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A Framework for Admission Control Based on Aggregate Traffic Measurements and Network Characterization

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A Framework for Admission Control Based on Aggregate Traffic Measurements and Network Characterization [1]

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Abstract-- **Connection admission control plays an important role in quality of service management for packet-switched networks. It has been recognized recently that measurement-based admission control algorithms are more appropriate for soft real-time services. The contribution of this paper is the presentation of a framework for admission control performed by ingress routers based on aggregate traffic measurements and network characterization. The signaling scheme is based on an extended version of the Session Initiation Protocol. State-of-the-art methods for measurements and aggregate interfering traffic generation are discussed as well.**

Keywords – Admission control, measurements, network characterization.

I. INTRODUCTION

In the past few years, the remarkable success of the Internet has brought to the research community new challenges. Next-generation applications have very different quality of service (QoS) requirements from those for which the Internet was originally designed, specially real-time and interactive video and audio applications. Also, the recent discovery of scaling phenomena in

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modern packet-switched networks ([Lel94], [Pax95a]) has paved the way for new developments in traffic control algorithms. Therefore, ensuring minimum QoS levels to these new applications is an important issue for the evolution of the current Internet.

This paper proposes an admission control framework for the CAC2 domain (see definition on section III) of the Hierarchical Communications Resource Manager (HCRM) environment [Cos02] (see fig. 1), which is an architecture for assuring end-to-end QoS acting only on the access networks. Such architecture considers the scenario of several access networks (ANs), which can include wireless users, interconnected via a high-speed IP-based distribution network (DN), e. g., the Internet, supported by one or more service providers. No assumptions are made about the underlying DN technology, whether it consists of IP routers or label-switching routers, or its capacity to support QoS mechanisms and QoS architectures like Differentiated Services (DiffServ) or Integrated Services (IntServ). Applications that are aware of the HCRM environment are designated as HCRM applications. Otherwise, they are called non-HCRM applications.

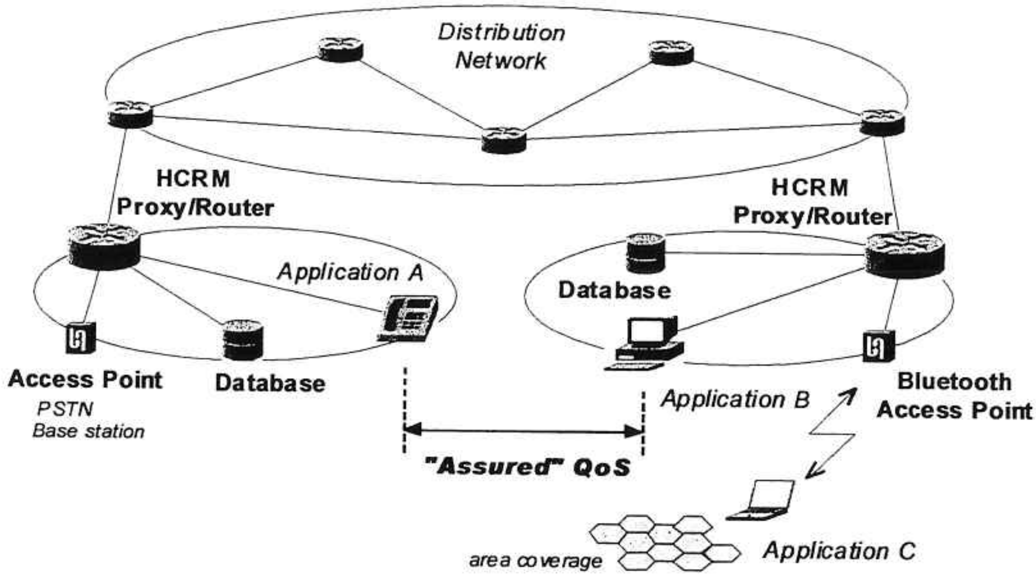

Figure 1: A possible HCRM scenario

Call admission control (CAC) decides whether a new connection is accepted or rejected. The objective of CAC is to ensure a priori that the network will not become congested, thus being a preventive control. In general terms, the CAC decision is based on the anticipated traffic characteristics of the new flow requesting admission, the QoS requirements specified by the application and the current network load. For the purposes of the CAC framework, this work considers the following end-to-end QoS parameters: packet loss rate (PLR), packet delay transfer (PDT), and packet delay variation (PDV).

