. This means that the approved QS- Response arrives at the sender at a time when no
5 DAMA capacity has yet been allocated. This is the same problem that was observed in the QS case.
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8 When this timing mismatch is compensated for by delaying the QS-Request by
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$$10 \quad Tq_{max} = Tr/2 + Ta - RTTm, \quad (2)$$

11 the performance significantly improves (indicated by the lowest curve)..
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14 The reduction in maximum E2ED is shown in Figure 8, for each of the four cases of Figure 7 but at different flow
15 rates.
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21 Single flow with DAMA and various QS strategies.

22 (a) large-frame configuration, (b) small-frame configuration.
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25 In these results the maximum delay increases with flow rate for all strategies except for QSD, for which it remains low
26 and constant in both the large- and small-frame configurations. Simulations however show that values of Tq
27 significantly smaller than Tq_{max} computed in (2) give very similar results, as depicted in Figure 8. It is therefore
28 sufficient to set $Tq = 520$ ms and $Tq = 55$ in the large- and small-frame configurations respectively. Appendix B
29 discusses how these values are calculated.
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34 Delaying an initial packet carrying a QS-Request could lead to a nofeedback timer expiry if the feedback does not
35 arrive within the initialized RTO. TFRC as a standalone protocol specifies an initial RTO of two seconds [6]. Since a
36 QS-Response must be received within this period, this places an upper bound on the total round trip delay that can be
37 presented by the end-to-end path. While the proposed Tq delays in this paper are short enough to prevent any
38 nofeedback timer expiry, the Datagram Congestion Control Protocol (DCCP), RFC 4340 [14], also supports a TFRC-
39 based congestion control method whose specification states that the initial RTO is only one second. We believe that
40 this is too low an initial RTO value for some Internet scenarios (including the one described in this paper), and justify
41 this claim by citing the specified initial RTO value for TCP of three seconds [20].
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47 **Aggregated flows scenario**

48 We have analysed the dynamics of TFRC over DAMA and have identified ways to improve performance by studying
49 the simple specific case of a single connection on an otherwise idle satellite network. In this section we consider a
50 satellite network and the parameters that are the same as described in Section 3.1, but with a satellite network that is
51 lightly loaded, rather than unloaded.
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55 We consider three set of five traffic flows streamed between randomly selected hosts connected to a satellite terminal.
56 The traffic generated by the sources approximate VoIP calls, video phone calls and video clips. Each flow has a Poisson
57 integration time, with the same parameters for each of the five traffic sources. The duration of the flows is exponentially
58 distributed for simplicity (this duration only determines the overall background load, whereas the interesting dynamics
59 involving TFRC occur in the first few seconds of flow life).
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5 The parameters of the three types of source are shown in Table II. *Tolerable delay* is the maximum delay jitter that the
6 transmitter considers acceptable, after which the packet is considered late and discarded. *Packet length* for 16 kb/s is
7 chosen to be consistent with Skype; for 256 kb/s flows the length represents that used by the videoconferencing
8 program VLC (equal to 7 MPEG packets). The *transmit buffer* is computed from the two previous parameters. *Mean*
9 *duration* values are chosen for a typical flow duration for phone calls (VoIP), videophone calls and video clips (IPTV).
10 The *mean interval* is the flow intergeneration mean time, chosen so that the *traffic share* of each type of traffic is equal
11 to the one in the last column. The total load on the link is about 2 Mb/s, that is one third of the shared capacity.
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17 Table II. STREAMING SOURCES
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20 In the simulation we used TFRC-SP for the 16 kb/s flows and TFRC for the 64 and 256 kb/s flows. This distinction is
21 not significant in these scenarios, because the satellite network is underutilised, (far from congestion).
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26 Start-up behaviour for 256 kb/s flow in the aggregated flow scenario.
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28 Figure 9 shows the E2ED of the IPTV connections (256 kb/s) in the aggregated flow scenario. Using QS brings
29 considerable advantages in the E2ED performance, even when the network is moderately congested (one third of the
30 total capacity). The error bars show the 5th and 95th percentiles over a total of 100000 simulated VoIP flows, 2500 video
31 conferencing flows and 833 IPTV flows.
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35 The improvement of QSD with respect to QS is less dramatic in the aggregated scenario compared to the single-flow
36 scenario. This is because when a new IPTV flow starts sending packets at a high rate, most of the time the satellite
37 terminal already has bandwidth allocated in response to requests from other flows traversing the same terminal. This
38 bandwidth is shared between all the competing flows, each of which suffers a little, but much less than the single flow
39 suffered in the completely unloaded scenario of the previous section. Additionally, the chosen DAMA algorithm does
40 not immediately relinquish the assigned capacity when terminals reduce the requests. In a dynamic scenario, where
41 connections continuously end, releasing bandwidth, this means that new connections often exploit some of the (unused)
42 capacity still allocated to the terminal.
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47 As a consequence, not delaying the QS request ($Tq = 0$) results in better performance than introducing a delay in this
48 scenario. However, the single-connection scenario analysed in the previous section, while not general, is realistic,
49 because it is an important situation when a single host or a small office is connected to the Internet through a satellite
50 connection and a multimedia flow is started on an otherwise idle network. For this reason it is useful to find a value for
51 Tq that is as small as possible, yet allows QSD to provide an advantage to the single-connection scenario. In Appendix
52 B we compute this value, which we call Tq_{opt} , as 520 ms and 55 ms in the large- and small-frame configs, respectively.
53 Figure 9 shows that setting $Tq = Tq_{opt}$ gives an E2ED performance that is midway between $Tq = 0$ and $Tq = Tq_{max}$.
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Distribution of E2ED for (a) VoIP, (b) Videoconference and (c) IPTV connections.

10 The variability of E2ED over time is important since this dimensions the required dejitter buffer at the receiver. Jitter is
11 very high at the beginning of a flow, then it stabilises to a low value due to framing on the satellite link and to
12 concurrent flows using the shared bandwidth. Figure 10 reports the distribution of the E2ED for the three classes of
13 flows over the first 30 s after the beginning of the flow. In Figure 10 a it is shown how the different strategies have little
14 influence on the delay behaviour of VoIP, due to the low bandwidth used, which generally allows VoIP to profit from
15 any allocated DAMA excess bandwidth. The same happens for 99% of the videoconference call packets, as shown in
16 Figure 10 b, where the only noticeable feature are the tails of the $Tq=0.52s$ and $Tq=1.23s$ cases, which end up being a
17 copy of the $Tq=0$ case, but shifted to the right by Tq : the packets that create the tails are the first ones in the flows, those
18 that are delayed by Tq . Figure 10 c shows the graph relative to IPTV flows, where we observe that performance of the
19 noQS case is clearly worse than the others, and that $Tq=0.52s$ and $Tq=1.23s$ are the ones with the sharpest descent,
20 being copies of one another apart from the second being shifted to the right (i.e., with highest delays) by $1.23s-0.52s$.
21 Notice how Figure 10 c shows that the choice of $Tq=Tq_{opt}$ is indeed the best among the proposed ones.
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28 Table III shows the fraction of packets lost because of transmit buffer overflow when TFRC throttles the data rate
29 output from the sending node during slow-start, while the data source transmits at full rate. An IPTV transmit buffer set
30 to tolerate a 5 s delay, is able to absorb all delays when QS is used. No packets are lost because of buffer overflow in
31 the large terminal uplink queue of 1000 packets, (the value used in Skyplex Data equipment).
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36 Table III. FRACTION OF PACKETS LOST DUE TO TRANSMIT BUFFER OVERFLOW.
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38 **Conclusions and future work**

