An Adaptive Fuzzy-Based CAC Scheme for Uplink and Downlink Congestion Control in Converged IP and DVB-S2 Networks

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***Abstract*—This paper introduces a robust buffer occupancy-based Connection Admission Control (CAC) mechanism to alleviate both uplink and downlink congestions in converged IP and broadcasting networks. The scheme also ensures a fair share of downlink bandwidth among competing satellite terminals (sub-networks) in the event of congestion. The proposed scheme is dubbed Weighted Fair CAC (W-FCAC). It accepts or rejects connections based on an adaptive fuzzy-based approach. The use of the fuzzy-based mechanism is for the purpose of overcoming issues related to instantaneous link capacity assessment, flow characterization and the associated high computational complexity, and use of traffic descriptors for new flows. Additionally, the adaptive fuzzy logic makes the proposed CAC approach robust to traffic dynamics. These features make the scheme highly suitable for DVB-S2 environments where the link capacity frequently fluctuates due to the adaptive coding/modulation of the physical layer during noisy periods. Simulation results elucidate that the proposed W-FCAC scheme prevents downlink congestion and fairly allocates network resources among satellite terminals. It also minimizes the frequency of congestion events while maintaining efficient utilization of network resources.**

***Index Terms*—IP/DVB networks, CAC, fuzzy logic, resource reservation, and QoS provisioning.**

I. INTRODUCTION

DUE TO THEIR large geographic reach, their reliable and high bit rate links, and their inherent broadcasting capabilities, satellite systems are seen as an important communication medium for the provisioning of various value-added services to both urban and rural areas, in particularly less favored regions [11]. In satellite networks guaranteeing Quality of Service (QoS) is vital given the limited resources of these networks compared to their wired counterparts. In this context, an appropriate connection admission control (CAC) scheme is of utmost importance to guarantee QoS for existing connections while maintaining high system utilization.

To maintain a high network utilization, multiplexing-based CAC techniques are particularly required in networks where the link capacity may vary due to physical layer adaptations [5], such as in Digital Video Broadcasting - Satellite - 2nd Generation (DVB-S2) networks. In fact, DVB-S2 uses the new Adaptive Coding and Modulation (ACM) technique that allows more efficient channel protection and dynamic link adaptation to varying propagation conditions. Thus, it becomes not possible for an upper-layer resource allocation mechanism to meet its commitments, in terms of reserved bandwidth, when the link's capacity fluctuates. Efficient bandwidth allocations at upper-layers can be possible only via a constant monitoring of the instantaneous available bandwidth at the physical layer.

Converged IP and broadcasting networks exhibit some unique features that should be intelligently reflected in the design of an effective CAC. For instance, wired networks perform admission control at ingress routers level. However, the asymmetric nature of converged IP and DVB networks requires admission control at both uplink (i.e., from the satellite terminals to the gateway) and downlink (i.e., from the gateway to the satellite terminals) levels.

As will be stated in the next section, a number of existing CAC methods address exclusively the uplink overloading issue by implementing effective admission controls at the Ingress Routers (IR). This consists in deploying congestion control mechanisms at terminal stations, which do not necessarily prevent congestion at downlink. Besides, it is difficult to efficiently manage admission control at downlink due to the large number of connections in the wide-coverage area of DVB-S2 networks. On the other hand, the bandwidth requirements at different areas covered by the network are not all the same for all satellite terminals (STs). A naive solution that provides the same service level to all STs is thus neither optimal from the network operator's perspectives nor fair from the satellite terminals' perspectives.

In this paper, our main concern is to design a scalable and robust CAC protocol for converged IP and DVB-S2 networks that reduces both uplink and downlink congestion occurrences. Another important concern consists in achieving high satellite link utilization while ensuring a weighted proportional fairness among satellite terminals. In the proposed scheme, two different CAC policies, namely downlink and uplink CACs, are used. Whilst both CAC policies take place at the satellite terminals, the measurements needed for downlink CAC are carried out at the DVB-S2/DVB-RCS gateway level. Effectively, the gateway calculates the connection blocking probability for each ST based on the queue occupancy dynamics and the ST traffic volume. It then transmits this information to each ST in the network that uses it for the downlink CAC

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operation.

In light of the above observations, the present work proposes a new implementation of our earlier work [16] incorporating several substantial improvements to the original W-FCAC scheme while retaining its basic intuition and spirit. We introduce a novel fuzzy-based CAC including an adaptation mechanism that solves the problem of parameters setting and makes the CAC scheme robust to network dynamics. In fact, the fuzzy control theory enables an intuitive understanding of how to control the system and renders it fairly independent from network conditions such as connection count and traffic type. Additionally, the introduced adaptive control compensates the waste (respectively the gain) of bandwidth that may occur in the DVB-S2 network due to increase (respectively decrease) in noise. This operation helps to increase throughput and to prevent packet drops due to congestion. It ultimately enhances the overall performance of the network.

Our combined CAC scheme is based on an effective auto-tuned fuzzy controller that monitors the transmission buffer occupancy at: (i) STs to cope with congestion at uplink, and (ii) the DVB-S2/DVB-RCS Gateway (GW) to increase/decrease the connection (flow) blocking probability. While the uplink CAC allows regulating the traffic and prevents local congestions and the associated excessive delays and packet losses, the downlink CAC addresses both the congestion issue and fairness in bandwidth allocation among satellite terminals. The objective of our downlink CAC is to ensure that during congestion events, ”under-loaded” satellite terminals continue accepting new connections while ”overloaded” satellite terminals adopt strict CAC policies. A network operator may henceforth guarantee to its subscribers a constant share of bandwidth according to a priori negotiated service level agreement (SLA).

The remainder of this paper is organized as follows. Section II provides an overview on major CAC techniques and discusses their applicability to IP/DVB-S2 environments. Section III describes the key components of the proposed system architecture and introduces the proposed CAC scheme. Section IV portrays the simulation setup and discusses the obtained results. Finally, the paper concludes in Section V with a summary recapping the main advantages and achievements of the proposed scheme.