The goal of this article is threefold. First, a literature survey on measurement-based admission control algorithms is presented. Second, a framework for ingress admission control is proposed. The proposed approach has the ability to take into account the adverse effects of interfering or cross-traffic, i. e., traffic generated by non-HCRM applications, over the admission controller node and upon the DN. This is performed through measurements of aggregate traffic that traverses the ingress router and through network characterization (indirect inference of characteristics of an end-to-end path between a pair of ingress-egress routers from edge-based network measurements), in terms of the estimated parameters for PLR, PDT, PDV, bottleneck bandwidth (BBW) and dynamic available bandwidth (ABW). Also, a new signaling scheme for admission control based on an extended version of the Session Initiation Protocol (SIP) is introduced. Third, state-of-the-art methods for measurements and aggregate interfering traffic generation are discussed.

The remainder of this paper is organized as follows: section II provides a survey of related research in the area of measurement-based admission control algorithms; section III details the HCRM framework for admission control; section IV discusses the topic of network characterization; V summarizes techniques for traffic generation; section VI concludes the paper.

II. LITERATURE SURVEY

Provisioning sufficient network resources to meet the QoS demands of bursty traffic is an important issue for networks that deliver multimedia real-time content. Such task may be performed by a CAC algorithm that is a set of actions taken by the network to decide whether a new flow is accepted or rejected. It is a preventive load control mechanism that protects the QoS requirement for all flows including the newly admitted one.

It has been recently recognized ([Flo96], [Jam97], [Bre00b], and [Qiu01]), that measurement-based admission control algorithms (MBACs) are more appropriate for soft real-time services. MBACs use measurements of existing traffic as a rule for admission control decisions rather than worst-case bounds about traffic behavior and can achieve much higher network utilization than model or parameter-based CACs. However, the utilization of MBACs obviously involves a tradeoff between high network utilization and occasional QoS violations. Traffic measurements are not always optimal predictors of future behavior, and so the measurement-based approach can induce occasional packet losses or delays exceeding the service level agreement. This means that MBACs service commitments can never be absolute and can only be used in the context of service models that do not make guaranteed commitments.

Breslau and Jamin [Bre00b] compared the performance of the following admission control algorithms: Measured Sum (MS), Hoeffding Bounds (HB), Tangent at Peak (TP), Tangent at Origin (TO), Measure CAC (MC) and Aggregate Traffic Envelopes (TE). Each of them has two major buildings blocks: a measurement process that infers the network load, and a decision algorithm to make admission control decisions. These CAC algorithms perform measurements on the aggregate traffic, not on individual flows because soft real-time services are intended to be scalable. The service requests contained a traffic descriptor describing the worst-case behavior of the flow. The traffic descriptor took the form of a token bucket with parameters r and b denoting the token rate and bucket depth, respectively. Should the admission control algorithm required a peak rate P, the peak rate was computed from the token bucket parameters as $P = r + b/T$, where T is the basic measurement interval used by the algorithm. The delivered QoS was measured in terms of packet drops.

In an attempt to balance scalability with QoS, several recent articles ([Gib99], [Bia00], [Ele00], [Kel00], and [Cet01]) proposed the quite new approach of using endpoint admission control, in which the endpoint (can either be a host or an edge router as it is in [Cet01]) probes the network by sending probe packets and no explicit support from the internal network routers is required.