39 This paper has discussed the impact introduced by a satellite link that uses Demand Assignment Multiple Access
40 (DAMA) on the performance of streaming multimedia flows that utilise the congestion-control offered by the TCP
41 Friendly Rate Control (TFRC) algorithm. TFRC can improve co-existence of TCP and UDP streaming flows and
42 therefore avoid congestion collapse. However, the paper shows that the varying delay introduced by DAMA can
43 significantly impact the performance. This effect is a result of interactions between the end-to-end congestion control
44 loop and the control loop used on the satellite link to request/allocate capacity to a specific terminal. Similar effects
45 have previously been observed for TCP sessions.
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50 To mitigate these effects this paper proposes and analyses the use of an experimental method, known as Quick-Start.
51 Quick-Start provides a way for the network-layer to inform the link-layer about the expectations of a new media flow,
52 and more efficiently schedule capacity to a new flow. In our proposal, we modify the QS agent at the uplink satellite
53 terminal to inform the DAMA system as soon as a QS Request is received.
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58 One side-effect of implementing QSD is that the satellite uplink router commits capacity as a result of receiving a QS-
59 Request. Hence if the sender does not utilise its approved QS rate, then this additional allocation could be wasted (or
60 allocated to other traffic flows). In this paper we assume directly connected end-hosts, or end hosts connected via QS-
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4 enabled networks whose transit delay is significantly less than the total satellite link delay. If the sender were to be
5 connected via an intermediate network with appreciable delay, this would delay the QS packets that arrive at the
6 satellite terminal resulting capacity being allocated before the media flow starts. This reserved capacity could be
7 wasted.
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11 Results are presented to show the performance with and without using the QS method. It is shown the QS can
12 significantly improve performance, especially when the total allocated capacity to a terminal is much less than the
13 volume of new traffic being added by the multimedia flow (e.g. when the link is idle, or has little existing traffic).
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16 We observe that when using QS, the performance improves when the QS agent delays forwarding the QS-Request. We
17 call this method QS-DAMA (QSD). This may partially align the reception of a QS Approval with the reception of the
18 allocated DAMA capacity. Through fluid-flow analysis we have derived appropriate values for this delay that improve
19 performance when a link has little existing allocated capacity. However, delaying the QS-Request also has the
20 disadvantage that in delaying the QS-Request packet, it also delays the first packet of the flow, which may result in the
21 flow measuring an inflated initial Round Trip Time (RTT), which paradoxically can result in preventing the flow taking
22 full advantage of the QS capacity (since the flow must pace its transmission according to the measured RTT). We
23 suggest that judicious choice of when to employ the extra delay can alleviate this problem.
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29 Although the analysis of performance employed parameters appropriate to the Skyplex platform, we expect the
30 techniques to be applicable to other similar systems, including DVB-RCS.
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34 **Appendix A: Estimation of unused capacity on the satellite channel**

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36 When the QS agent at the uplink terminal receives a QS-Request, it must evaluate whether there is enough capacity on
37 the shared satellite channel to be allocated to satisfy the received request. Terminals may become aware of current
38 bandwidth utilization using a centralised approach A discussion of both approaches follow:
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40

41 A.1 Centralised estimation

42 A.1.1 Continuous broadcast

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45 The RNCC broadcasts the amount of free capacity. This could be the BTP, requiring an appropriate field to be
46 added to the DVB standard, or by sending a packet/frame to all the terminals in a private format.
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50 A.1.2 On demand

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52 The RNCC answers queries from the terminals requesting the amount of free capacity in a private format. This
53 method implies an additional delay equal to RTT_m for the QS-Request to be forwarded.
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57 A.2 Distributed estimation

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59 Each terminal individually evaluates the amount of free capacity. There are two possibilities, depending on DAMA
60 using FCA (free capacity assignment).
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A.2.1 DAMA does not use FCA

Estimation is accomplished by examining the BTP and summing the capacity of all unassigned slots.

A.2.2 DAMA uses FCA

The only possibility left is to listen for other terminal's transmissions. Depending on the topology and capabilities of the network, it may be impossible to use this method.

A.2.2.1 Single spot without fade countermeasure

The estimation is possible but inaccurate, because a terminal may not transmit in a slot it has requested, or could be transmitting in a slot it has not requested, but was assigned by FCA.

A.2.2.2 Single spot with fade countermeasure

If up-power control or adaptive modulation and coding are used as fade countermeasure systems, a terminal in deep fading may be unable to listen for transmissions directed to other terminals. This would lower the accuracy of estimation during fades.

A.2.2.3 Multiple spots

If the satellite network is multi-spot, each terminal can only listen for transmissions directed to its spot, so it can only have an estimate of the unused capacity for transmissions directed to its own spots.

Our simulation assume that the free capacity can be determined without delay, so we consider case A.1.1. In [10] two methods are considered for evaluating the unused bandwidth: considering a moving average of a number N of equally spaced observations and considering their moving peak. In our setting, we make a new observation at each BTP, so the estimation interval is Tb . We considered only the last estimation, so we set $N=1$. Different values for N could be considered in future research.

The algorithm used by the QS agent for deciding whether to approve a request is the Target algorithm defined in [10]. The agent considers the channel to be underutilised if the free capacity is at least 20% of the shared bandwidth, which in [10] means setting $qs_thresh = 0.8$. In order to avoid over allocating bandwidth to several consecutive requesters, the QS agent remembers the requests approved in the last M time intervals. In our simulations M is set to 2, and the variable $state_delay$ contains the length of the time interval. We ensure that the agent remembers approval of QS-Request for the maximum time that can elapse from the reception of the request to the time it is reflected in the received BTP. This time is equal to $Tr + Ta$, so we set $state_delay = (Tr+Ta)/2$.

Appendix B: Optimal value for the QSD delay Tq

Equation (2) provides a simple way to compute a value for the QS delay Tq . However, simulations show that the value obtained is significantly higher than necessary. Lowering Tq has beneficial effects in the multiple-connection scenario analysed in Section 4. The DAMA algorithm we adopted deallocates bandwidth slowly, hence a terminal has often more available capacity than requested. When additional capacity is available, it is used by newborn connections: for these the smaller the Tq delay, the better.