II. Background and motivations

Connection Admission Control (CAC) is one of the most effective mechanisms which not only ensures acceptable quality for newly arriving connections, but also guarantees that QoS of existing connections does not deteriorate. They are particularly important for environments where the total link capacity is shared by several users such as converged IP and DVB networks. Given the limited resources of gateways, CAC is crucial to provide users with their negotiated QoS while protecting the network from congestion and preventing excessive end-to-end delays and packet drops. A wide set of CAC schemes has been proposed in the literature [1], [2], and [13]. Existing CAC techniques can be classified as either resource reservation-based or statistical multiplexing-based schemes.

A. *Resource reservation-based approaches*

Resource reservation-based CAC schemes have some known scalability issues and lead to self-induced congestion due to the heavy resource reservation process (e.g., path selection, routing, bandwidth reservation, two-ways connection establishment, etc.). Besides, static reservation-based approaches do not satisfy flexibility requirements of typical network operators. In fact, a static resource allocation is not able to accommodate changes in per-ST offered load and thus leads to under utilization of the satellite spectrum. On the other hand, satellites are well characterized by significant fluctuations in their channel capacities. To cope with such wireless link fluctuations in DVB-S2 networks, a novel Adaptive Coding and Modulation (ACM) technique is introduced [5]. However, this ACM approach renders the resource reservation process of resource reservation-based CAC schemes highly difficult.

Many research works [2] have investigated resource reservation-based CAC schemes to guarantee a reasonable QoS level in different network conditions. However, only few works have considered the unique features of converged IP and Broadcasting networks in the design of their CAC schemes. In [15], Qian et al. proposed a mechanism comprising an uplink CAC protocol and a resource reservation mechanism. The latter is based on ”static bandwidth” assumptions, a fact that may likely lead to resource underutilization or congestion in both uplink and downlink. Besides, the authors consider only the uplink congestion without addressing the downlink congestion. In [6], Bohm et al. presented the performance analysis of a movable boundary access technique for admission control and resource allocation in an IntServ multi-beam multiservice satellite. The scheme achieves high uplink utilization and increases the system scalability. However, in this approach, the non-prioritized flows usually suffer from packets drop since the bandwidth is guaranteed only for the prioritized flows. In [7], Molinaro et al. provided a scalable end-to-end CAC architecture based on DiffServ in the terrestrial core, IntServ in the satellite access, and Aggregated RSVP [22] for interoperation between the two domains. The proposed CAC procedure consists of two phases: the terrestrial admission phase and the satellite admission phase. The two phases are performed in succession, commencing with the terrestrial CAC phase. Upon a successful terrestrial CAC, the satellite CAC phase is launched. Scalability issues pertaining to the terrestrial admission phase are discussed and adequate solutions are provided. Given the fact that satellite CAC is performed only after successful terrestrial CAC, scarce resources of satellites are intelligently and efficiently utilized as they are reserved for only users that are admitted to access the terrestrial domain. In [9], R. Abi Fadel et al. presented a more realistic scheme integrating resource reservation only on satellite links. The proposed approach admits low priority flows until the number of allocated channels reaches a certain threshold. As for higher priority flows, they are accepted until the capacity limit is reached. This scheme is, however, based on static assumptions (e.g., constant thresholds) which makes it not suitable for environments with varying conditions. In [29], Niyato et al. proposed an open-loop fuzzy logic admission control system to cope with imprecise and noisy input information. The scheme comprises three modules: a traffic source estimator based on the Markov Modulated Poisson Process (MMPP) model, a resource allocator and a fuzzy based-admission controller. The performance of this scheme depends on the tuning of the fuzzy membership functions. In [30], Rong et. al. proposed an admission control mechanism for WiMax networks that decouples between the uplink and downlink controls. In this approach the downlink admission phase requires managing all the incoming connections at the base station level, which may present some scalability issues in DVB-S2 networks. This issue is addressed in our paper by performing the downlink admission control at the satellite terminal level. Moreover, a common shortcoming of the above-introduced schemes consists in their inefficiency to cope with variations of the network capacity, an important feature of DVB-S2 networks.

B. Statistical multiplexing-based approaches

Statistical multiplexing-based CAC schemes can not completely eliminate congestion during some peak periods. However, they enable fair sharing of resources amongst users and yield a much better utilization of resources. This renders statistical multiplexing-based schemes more suitable for converged IP and broadcasting networks.

Only a few number of research works have addressed the issues of statistical multiplexing in the context of broadcasting networks. These works take advantage of the satellite architecture by using the Network Control Centre (NCC) located at the terrestrial part of the system [8]. This allows an accurate admission control based on an overall assessment of the network resource availability. It also significantly reduces the signaling traffic on the air interface since the satellite terminals are connected to the NCC via wired connections.

In [3], Pace et al. proposed a centralized CAC procedure located at the NCC of a DVB-RCS satellite system. Based on major traffic descriptor's parameters (e.g., peak bit rate, data burstiness, and service category), the proposed CAC algorithm decides whether to accept or to decline a connection according to an estimation of the excess demand probability. The resulting handling policy is dynamic and effectively exploits the available bandwidth through statistical multiplexing [4]. However, this approach lacks an efficient congestion control procedure and does not ensure fair allocation of downlink resources among competing users. In [21], De Rango et al. studied a CAC algorithm using bandwidth level discretisation of aggregated group of pictures (GOP). A high multiplexing gain is obtained through the characterization of discrete bandwidth levels associated with MPEG traffic sources. However, its applicability to IP traffic remains unsolved.