If the endpoint is a host rather than an edge router, it will probe the network at the data rate it would like to reserve and recording the resulting level of packet losses. The host then admits the flow only if the loss percentage is below some threshold value. However, endpoint admission control performed by hosts has serious flaws. The setup delay is substantial, on the order of seconds, which may limit its use for certain scenarios, as it is the case for the HCRM environment. According to [Rie99], a complete description of data network traffic requires understanding of its dynamics over not just large time scales (seconds and larger) but also over small time scales (hundreds of miliseconds and shorter). Also, the utilization and loss rate can degrade to a reasonable extent under high loads even with slow-start probing [Bre00a]. It has to be considered that all endpoints have to probe the network in an uncoordinated fashion, possibly causing a considerable load due to probing in the network, and that a certain host has no way to make inferences of future behavior of network load based on past measurements done by other hosts.

On the other hand, measurement-based admission control accomplished by edge routers is a very attractive solution, because there is the real possibility of making quite reasonable estimates of the properties of end-to-end paths from edge-based measurements [All99], [Rib00]. The approach adopted by [Cet01] and [Sch01] is based on implicit measurements of available service of a passively monitored path between a pair of ingress-egress routers realized at the egress router, whereas [Rib00] proposes an explicit measurement method for the estimation of ABW by means of multifractal modeling of the cross-traffic (all but probe traffic is considered cross-traffic in the sense of that paper).

III. ADMISSION CONTROL

A. Call Admission Algorithm

As depicted in fig. 2, a HCRM router defines two CAC domains. The admission control algorithm for the CAC1 domain, namely CAC1, is responsible to decide if the HCRM domain, where the HCRM applications are located, has enough resources to meet the QoS demanded by incoming, outcoming, and intra-domain flows (the association of an AN and its local HCRM router is called a HCRM domain [Cos02]). On the other hand, the admission control algorithm for the CAC2 domain, namely CAC2, is responsible to decide if both the HCRM router and the DN have the required resources for incoming connections. In both cases, the CAC algorithms must know the resources available in both domains. They also have to cope with cross-traffic. The remainder of this section introduces the CAC2, which is currently under a thorough investigation. The CAC1 is not presented in this paper, however it follows the same idea of CAC2 with some minor modifications.

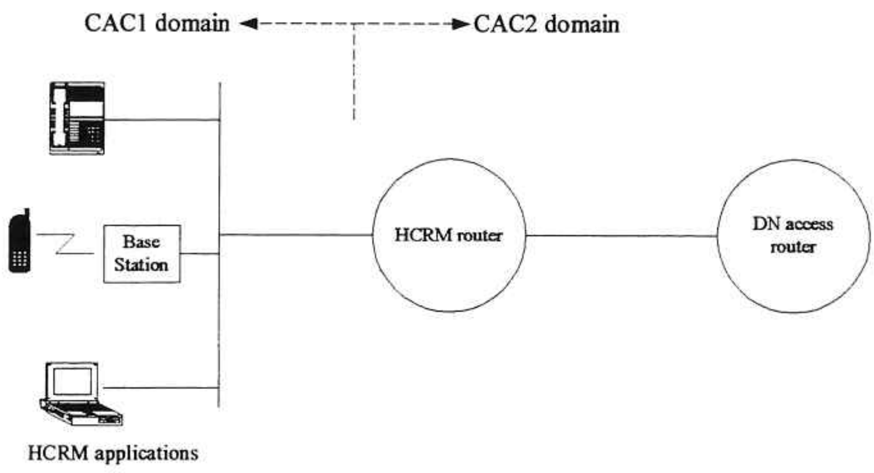

Figure 2: Domains defined by the HCRM router

For CAC2, consider the model depicted in fig. 3. In [Cet01] admission control decisions are made at the egress routers and the key technique is the measurement-based theory of Aggregate Traffic Envelopes (TE) [Qiu99] to accurately characterize and control both arrivals and services in a general way. The referred scheme uses measurements of the maximal traffic envelopes of the aggregated traffic, capturing variability on different time scales. Both the average and variance of these traffic envelopes, as well as a target loss rate, are used as input into the admission algorithm.