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5 It would be useful to compute the minimum Tq value Tq_{opt} for which the advantages shown in Figure 7 hold. The
6 optimal value is thus in the range from 0 to the value from (2), that is 1.23 s and 0.34 s in the large- and small-frame
7 configs, respectively.
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10 Tq_{opt} should be computed as the minimum value of Tq such that the delay keeps decreasing after the initial local
11 maximum, rather than showing the hump visible in Figure 7 for the case of $Tq=0$. We developed a fluidic model for the
12 single-connection scenario to study the delay behaviour for the two considered configurations. This is available for
13 interactive use and download at [19]. Figure B1 shows the default configuration computed by the model in the large-
14 frame configuration with Tq set to 400 ms. The four monotonely increasing curves are the cumulative outputs in kb/s at
15 four different points in the network model as shown in Figure 3: at the output of the traffic generator (the generator's
16 rate), at the output of the transmit buffer (the TFRC rate), at the output of the uplink queue (the DAMA rate) and at the
17 output of the receiving terminal (the received rate). Horizontal distances from one curve to the next are equal to the
18 amount of buffered traffic in the transmit buffer (the TFRC buffer) the uplink queue (the DAMA buffer) and the radio
19 link, respectively. Vertical distances are equal to the respective delays, that is the delay introduced by TFRC in the
20 transmit buffer, the delay introduced by DAMA in the uplink buffer and the propagation plus framing delay $RTTm$,
21 respectively (see Table I). The E2ED is the vertical distance between the first and the fourth curve, that is, the total
22 delay between the generator and the receiving terminal; in Figure B1 it is plotted versus the sending time.
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31 The main difference of the fluidic model with respect to the simulation are that packetisation at the generator's output is
32 not considered, framing at the uplink queue output is not considered and the receiver's estimate of the round trip time is
33 fixed and set equal to $Frstep = RTTm + Tq$.
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38 Fig. B1. Fluidic modelling of traffic queuing in the large-frame configuration.

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40 Figure. B1 presents the results of the fluid model for a single connection scenario. The generated traffic accumulates in
41 the transmit buffer until the first feedback report is received (the QS Approval) at time $RTTm + Tq = 1178$ ms. From this
42 point on, the transmit buffer empties linearly, because its output rate is 320 kb/s while the rate of the generator is
43 256 kb/s. From the reception of the first feedback report to the reception of the first DAMA allocation at time
44 $Tr + Ta = 2460$ ms the uplink queue increases, after which it empties at the same rate as the transmit buffer, i.e., 320-
45 256 kb/s. The second feedback report is ignored [11], and the sending rate is maintained until the third feedback report
46 is received at $3Frstep = 3534$ ms. The 3rd feedback report has been sent by the receiver at time $qen = 3Frstep - RTTm/2$
47 and is based on traffic received in the interval from $qen - Frstep$ to qen , that is, traffic that exited the uplink queue during
48 the time interval from $qen - Frstep - RTTm/2 = RTTm + 2Tq = 1579$ ms to $2RTTm + 3Tq = 2757$ ms. During this time interval
49 the first DAMA allocation is received in our scenarios. This means that the traffic received during this time interval is
50 initially very low (the minimum DAMA allocation) and then is equal to the QS request (because of the QSD request).
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57 Since the 3rd feedback report is significantly lower than the QS-Request (unless we set a very high Tq), TFRC slows
58 down to the reported rate until it receives the 4th feedback report. At this point, it grows gradually its rate up to the
59 maximum of twice the 4th feedback report and twice the previous rate (that is, the 3rd feedback report). In Fig. B1 this
60 rate is reached when the 5th feedback report is received; at that moment, the uplink queue empties and the E2ED stops
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growing, because the TFRC rate is the same as the rate of the generator. Experimenting with various values for the involved parameters shows that the behaviour shown in Fig. B1 is typical of the situation when Tq is near its optimal value, that is when increasing it further does not significantly lower the maximum E2ED.

To compute Tq while approximating on the safe side, we consider the initial received rate as 0 – rather than the minimum DAMA allocation rate – and the final received rate as the rate of the generator of 256 kb/s – rather than the QS-Request. From the above discussion, we want the TFRC rate at the 5th feedback report to be equal to the generator's rate. This means that the rate of the 3rd feedback report should be half the generator's rate, which in turn means that the first DAMA allocation should be received in the middle of the interval above defined, leading to the equation

$$Tr + Ta = RTTm + 2Tqopt + \frac{RTTm + Tq}{2} \Rightarrow Tqopt = \frac{2(Tr + Ta) - 3RTTm}{5}. \quad (B1)$$

Equation (B1) yields $Tqopt = 520$ ms and $Tqopt = 55$ ms for the large- and small-frame configurations, respectively. As said, these values are computed with many approximations, the most important being the fact that the QS-Request (320 kb/s) in our case is significantly larger than the rate of the generator (256 kb/s). Since the approximations are all done on the safe side, the values obtained for $Tqopt$ are larger than those that minimise the maximum E2ED in the worst case as seen in the simulations.

The purpose of computing $Tqopt$ as the value of Tq is to find the minimum Tq value for which the packet delay keeps decreasing after the initial maximum. The packet that suffers the initial maximum is sent at a time th_maxt approximately equal to

$$th_maxt = ((Tr+Ta)-(RTTm+Tqopt))*mindama/full,$$

where $mindama$ is the minimum DAMA allocation given to terminals even when they request no traffic, and $full$ is the sending host streaming rate. The delay th_maxd experienced by the packet sent at th_maxt is approximately equal to

$$th_maxd = (Tr+Ta)+RTTm/2-th_maxt,$$

so one can say that the maximum delay experienced by a flow is for packets sent after th_maxt after the flow, that it is equal to th_maxd , and that this delay is not exceeded by other packets in the flow if $Tq = Tqopt$. The expressions given above for these quantities are approximately valid for a wide range of parameters.

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Table I. SYMBOL DEFINITIONS

parameter	symbol	small-frame	large-frame
allocation period	T_f	45.6 ms	273 ms
BTP period	$T_b = 3T_f$	137 ms	820 ms
measurement intv.	$T_r = T_b$	137 ms	820 ms
propagation delay	T_p	252 ms	252 ms
allocation delay	$T_a = 6T_b, 2T_b$	820 ms	1641 ms
mean RTT	$RTT_m = T_f + 2T_p$	550 ms	777 ms
max QSD delay	$T_{qmax} = (T_r/2 + T_a) - RTT_m$	339 ms	1273 ms

Table II. STREAMING SOURCES

rate	tolerable delay	packet length	transmit buffer	mean duration	mean interval	traffic share
16 kb/s	0.1 s	160 B	2 pkt	60 s	1 s	50%
64 kb/s	0.1 s	512 B	2 pkt	180 s	40 s	15%
256 kb/s	5 s	1316 B	128 pkt	300 s	120 s	35%

Table III. FRACTION OF PACKETS LOST DUE TO TRANSMIT BUFFER OVERFLOW.

type	tot	VoIP	Video	IPTV
No QS	0.11	0.11	0.11	0.025
QS	0.044	0.045	0.044	0
QSD ($T_q=0$)	0.036	0.037	0.036	0
QSD ($T_q=0.52$)	0.020	0.020	0.020	0
QSD ($T_q=1.23$)	0.012	0.012	0.012	0