Other research works have devised fuzzy-based approaches to overcome traffic model uncertainty [25] [26] [27] [28]. The two approaches proposed in [25] and [27] are, however, not suitable for DVB-S2/DVB-RCS environments as they lack adaptive mechanisms that can enable them to cope with the variable capacity nature of such networks. In [26], Ye et al. proposed a fuzzy-based CAC scheme for wideband CDMA cellular systems. The scheme copes with the dynamic nature of multimedia traffic. It adopts a fuzzy based approach to overcome errors in the estimation of the bandwidth availability. However due to the use of a recursive least square (RLS) predictor to predict the mobile station (MS) mobility information, the computational complexity of the proposed approach renders it not suitable for high speed networks. As a remedy to this issue, Shen et al. proposed, in [28], an intelligent CAC for CDMA systems supporting differentiated quality of service. The scheme uses a recurrent neural network (PRNN) to accurately predict the next-step existing-call interference, and the fuzzy logic theory to estimate the new/handoff call interference. Due to its adaptability, this approach is well suited for high speed communication networks. However, one of its limitations pertains to its focus on congestion in only the uplink; a downlink congestion controller is lacking.

It should be emphasized that most of the assumptions upon which the abovementioned works are based do not or do barely consider the typical characteristics of DVB-S2 networks and the varying channel capacity of their physical layers. Additionally, they do not consider fairness issues either. Furthermore, congestion control is often tackled at the uplink level without taking into consideration possible congestion events at the downlink level that may impact the QoS performances of all active flows traversing the satellite. Finding an adequate remedy to these issues underpins the focus of this research work.

III. W-FCAC: A WEIGHTED-FAIR CAC FOR CONVERGED IP/BROADCASTING NETWORKS

A. Overall architecture

In this paper, we consider a DVB-S2 Geostationary (GEO) satellite with regenerative payload in the downlink that uses DVB-RCS in the return link (i.e., uplink), as described in more details within the IST-funded project IMOSAN[1] [10]. IMOSAN introduces an integrated management solution allowing optimum usage of the satellite spectrum by using the recently adopted DVB-S2 standard [11] as a downlink and DVB-RCS as an uplink. The combination permits the use of a powerful physical-layer channel coding scheme (Forward Error Correction: "FEC") guaranteeing a fairly error-free operation at about 0.7 to 1 dB from the Shannon limit. A specific Adaptive Coding and Modulation (ACM) technique is also adopted. It provides more accurate channel protection to individual terminals or groups of users via dynamic link adaptation to propagation conditions (Fig. 1).

The enhancements we suggest adding to IMOSAN consist in a novel multi-layer optimization using the Satellite Resource Management System (SRMS) coupled with a satellite Weighted-Fair Connection Admission Control scheme (W-FCAC).

The SRMS module manages the satellite network resources. It takes as inputs the channel condition SNIR (Signal to Noise and Interference Ratio) received through the return channel from STs, the service prioritization list, and the average transmission buffer occupancy. If SNIR measurements indicate a change in the satellite channel conditions, SRMS

[1]This work is partially supported by the 6th EU Framework Program for Research and Development 2006-2008, within the IST-IMOSAN project (http://www.ist-imosan.gr).

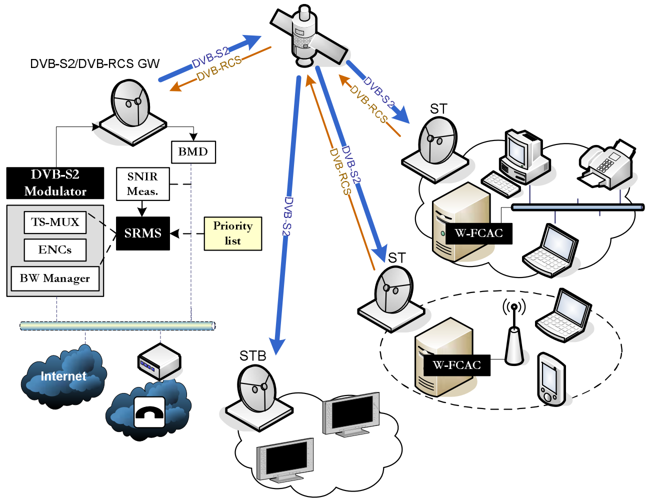

Fig. 1. The overall architecture of the envisioned IMOSAN DVB-S2/DVB-RCS network.

re-calculates the appropriate encoding parameters and the bandwidth requirements for each service or user according to the prioritization list. Afterwards, SRMS issues a signaling message to the Bandwidth Manager (BWM) and to the Multiplexer modules requesting them to perform appropriate adaptation (see [23] for more details). In the same manner, if the mean buffer occupancy exceeds a certain threshold, considered as a congestion indicator, SRMS calculates the connection blocking probability (that depends on the downlink buffer occupation level and the downlink bandwidth consumed by that ST) and sends it to each W-FCAC module.

B. Adaptive fuzzy-based connection blocking decision

The reason beneath the application of the proposed self-configuring fuzzy marker to the problem of connection admission control in converged IP and DVB-S2 networks underlies behind the difficulties in obtaining a precise mathematical model of the network behavior. In fact, fuzzy control focuses on gaining an intuitive understanding of how to best control a plant (or a system) while conventional approaches (e.g., proportional-integral-derivative (PID) [19]) focus on modeling the network and using the deduced model to construct a controller. On the other hand, conventional approaches usually use several control parameters and their effectiveness depends heavily on the setting of these parameters. We tackle this issue by introducing a self-configuring mechanism guaranteeing the parameters consistency in variable network conditions (e.g., connection count, traffic load, and link bandwidth variation).

1) Fuzzy controller design: A key point behind the design of the proposed fuzzy marker, described in more details in our previous work [24], is to keep the router buffer utilization in the vicinity of a targeted value q_{ref} by blocking or accepting new incoming connections. As shown in Fig. 2, the Fuzzy Inference Engine (FIE) dynamically calculates the blocking probability based on two network-queue state inputs: (1) the error on the queue length x_1, which represents the difference between the instantaneous queue lengths q and q_{ref}; and (2) the error variation x_2, which can be interpreted as a prediction horizon. The maximum router queue length B is used to

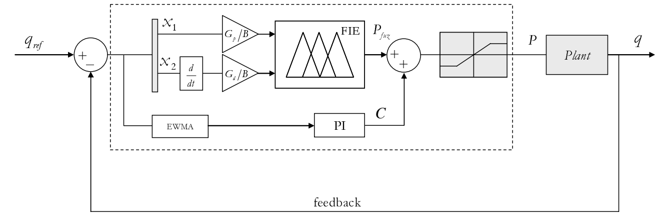

Fig. 2. Adaptive fuzzy-based connection blocking decision.

normalize x_1 and x_2 values making the scheme more robust towards changing configurations.