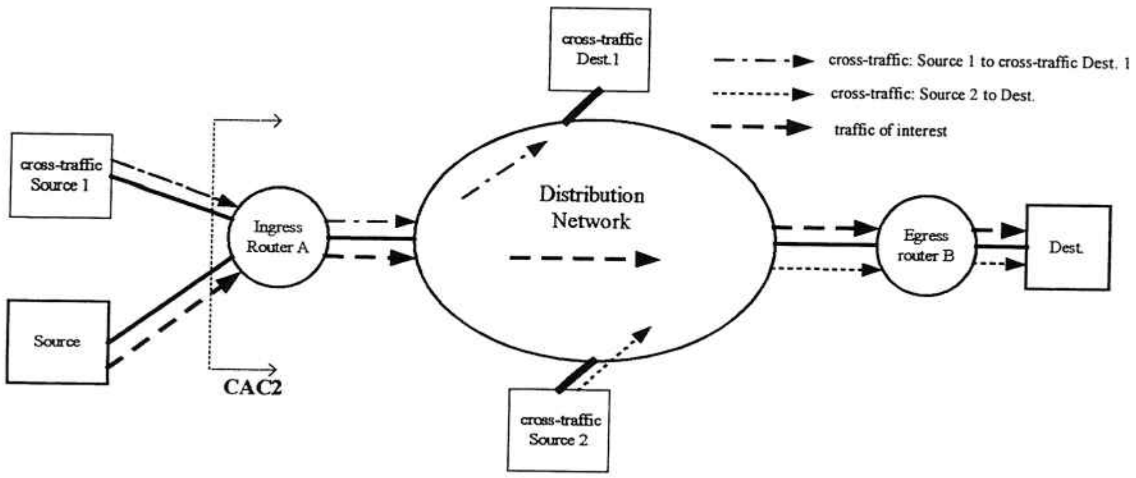

Figure 3: Model for CAC2

In the HCRM environment, the ingress HCRM router (router A on fig. 3) runs the CAC2 based on a characterization of the DN and explicit measurements of the aggregate traffic entering the DN. The measurements are performed over a period called the *measurement period*. Considering $ABW(n)$, $PDT(n)$, $PDV(n)$, and $PLR(n)$ the most recent observed DN's parameters, i. e., those measured over the n-th measurement period, the estimated parameters $\hat{ABW}(n+1)$, $\hat{PDT}(n+1)$, $\hat{PDV}(n+1)$, and $\hat{PLR}(n+1)$ can be forecasted using an Autoregressive Integrated Moving Average (ARIMA) process [Box76] in the following way:

$$\hat{ABW}(n+1) = \alpha_{ABW} ABW(n) + (1-\alpha_{ABW})\overline{ABW}(n-1) \quad (1)$$

$$\hat{PDT}(n+1) = \alpha_{PDT} PDT(n) + (1-\alpha_{PDT})\overline{PDT}(n-1) \quad (2)$$

$$\hat{PDV}(n+1) = \alpha_{PDV} PDV(n) + (1-\alpha_{PDV})\overline{PDV}(n-1) \quad (3)$$

$$\hat{PLR}(n+1) = \alpha_{PLR} PLR(n) + (1-\alpha_{PLR})\overline{PLR}(n-1) \quad (4)$$

Where

- $\overline{ABW}(n-1)$, $\overline{PDT}(n-1)$, $\overline{PDV}(n-1)$, and $\overline{PLR}(n-1)$ are the exponentially weighted moving average over M past measurement periods
- α_{ABW}, α_{PDT}, α_{PDV}, and α_{PLR} are arguments for the linear interpolations

The reader can verify that CAC2, presented as a flowchart in fig. 4, is fairly simple. This simplicity will facilitate future implementations, and it is a significative characteristic of the proposed scheme. It is assumed in fig. 4 that the traffic descriptor is the peak rate P and that the end-to-end QoS objective [Sai94] is divided and allocated between the HCRM ingress router and the DN. Thus, $PLR^{(DN)}$, $PDT^{(DN)}$, and $PDV^{(DN)}$ are the QoS parameters allocated to the DN portion. Similarly, $PLR^{(HCRM)}$, $PDT^{(HCRM)}$, and $PDV^{(HCRM)}$ are the QoS parameters allocated to the HCRM router. The CAC2 first performs a procedure which consists in a set of tests for the DN portion of the CAC2 domain. Those tests consider that the new flow requesting admission, if admitted in the DN, would experience a future performance as the one specified by the estimated parameters $\hat{PDT}$, $\hat{PDV}$, and $\hat{PLR}$. Also, the peak rate is compared to the forecasted $\hat{ABW}$. Should any test fail, admission is denied, otherwise the algorithm continues its processing. If CAC2 concludes that the DN has the required resources, it runs a MBAC algorithm as TE [Qiu01], for instance. For this type of MBAC, the new flow is admitted if it passes in both *schedulability* and *loss probability* tests.