Figure 1
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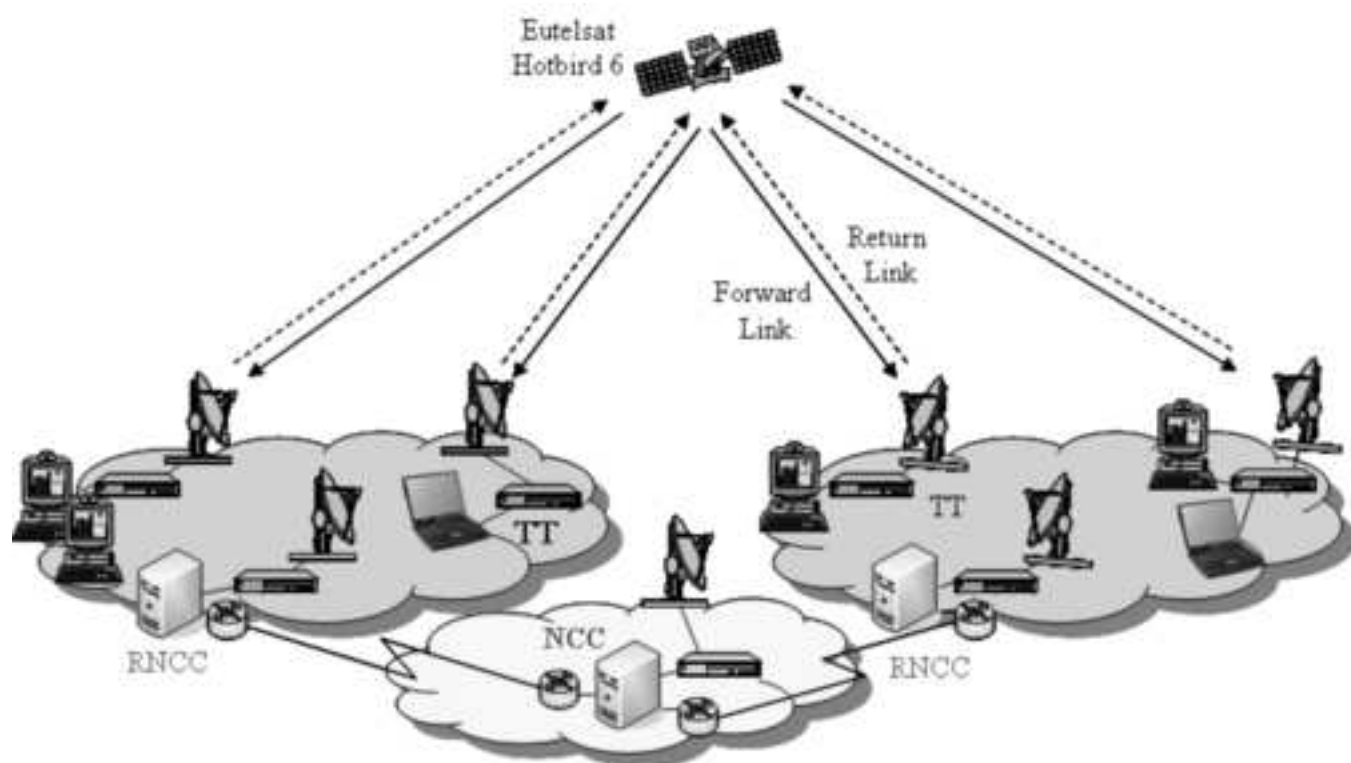