The parameters G_p and G_d represent the proportional and the derivative gains, respectively. The choice of the gains results in scaling the horizontal axis of the membership functions. Note that choosing a G_p value greater than one uniformly spreads out the membership functions making the control more reactive. This induces a rapid convergence to q_{ref}. However, a significantly large proportional gain yields a faster convergence but renders the system more oscillatory. Furthermore, a small derivative gain impacts the responsiveness of the scheme [17]. Thus, we set G_p and G_d to three and one, respectively ($G_p = 3, G_d = 1$). It should be stressed out that these values are obtained from empirical results and do not change the fundamental performance of the used controller due to the action of the adaptive mechanism introduced below.

As the triangular and trapezoidal shaped functions offer more computational simplicity [25], we have selected them for our inputs variables. We define the inputs universe of discourse and output as $(0 = neg\_smallest, 1 = neg\_very_{l}arge, 2 = neg\_large, 3 = neg\_small, 4 = zero, 5 = pos\_small, 6 = pos\_large, 7 = pos\_very\_large, 8 = pos\_largest)$ and the output as $(0 = zero, 1 = verylow, 2 = verylowplus, 3 = low, 4 = medium, 5 = high, 6 = highplus, 7 = veryhigh, 8 = highest)$.

Note that it is possible to expand the fuzzy marker to use the input rate or loss ratio for example. There may be significant improvements in the performance if this information is represented with the control rules. However, the memory requirements become significant. To ensure the applicability of the CAC algorithm in real time, we do not consider the use of the input rate or loss ratio.

The blocking probability is determined empirically except for the values 0 (smallest) and 8 (largest) that correspond to the minimum (set to zero) and the maximum (set to one) blocking probability, respectively. Thus, we deduce these values for the output P_{fuz} : $(0 = 0, 1 = 0.11, 2 = 0.22, 3 = 0.35, 4 = 0.55, 5 = 0.7, 6 = 0.9, 7 = 0.95, 8 = 1)$.

Based on the inputs parameterization, the output values, and the rules, the blocking probability can be calculated more dynamically compared to conventional approaches.

2) Self-configuring mechanism: Modeling the variation of the Internet's traffic is a complex task. It is thus difficult to design a static fuzzy CAC capable of giving high performance with variable network configurations (e.g., work-load variation, traffic type, etc). The use of a self-configuring mechanism is thus appropriate. One of the most popular approaches is i) to use equally space triangular membership functions and common rules, and ii) then to find a technique to "modify", "tune" or "adapt" them to the plant variation such as the workloads. Several adaptive Fuzzy controllers have been proposed in the recent literature [18]. Most of them require significant resources in terms of memory and computing time. They are thus not applicable to real-time systems where routers handle a significant amount of packets per second.

In our approach, we avoid the membership functions modification in order to use the memory saving scheme [17]. Our proposed scheme simply makes a global translation in the output membership functions. This has a direct impact on the CAC decision robustness when network conditions change as it smoothly adjusts the blocking probability level. The closed loop of our adaptive fuzzy-based connection blocking model is depicted in Fig. 2.

The translation mechanism is achieved using the discrete classical PI controller [20] (see Equation 1). We apply the exponential weighted moving average (EWMA) function as an input to tune our compensation. This permits smooth adaptations which prevent fluctuations of the queue size.

$$C_k = C_{k-1} + k_p(avg_k - q_{ref}) - k_i(avg_{k-1} - q_{ref}) \quad (1)$$

where k_p, k_i, avg_k, and C_k denote the proportional gain, the integral gain, the mean queue length at the k^{th} step, and the PI output at the k^{th} step which represents the compensation blocking decision, respectively. Thus, the blocking decision can be written as follows:

$$P_{block}[k] = \max(\min(P_{fuz}[k] + C_k, 1), 0) \quad (2)$$

The equation above stabilizes the buffer occupancy, during a network congestion event, around the constant q_{ref} that is set to $B/2$. Indeed, P_{fuz} stabilizes the buffer length for a predefined work load. When the work load varies, C_k increases or decreases the blocking aggressiveness in a way that stabilizes the buffer length. This helps to prevent both buffer overflow and underflow while it maintains at the same time confined packet loss rate and bounded delay.

C. W-FCAC algorithm

In this section we present our new CAC algorithm, dubbed Weighted-Fair Connection Admission Control (W-FCAC). This CAC scheme guarantees a weighted fair share of the downlink bandwidth during congestion events while it overcomes four major obstacles by implementing a queue occupancy-based congestion control approach. The first obstacle consists in the link capacity measurement that can not be precisely modeled in wireless networks due to continuous changes in the channel quality (e.g., fading, propagation anomalies, and jamming). The second pertains to the high computational complexity behind flows' characterization (e.g., mean flow mean bit-rate, flow burstiness, etc.) during the admission phase. The third problem relates to the use of traffic descriptors carrying specific information on the traffic pattern. The last difficulty consists in an accurate assessment of the available bandwidth in the context of adaptive physical layer coding and modulation. Overcoming these problems would make the CAC scheme more attractive for a network operator willing to increase its control leverages, and thus the revenues of its underlying resources.

Since in typical geostationary satellite networks (GEO), congestions may occur at both uplink and downlink, our proposed CAC consists of the two following phases: a terrestrial admission control phase that controls the uplink congestion and a satellite phase that controls congestion at downlink through modifying the uplink connection blocking probability. It should be stressed out that the downlink-level congestion control aggressiveness is proportional to i) the DVB-S2/DVB-RCS buffer-occupancy and ii) the STs' bandwidth consumption.