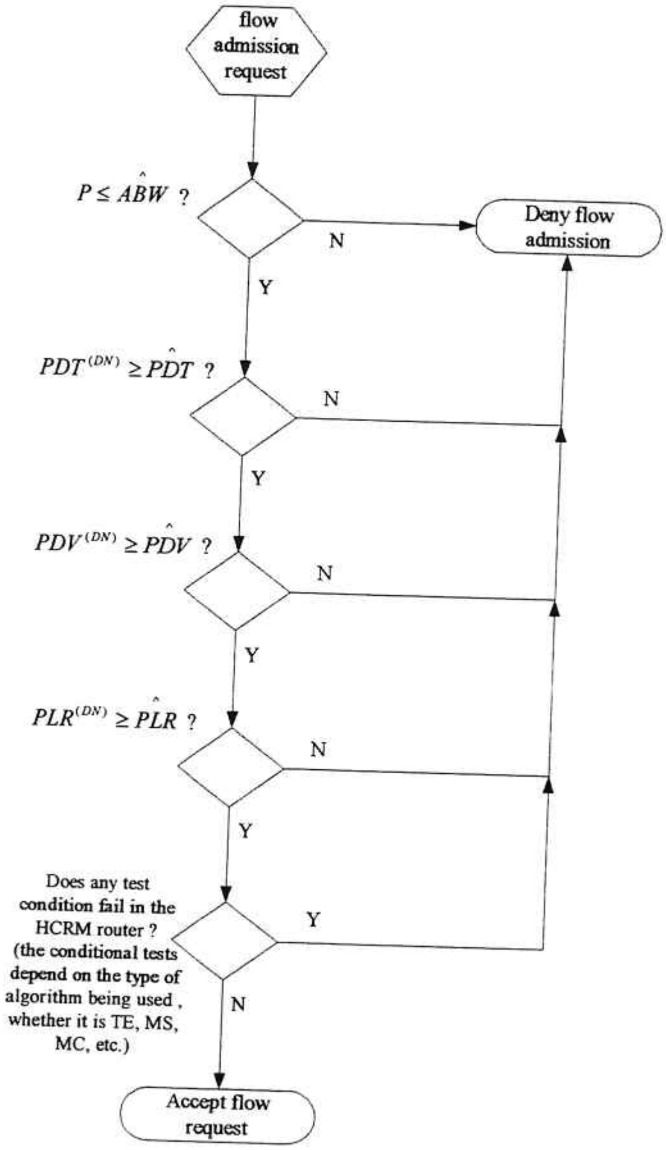

Figure 4: Flowchart of the CAC2 algorithm

B. *Signaling Scheme*

The body of an INVITE SIP method usually conveys the parameters associated to a multimedia session described by the Session Description Protocol (SDP) [Joh01]. The same applies to code "200" (successful) response messages. In order to obtain a meaningful QoS signaling, the sender application must characterize its traffic source in terms of traffic descriptors such as Average

Rate, Peak Rate, Maximum Burst Size, etc., and the receiver application must inform the desired QoS parameters such as PDT, PDV, and PLR.

The user agent client (UAC) has two options for sending request messages: 1) it sends the request to a locally configured SIP proxy server, or 2) it sends the request to the associated IP address and port of the Request-URI (Uniform Resource Indicator). In the HCRM environment, the HCRM-enabled UAC always sends the request to its locally configured SIP proxy server, i. e., the local HCRM router.