Figure 2

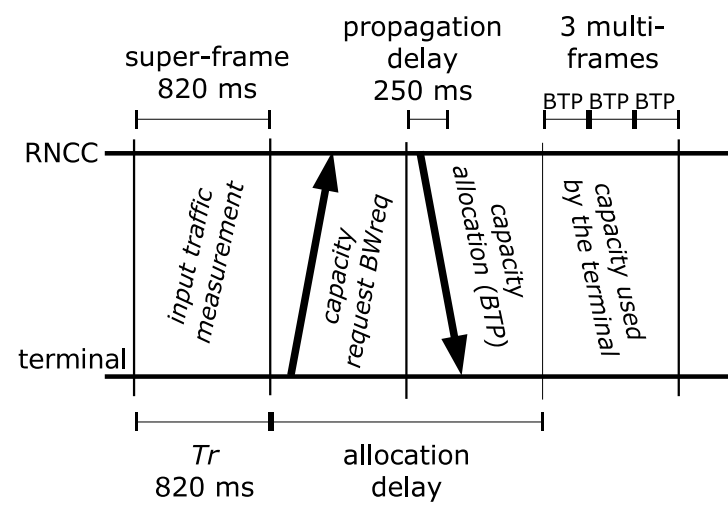


Figure 3

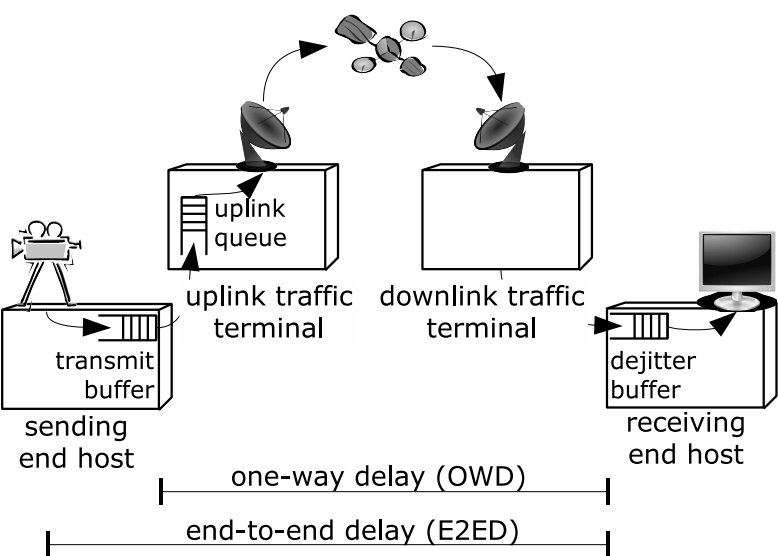


Figure 4a

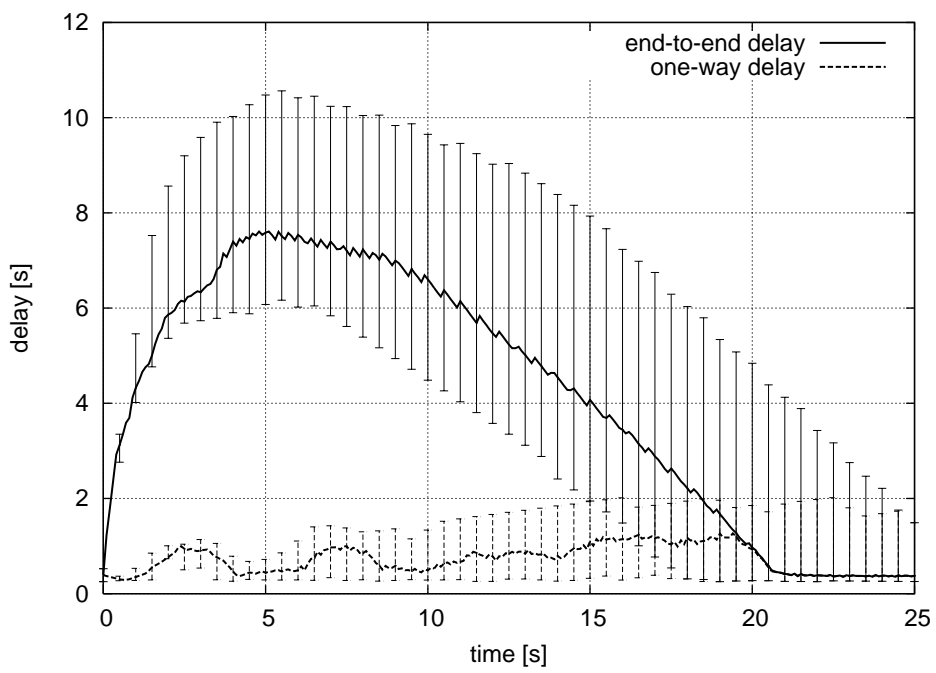


Figure 4b

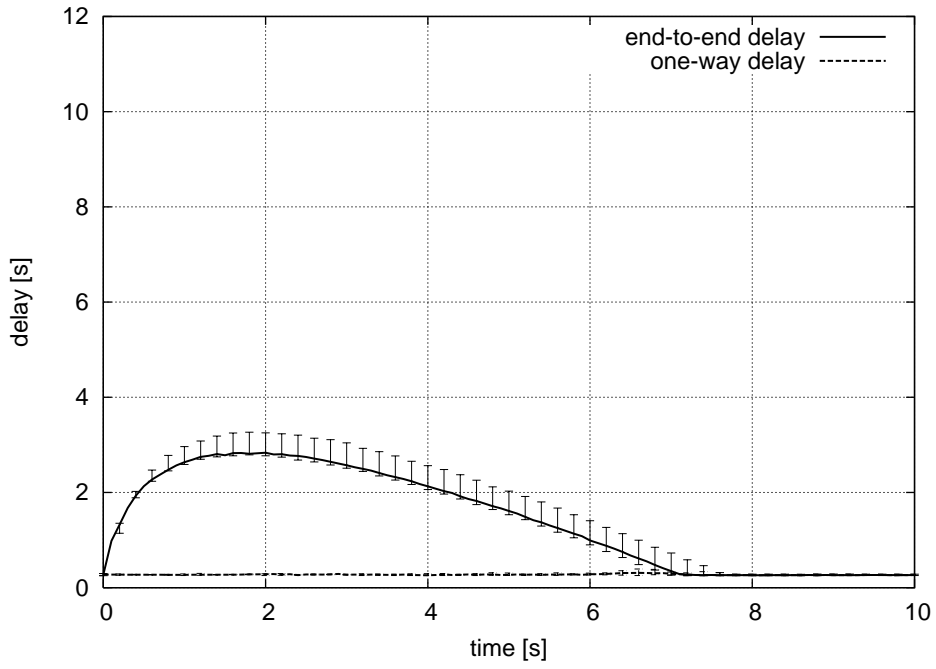


Figure 5a

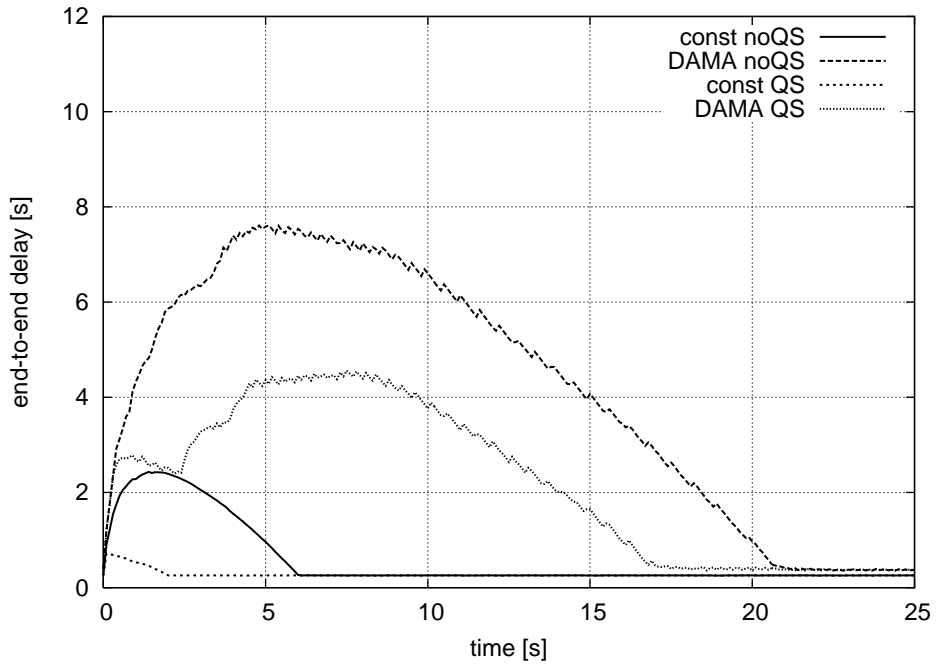


Figure 5b

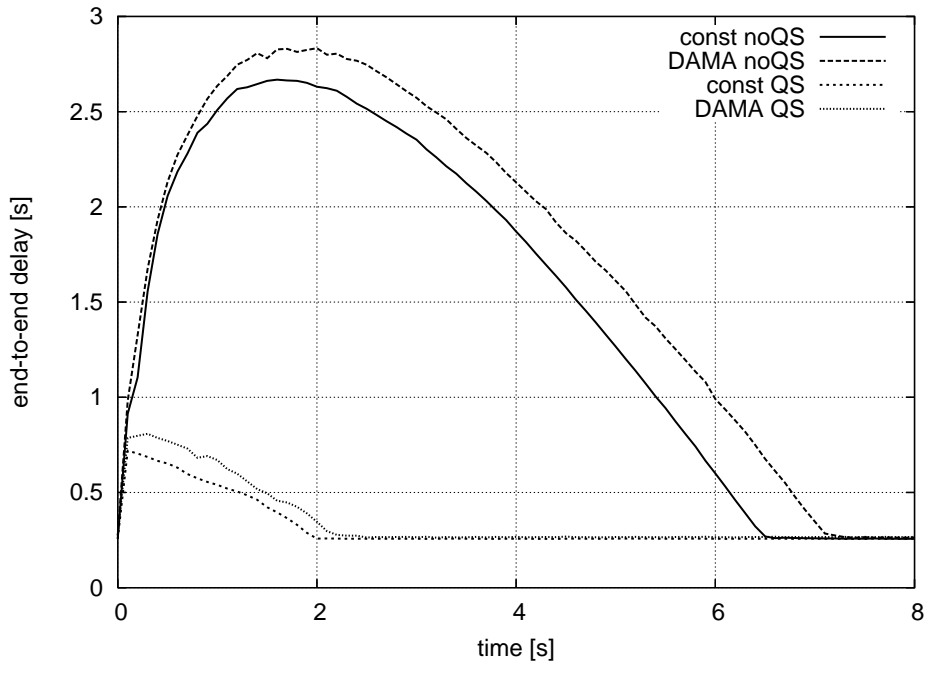


Figure 6

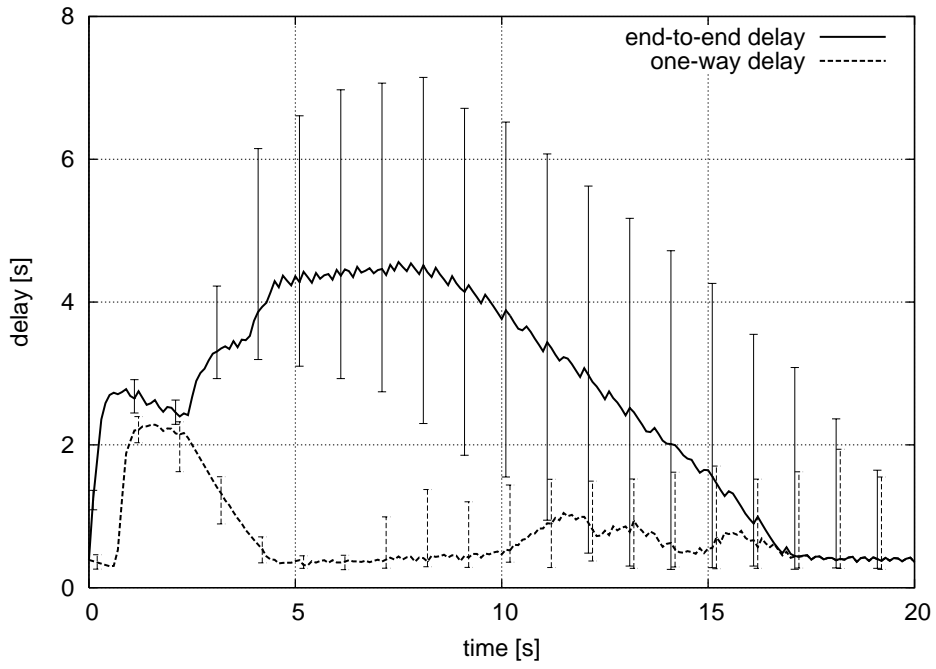


Figure 7

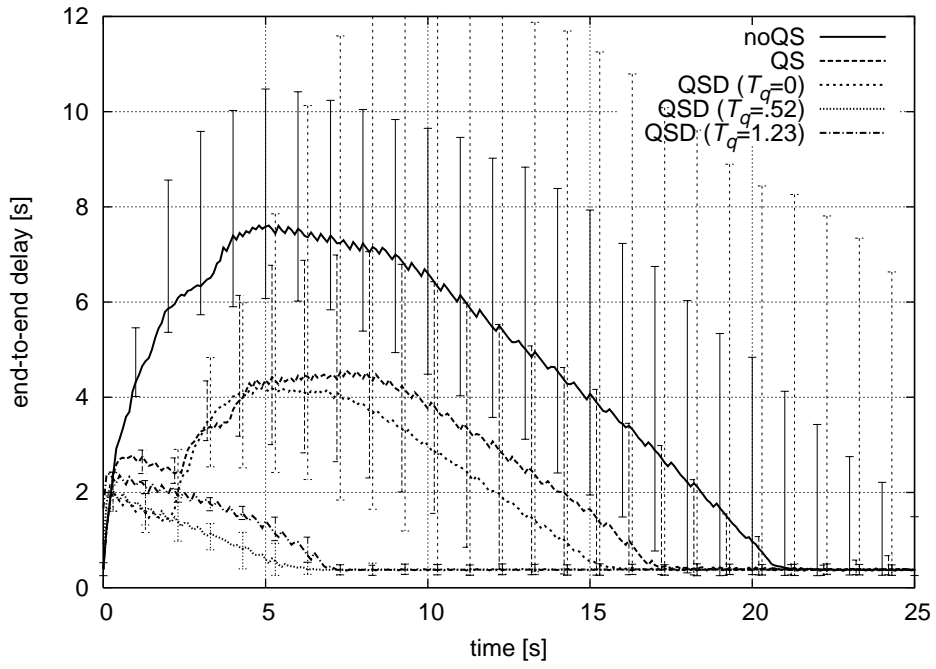


Figure 8a

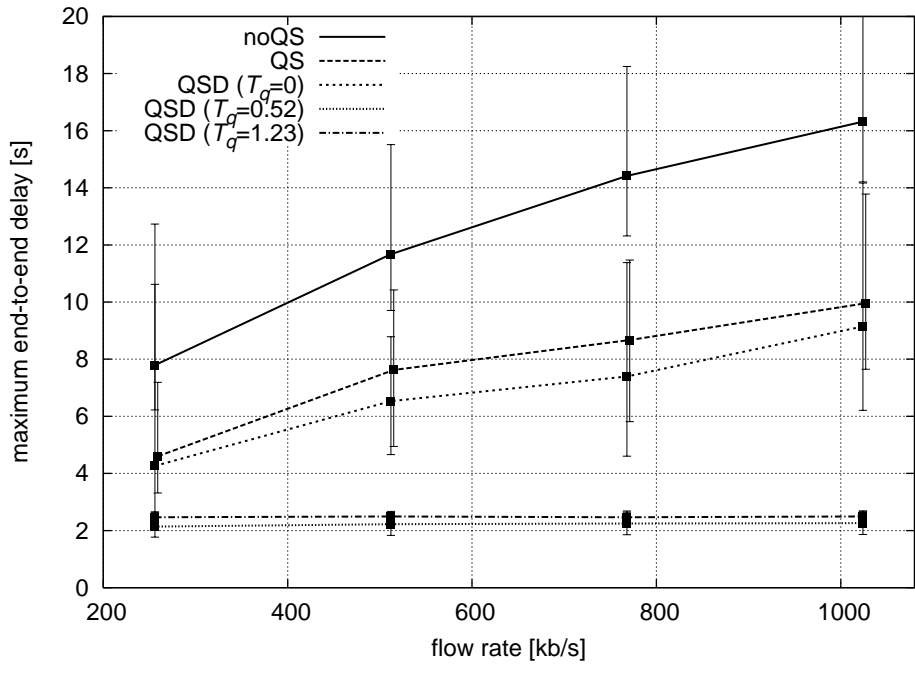


Figure 8b

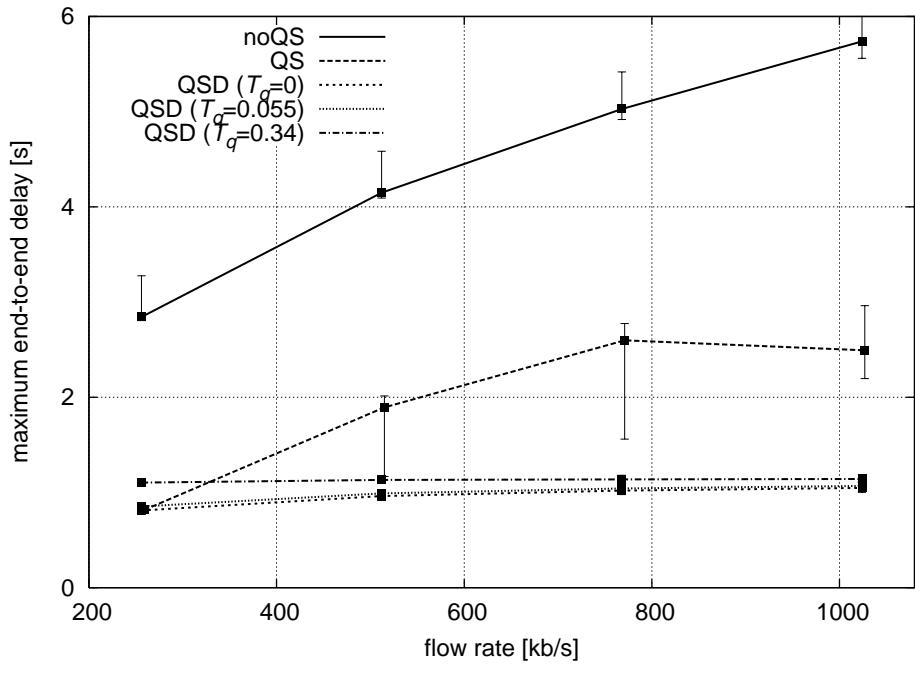


Figure 9

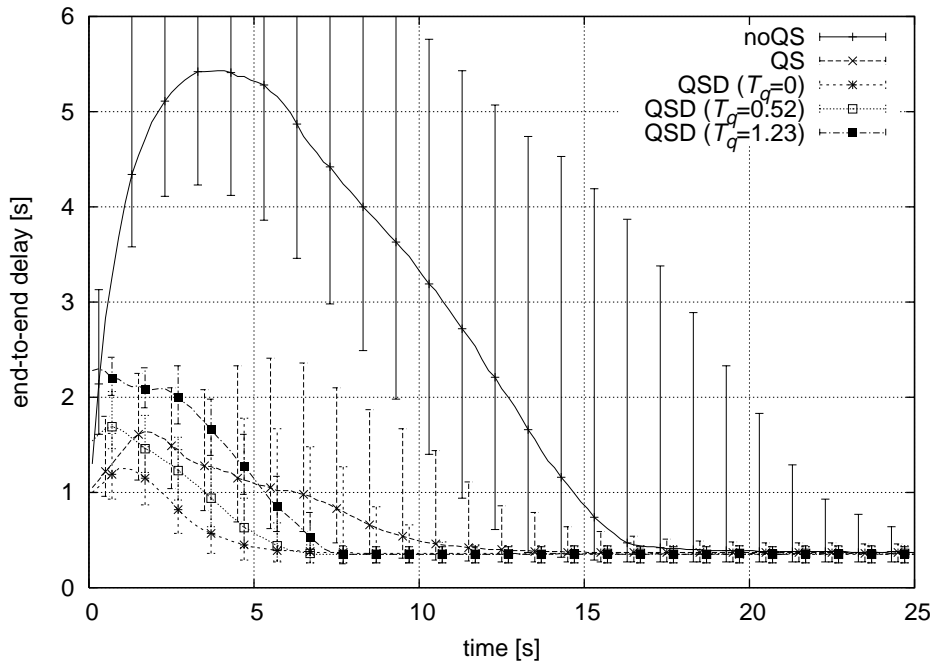


Figure 10a

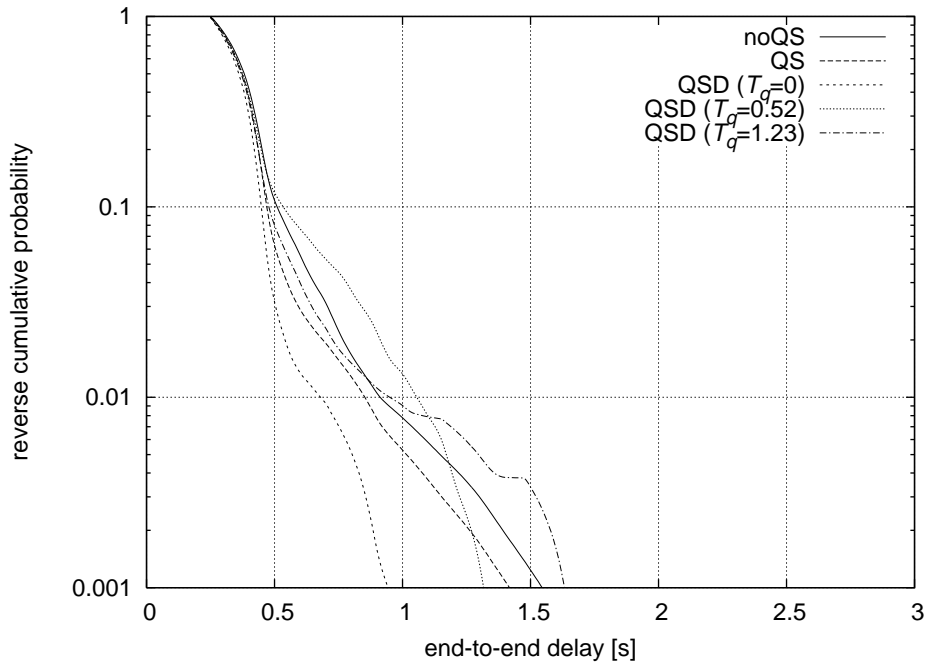


Figure 10b

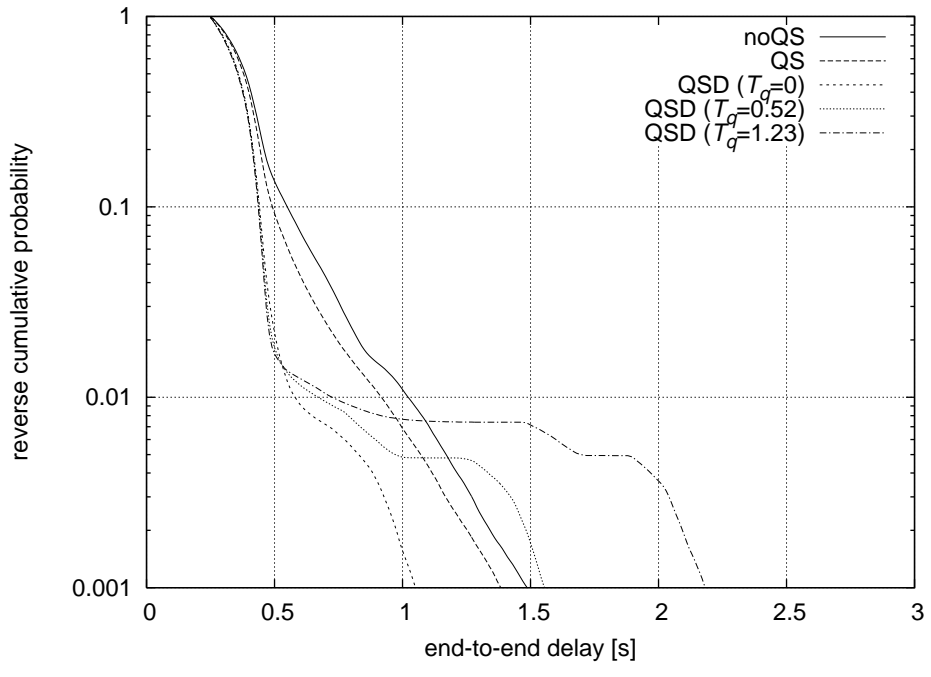


Figure 10c

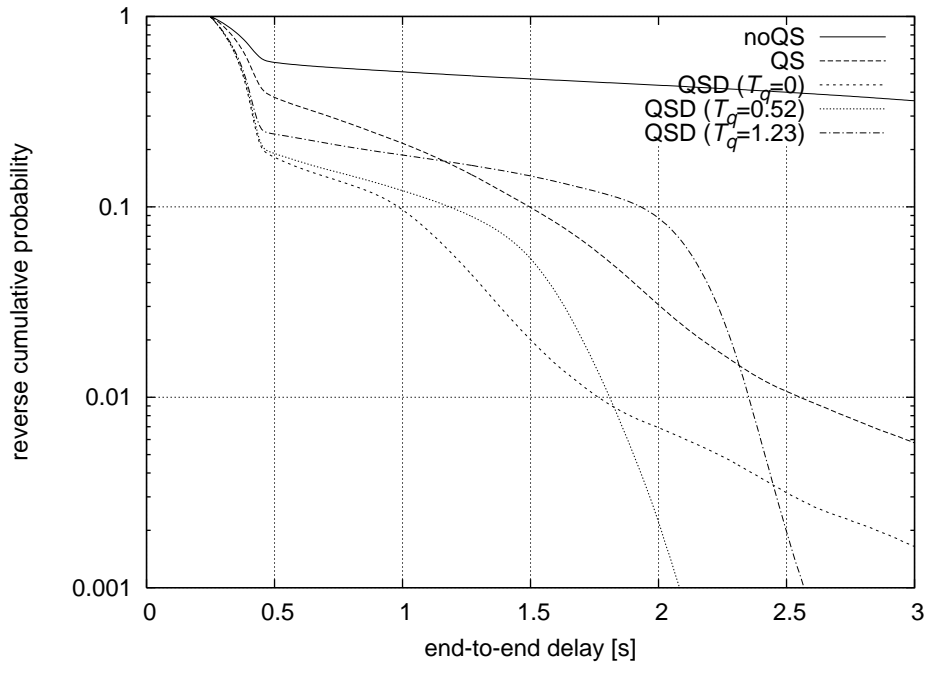
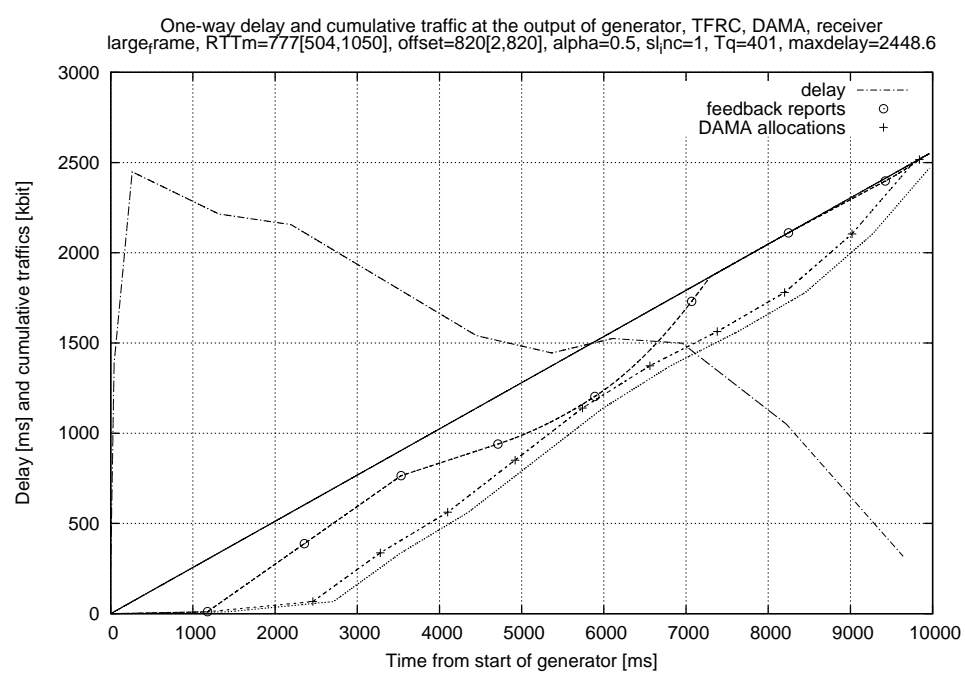


Figure B1