1) Uplink admission control: The objective of this section is to expose the details of the uplink CAC scheme. The proposed algorithm monitors the queue length of the ST's transmission buffer in order to determine if a newly arriving connection can be accepted without congesting the system. The originality of our approach consists in the fact that the admission control functionality is implemented only at satellite terminals with no interactions with the Network Control Centre "NCC". This permits to offload the NCC module in contrast to the approach, proposed by Pace et al. [3], that centralizes the admission control functionality for all STs at the NCC. Therefore, the proposed scheme reduces considerably the signaling traffic between the NCC and satellite terminals, favoring network resource optimization and CAC scalability[2].

Each ST monitors connections at the IP layer. A connection is defined as the flow of packets that share the same destination and source addresses, the same destination and source port numbers, and the same protocol identifiers. Thus, when a new connection is intercepted, the ST estimates the blocking probability following the adaptive fuzzy controller described above.

The blocking probability is adjusted based on past history and the rate of change in the ST queue occupancy error that represents the difference between the instantaneous queue length $q(.)$ and the expected queue length q_{ref}. This allows mitigation of the effects of transient congestion while reacting rapidly to incipient baseline congestion in the system.

The connection admission control scheme decides whether a new connection can be accepted or declined by selecting a random number RN from within the range $[0, 1]$. The connection is accepted if and only if the selected number is larger than the deduced blocking probability $P_{up}(.) = P_{block}(.)$ (see Equation 2); otherwise the connection is buffered or stopped.

In order to maintain high link utilization by minimizing the probability of buffer underflow, we do not block connections when the instantaneous queue length is below a certain threshold min_{th}. Unless otherwise specified, min_{th} is set to $B/10$ throughout this paper. This value is chosen heuristically. Higher values induce buffer overflows and lower values result in high packet drops. It is worth mentioning that the proposed uplink admission control is useful to solve the congestion problem at uplink but it is not sufficient to prevent downlink congestion especially when the uplink channels are in relaxed conditions. Thus, there is a need to control the congestion in the downlink as well in order to avoid situations where QoS

[2]The NCC module still controls the overall bandwidth allocation for each ST's return channel (uplink).

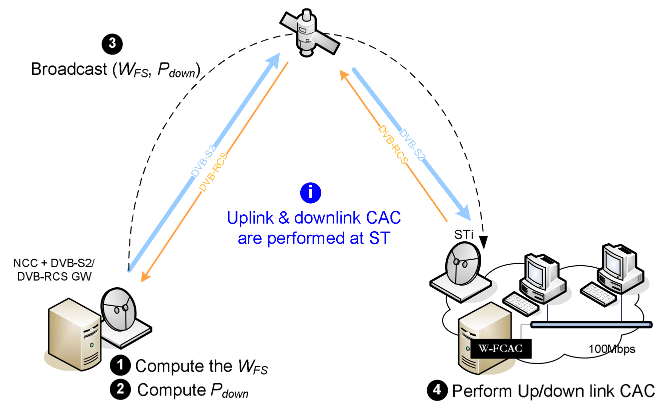

Fig. 3. Communication between the GW and the STs.

(e.g., delay, loss, jitter, etc.) deteriorates due to overflow of GW's buffer.

2) Downlink admission control: The second part of our CAC scheme consists in an adaptive model that enables adjusting the connections blocking probability in response to congestion at downlink. The decision of the connection acceptance is taken, at the ST level, following the evaluation of the DVB-S2/DVB-RCS buffer occupancy (see Fig. 3 for more details). Accordingly, based on the downlink queue state (instead of the uplink queue state), a downlink blocking probability P_{down} is deduced using Equation 2. More specifically, all measurements are carried out at the DVB-S2/DVB-RCS queue level in order to maintain the length of this latter at acceptable values and thus to guarantee acceptable QoS for all users.

Enforcing admission control according to P_{down} prevents congestion at downlink. However, it should be recognized that different STs contribute unequally to the congestion. This means that applying the same blocking probability would rather penalize STs that consume less bandwidth compared to the mean bandwidth fair share (or weighted fair share in our case). It is therefore vital to reflect the consumed bandwidth ratio of each ST in the computation of P_{down} and to derive a blocking probability for each ST.

For a number N of STs, the weighted bandwidth fair share BW_{FS} is obtained as follows:

$$BW_{FS}[k] = \frac{\sum_{i=1}^{N} BW_i[k]}{\sum_{i=1}^{N} W_i} \quad (3)$$

where W_i and BW_i denote the weight and the average consumed bandwidth of the i^{th} ST, respectively. Instead of using the classical average consumed bandwidth, we use the exponential weighted moving average (EWMA) that balances the current measured value in respect to previously measured values. The weight W_i may be appropriately adjusted by the DVB-S2 network operator based on a priori negotiated resource allocation (e.g., SLA).

$$BW_i[k] = (1-\alpha)\ BW_i[k-1] + \alpha\ bw_i[k] \quad (4)$$

The BW_i value is controlled by the parameter that represents a weight given to the instantaneous measured bandwidth . Note that BW_{FS} and the downlink blocking probability P_{down} are periodically broadcasted from the gateway to the terminals using a SNMP-based signaling protocol, as recommended by the ETSI standard EN 301 790 v1.4.1 [12]. Throughout this paper, the period of this transmission is set to three seconds. It should be noticed that larger values for the reconfiguration period may decrease the system's responsiveness to transient congestion; whereas lower configuration values would increase the system's responsiveness but at the price of significant overhead. The general form of the bandwidth ratio of the i_{th} ST can be deduced as follows:

$$BR_i[k] = \frac{BW_i[k]}{W_i\ BW_{FS}} \quad (5)$$

The bandwidth ratio of a given ST (BR_i) may be seen as the level of contribution of the ST to the overall traffic load at the DVB-S2 gateway.

Based on the above formula, we can express the blocking probability of each ST by the following equation:

$$P_i[k] = \begin{cases} \min(\max(P_{down}(BR_i[k])^{\beta}, 0), 1) & \text{if } BR_i[k] > 1 \\ 0 & \text{if } BR_i[k] \le 1 \end{cases} \quad (6)$$

where β is a parameter that controls the blocking probability aggressiveness of the CAC scheme according to the currently consumed bandwidth (i.e. $\beta > 1$). In fact, when a ST_i consumes more than the weighted fair share, BR_i becomes larger than one and P_i consequently increases. Otherwise, all new connections are accepted since the blocking probability becomes equal to null. Finally, the resulted blocking probability is transmitted to the corresponding ST.

The above-mentioned admission criteria guarantees weighted fairness in the bandwidth consumption in the downlink during congestion events. It should be recalled that the downlink congestion control is performed only when the ST uplink is free from congestion. In fact, the uplink congestion control has a direct impact on the downlink congestion since flows are usually initiated from the terminal level as we consider passive users, the most common scenario in satellite networks. Thus, applying downlink and uplink congestion controls, both at the same time, is counterproductive and leads to an aggressive blocking probability which results in poor utilization of the network resources. This is likely to occur since most traffic is based on interactive web-like connections where each uplink flow has a corresponding downlink flow.

IV. Performance Evaluation

Having described the details of our proposed connection admission control scheme W-FCAC, we now direct our focus on evaluating its performance using computer simulations using OPNET 11.5 [14]. W-FCAC is compared to a classical CAC scheme that uses only uplink congestion control (at STs) so as to show the benefits behind using a combined uplink/downlink congestion control. The simulations focus on the abilities of our combined CAC schemes to: (i) quickly react to traffic dynamics that may lead to sudden increase/decrease in the queue occupancy, (ii) adapt to the channel fluctuations

TABLE I
SIMULATIONS PARAMETERS.

Parameter	Value
Downlink capacity over time:	
0-400s	4.0 Mb/s
400-800s	4.5 Mb/s
800-1200s	3.5 Mb/s
ST return channel capacity	800 Kb/s
Number of satellite terminals	3
W_1, W_2, W_3	1
Number of stations per ST	25
k_p	0.0001822
k_i	0.0001816
T	1.0 s
B (MPEG2-TS packets)	1000
α	0.125
β	1.3
Propagation delay (Geo satellite link)	250 ms

(due to ACM feedback loop) and (iii) fairly allocate the bandwidth among the competing STs.

A. Simulation model

In this section, we present the simulation parameters and describe the envisioned network architecture and the test scenarios. Fig. 1 illustrates a typical DVB-S2 network where a gateway is connected to the Internet (FTP servers in the simulation) and handles traffic to different STs via a GEO satellite. Two scenarios are considered in the performance evaluation: a scenario with only uplink CAC and another with both uplink and downlink CAC.

We test the system under homogeneous traffic conditions using heavy FTP sources during 1200 seconds, a duration long enough to capture and study the behavior of our proposed CAC scheme. At the beginning of the simulation, the hosts behind each satellite terminal are activated randomly following a uniform distribution ranging from 60 to 110 seconds. Then, the hosts initiate simultaneous FTP downloads for a period of time ranging from 50 to 60 seconds. At the end of a download session, each host waits approximately for 10 seconds before restarting a new session.

The other key parameters used in the simulations are listed in Table I. Recall that the parameters k_p, k_i, α, and β are lead out from empirical results.

B. Simulations results

1) Downlink congestion control: Figs. 4 and 5 depict the variations of the instantaneous and the average downlink (i.e., at the gateway) buffer length measured when using a traditional uplink CAC scheme and the W-FCAC scheme, respectively. Fig. 4 demonstrates that the conventional CAC scheme maintains only uplink CAC and fails to control downlink congestions during the lifetime of the simulation in contrast with W-FCAC. In fact, as depicted in Fig. 6, the aggregated input rate in case of the conventional approach is substantially higher than the link capacity, leading to several buffer overflows. This has direct consequences on the large buffering delay and the high loss rate experienced in Fig. 8. On the other hand, Figs. 5 and 7 indicate that W-FCAC keeps the queue length around the expected value (500 MPEG2-TS

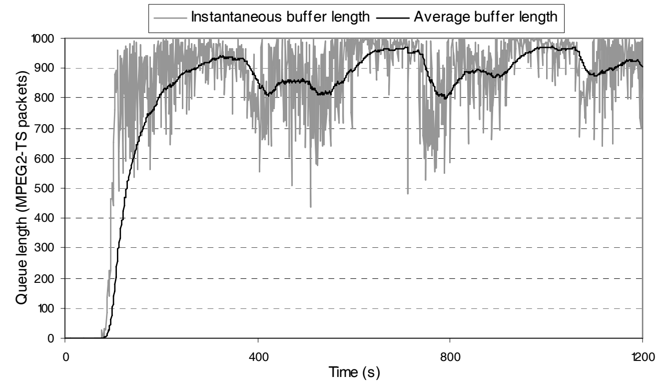

Fig. 4. Variations of the downlink queue length in case of only uplink CAC (MPEG2-TS level).