*** Author Biography**

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Secchi Raffaello received his Laurea degree in Telecommunication Engineering on July 2002 from the University of Pisa (Italy). From January 2003 to December 2005 he was a Ph.D. student at the University of Pisa and received his Ph.D. from the on May 2006, by discussing a thesis on Traffic Modelling and Control in High Speed Networks. Since 2006 he is a Postdoctoral Fellow with the Information Science and Technology Institute (ISTI) of National Research Council in Pisa.

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Arjuna Sathiaseelan (PhD 2005, B.E. 2000) is a Research Fellow at the University of Aberdeen. His current research interests are in the integration of satellite broadband access in Next Generation Networks. He leads work on Network Simulation, design of multimedia transport protocols, TCP protocol optimisation, and performance analysis. He is the author of several working group Internet Drafts in the IETF DCCP working group.

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I received my electronic engineering degree from the University of Pisa, Italy, in 1991. I am a full-time researcher at the ISTI-CNR institute (formerly CNUCE) in Pisa, Italy, where I have worked since 1989 in the fields of satellite communication protocols and fade countermeasure systems, and where I am a member of the Wireless Networking Laboratory. I was Italian representative in the European COST action 285.

My research interests include communications protocols and their implementation, terrestrial and satellite wireless communications, internet technology with regard to TCP over wireless channels, simulation of communications systems. I coauthored more than forty refereed scientific papers.

I am interested in encouraging the use of free software licenses in the research community.

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Alberto Gotta received the Master of Science in Telecommunication Networks and Systems Engineering from the University of Genoa, Italy, in 2002. From 2002 to 2004 he was a researcher with the Research Unit of the Italian National Consortium for Telecommunications (CNIT) at the University of Genoa. Since 2004 he has been a researcher with the ISTI Institute of the Italian National Research Council (CNR). He has worked in the SatNEx project funded under the Network of Excellence mechanism in the EU FP6. He is currently involved in the SatNEx II project and in the EU funded project RINGrid - Remote Instrumentation in Next-generation Grid.

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