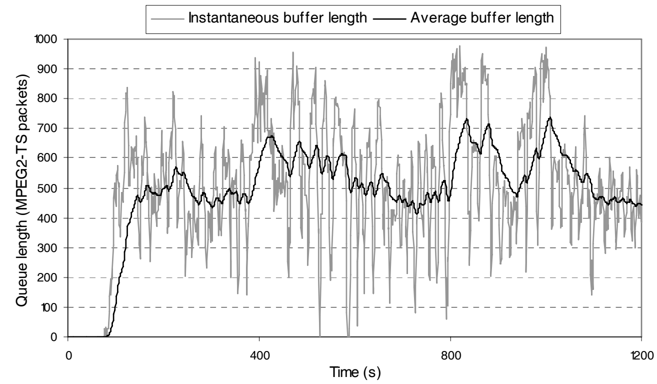

Fig. 5. Variations of the downlink queue length in case of W-FCAC (MPEG2-TS level).

packets) and maintains the input rate almost equal to the link capacity. The efficiency of W-FCAC is particularly noticeable when the link capacity varies at t=400s and t=800s. Indeed, W-FCAC continuously prevents both buffer overflows that impact badly the system by introducing additional delays and packets loss, and buffer underflows that lead to significant bandwidth drops. This shows the resiliency of the W-FCAC scheme to network dynamics. This also shows that the settings of k_p and k_i have a negligible impact on the performance of the proposed algorithm.

Another important observation is that the conventional approach fails to reduce the effects of baseline congestion even when more link capacity becomes available at t=400s due to the adaptive coding and modulation mechanism. Moreover, the conventional scheme exhibits significantly high packet drops during the period t=800s to t=1200s due to decrease in link capacity (Fig. 8). It should be noted that the discard of a MPEG2-TS packet usually results in the discard of a whole IP packet since each IP packet is encapsulated into a ULE (Unidirectional Lightweight Encapsulation) packet and is then fragmented into MPEG2-TS packets. This leads to an important degradation of the goodput due to frequent packet retransmissions. Thus, unlike the conventional approach, W-FCAC prevents network congestion and protects already back-logged flows by offering them sustainable QoS guarantees.

2) Bandwidth Sharing: Figs. 9 and 10 show the average bandwidth ratio received at the IP level (as a function of time)

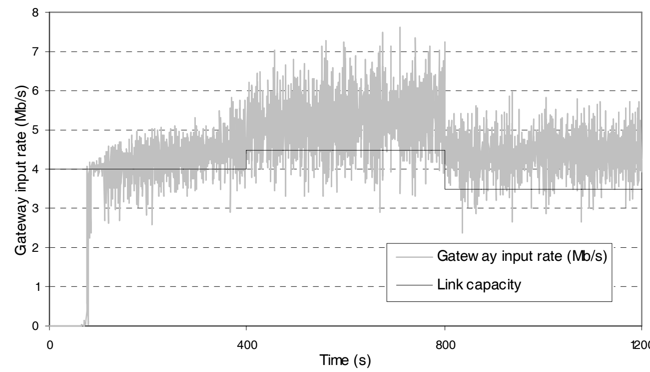

Fig. 6. DVB-S2/DVB-RCS Gateway input rate in case of only uplink CAC (MPEG2-TS level).

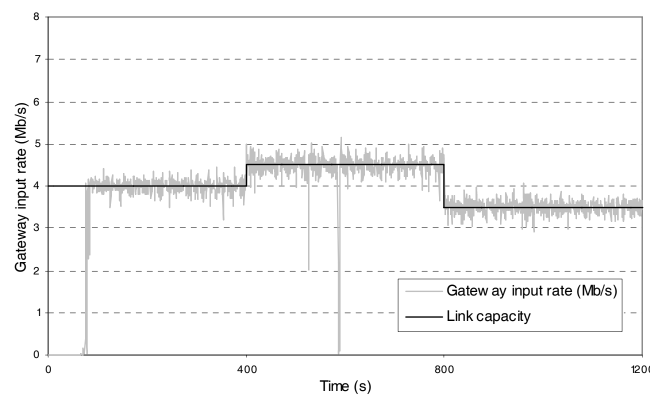

Fig. 7. DVB-S2/DVB-RCS Gateway input rate in case of W-FCAC (MPEG2-TS level).

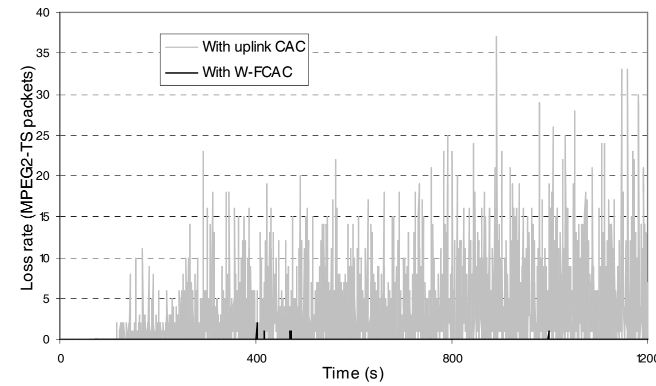

Fig. 8. Loss rate variation in case of only uplink CAC and W-FCAC (MPEG2-TS Level).

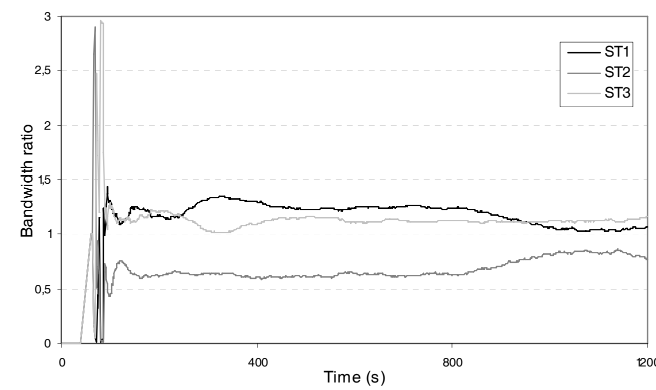

Fig. 9. Average received bandwidth ratio in case of only uplink CAC (IP level).

for different satellite terminals. It is quite obvious from Fig. 9 that handling flows using only an uplink CAC does not guarantee a fair bandwidth sharing among different STs. In fact, the downlink capacity is shared by different STs that contribute with different offered traffic loads. As a consequence, packet drops, upon buffer overflows, are unevenly experienced by all flows regardless their destination STs and their respective downlink traffic load. Certain STs (heavily loaded) may conquer the downlink bandwidth and prevent other lightly loaded STs from gaining further bandwidth. This is clearly apparent in Fig. 9 where ST1 and ST3 monopolize the downlink most of the time (due to their relatively shorter round trip time ”RTT”), although all stations (including ST2) are supposed to receive the same service. Thus, the conventional approach fails to fairly allocate the bandwidth amongst STs except for the period of time t=1050s to t=1200s. However this comes at the price of poor utilization of resources. Indeed, at this stage of simulation almost all flows experience excessive packet drops (Fig. 8). This deteriorates the instantaneous bandwidth of STs as can be seen from Fig. 11. Consequently, the distance between the STs consumed bandwidth decreases at the price of a substantial waste in network resources.

As depicted in Figs. 9 and 10, our combined buffer occupancy and bandwidth consumption-based CAC exhibits a more fair behavior in contrast with the conventional scheme. Indeed, the achieved bandwidth consumption ratio of the different STs is oscillating around the ideal bandwidth fair share (ratio equal to 1) without any waste of network bandwidth. It should be also stressed out that, during the whole simulation, the connection blocking probability of ST2 is always zero as its consumed bandwidth never exceeds the bandwidth fair share. In contrast, the blocking probability of ST1 and ST3 vary frequently, which implies a large oscillation (around the bandwidth fair share) in the consumed bandwidth of the two STs.

3) Goodput: Figs. 11 and 12 indicate another good performance of the W-FCAC scheme in terms of the received data at the application level (i.e., goodput). The poor performance of the conventional scheme is principally due to packet losses, due in turn to buffer overflows that involve frequent packet retransmissions along with their associated signaling messages (downlink bandwidth waste). These packet losses are particularly noticeable in Fig. 11 when the link capacity drops to 3.5 Mb/s during the period of time t=800s to t=1200s. W-FCAC achieves an average application-level data rate (goodput) of 106.5 Kbyte/s per ST while the conventional scheme barely reaches 72.3 Kbyte/s. This corresponds to a 47.3% gain in goodput.

V. Conclusion

In this study, we have addressed both the congestion and the resource-sharing problems in converged IP and broadcasting networks. As a remedy, we have proposed a novel weighted-fair connection admission control scheme, W-FCAC, based on an adaptive fuzzy control approach. The proposed CAC is

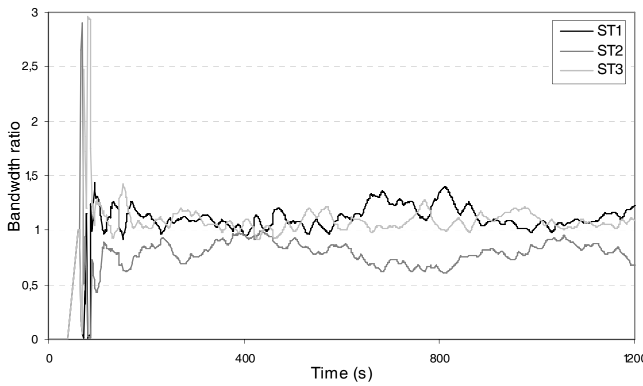

Fig. 10. Average received bandwidth ratio in case of W-FCAC (IP level).

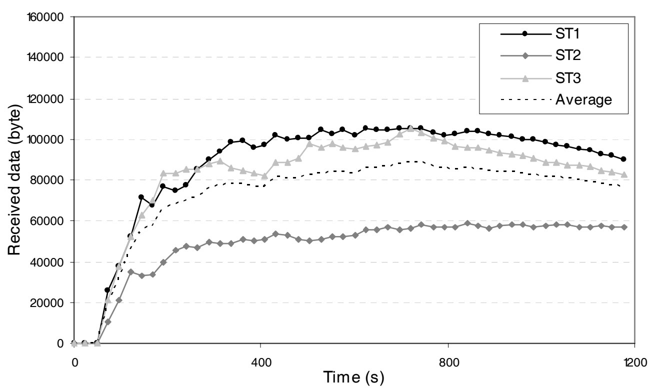

Fig. 11. FTP clients received bandwidth in case of only uplink CAC (Application level).

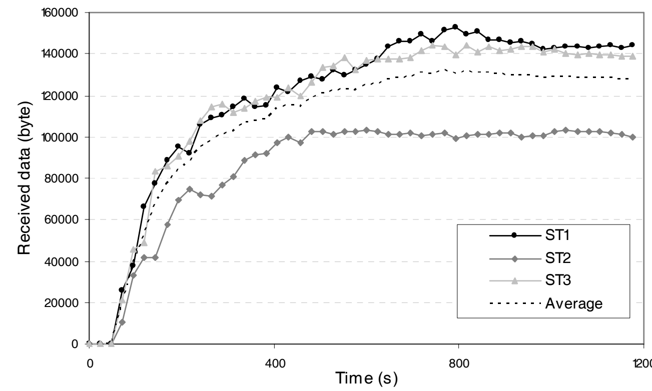

Fig. 12. FTP clients received bandwidth in case of W-FCAC (Application level).

different from conventional methods as it takes into account the asymmetric nature of satellite networks and uses a specific downlink CAC, in addition to the usual uplink CAC. The W-FCAC scheme tracks the occupancy levels of both uplink and downlink queues to enforce two different CAC policies. By monitoring the downlink queue occupation dynamics, the downlink CAC is able to promptly and transparently react to fluctuations in link capacity due to physical-layer adaptive coding/modulation. Further, downlink flows are treated differently based on their destination terminals and their respective bandwidth consumption.

Extensive simulations showed that by controlling the queue occupation level, W-FCAC considerably minimizes the frequency of congestion occurrences and maintains high utilization of wireless channels. Additionally, the scheme simultaneously guarantees a fair share of network resources among competing STs.

Finally it should be stressed out that a cross layer approach in DVB-S2 that couples CAC at the IP level with the bandwidth request functionality at the physical layer should enhance further the performance of the proposed concept. This forms the focus of the authors' future research work.

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