In this work, the traffic descriptors and QoS parameters associated to each new requested flow are transported in the *format transport attribute* of SDP and are used by the HCRM routers for admission control. The format transport attribute is specified like:

```
a=fmtp:<format> <format specific parameters>
```

The initial INVITE message conveys the caller capabilities, the QoS parameters associated to the media flows he (or she) desires to receive, and possibly the traffic descriptors of the flows to be sourced at the caller, if the session is expected to be bidirectional as in the case of an audio-conference. The callee's response also contains its capabilities, intended QoS parameters for the received flows and traffic descriptors for the flows he (or she) will send. The HCRM routers run CAC algorithms by the time they receive the callee's response and each of them forwards the response message to the caller over the reverse path. When the CAC denies the admission of a specific flow it resets its associated port number.

In the HCRM environment, the well-known port for extended SIP is 35,000, with UDP as its transport protocol. Fig. 5 depicts the call setup considering two users located at different HCRM domains. Below, the reader can observe a possible INVITE method for the case of fig. 5:

INVITE sip:amazonas@lcs.poli.usp.br SIP/2.0
Via: SIP/2.0/UDP 148.130.220.124:35000
To: Amazonas <sip:amazonas@lcs.poli.usp.br>
From: Alexandre Lima <sip:alima@qos.com.br>
Call-ID: 123456789@work.qos.com.br
CSeq: 1 INVITE
Subject: HCRM

Contact: sip:alima@qos.com.br
Content-Type: application/sdp
Content-Length: XXX

v=0
o=Lima 2880868695 2880868695 IN IP4 work.qos.com.br
s=Meeting
c=IN IP4 148.130.220.124
t=0 0
m=audio 49920 RTP/AVP 0 5 8
a=rtpmap:0 PCMU/8000
a=fmtp:0 PDT=150 PDV=30 PLR=2*10e-2 PR=64k
m=video 0 RTP/AVP 32
a=rtpmap:32 MPV/90000
a=fmtp:0 PR=8M
a=sendonly
m=video 50000 RTP/AVP 31
a=rtpmap:31 H261/90000
a=fmtp:0 PDT=100 PDV=10 PLR=1*10e-3 PR=384k

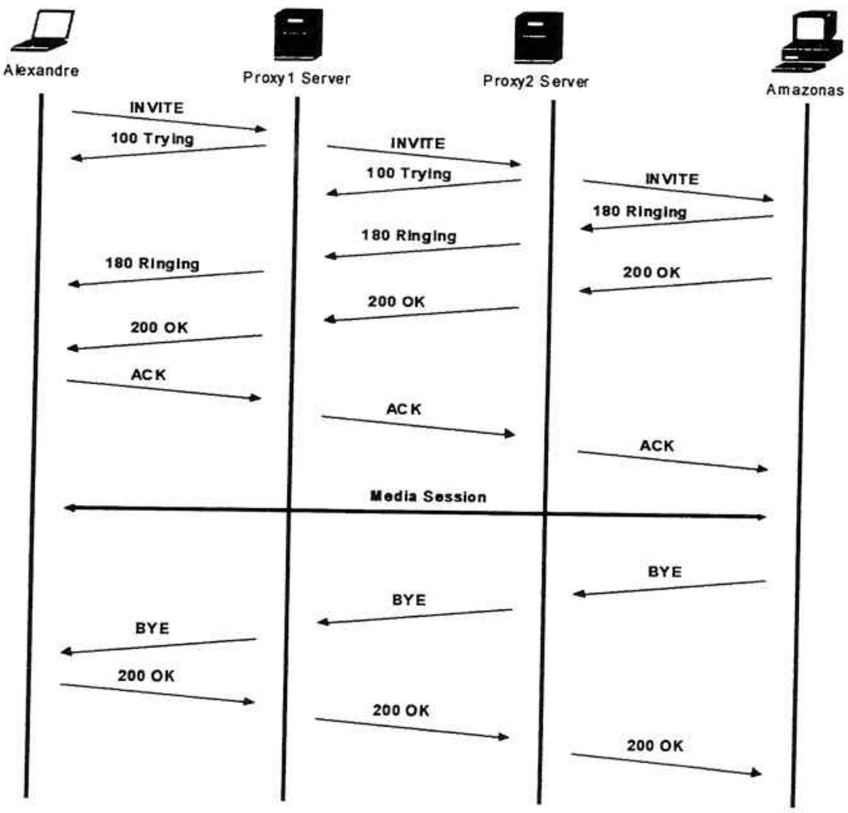

Figure 5: call setup

The SDP body of the INVITE method exemplified above specifies three different media flows:

- A bidirectional PCM μ-law audio flow. The caller requests a maximum PDT of 150 ms, PDV up to 30ms, and PLR less than 2%. Since PCM generates Constant Bit Rate (CBR) traffic, the peak rate (PR) equals the constant rate of 64 kbps.
- A unidirectional video streaming using MPEG-2. The PR is 8 Mbps. None QoS parameters are specified because it is a send-only flow. Also, the port number has no meaning and should be set to zero.
- A bidirectional ITU H.261 video flow. The QoS parameters and traffic descriptor (peak rate) are informed.

An ACK method is issued by the UAC upon reception of the code "200" response message. This ACK must include a SDP body as well, similar to the one conveyed in the INVITE, in order to feedback the UAS with the final media session parameters.

IV. NETWORK CHARACTERIZATION

An accurate network characterization is of fundamental importance because the efficiency of QoS control dramatically depends on the HCRM's ability to faithfully construct real-time estimates of network's performance parameters. In order to obtain a continuous characterization of the DN (located at the CAC2 domain), measurements have to be performed "on the fly" between each pair of ingress-egress HCRM routers since the start up of the system. Each pair of ingress-egress HCRM routers continuosly measures the set of parameters specified by BBW [Cur01], ABW [Rib00], PLR_{est}, PDT_{est}, and PDV_{est}. Although a discussion of the CAC1 domain's characterization is beyond the scope of this paper, it is worth to mention that it follows the same basic concepts that are presented in the remainder of this section for DN's characterization.

Duffield *et al* [Duf01] point out *Multicast Inference of Network Characteristics* (MINC) as a very promising technique for the measurements of PLR, PLT, and PDV. MINC utilizes end-to-end multicast measurements to estimate link-level loss rates and delay statistics by using the inherent correlation in performance experienced by multicast receivers. However, there are two main deficiencies: 1) a significant number of networks does not support multicast, and 2) the internal performance observed by multicast packets often differs significantly from that observed by unicast packets. Duffield *et al* adapted the multicast inference technique proposed in [Cac99] to perform estimation of loss rates using unicast probes. Experiments were conducted using the National Internet Measurement Infrastructure (NIMI) [Pax98] and promising results were achieved. A number of other multicast-based estimators are at disposal for inference of PLT [Pre99] and PDV [Duf00].

For BBW estimates, one can use the packet pair technique, which estimates the path capacity from the dispersion (spacing) experienced by two back-to-back packets. Faithful estimation of ABW is more difficult to achieve. Carter and Crovella created the tool `cprobe` [Car96], which estimates the ABW from the dispersion of trains of eight packets. As showed by Dovrolis *et al* [Dov01], the underlying assumption that dispersion of long packet trains is inversely proportional to the dynamic available bandwidth is not true. More recently appeared the *Delphi* algorithm [Rib00], for inferring the dynamic available bandwidth of a path. This algorithm is based on an efficient exponentially spaced probing packet train and a multifractal parametric model for the cross-traffic that captures its multiscale statistical properties and queuing behavior (multifractal cross-traffic estimation). Delphi is sender based and assumes that the lowest available bandwidth occurs at the bottleneck link, that is, most of the queuing delay that probe packets face is at the bottleneck queue. According to the authors, in a situation where the probe packets are delayed at two queues, Delphi over-estimates the cross-traffic and hence for congestion control purposes is conservative.

Synchronization between the sender and the receiver routers is a must for a highly accurate probing scheme. Such requirement usually demands the use of a GPS system combined with NTP synchronization software. However, it is argued [Pas02] that accurate rate, and not synchronized offset, is the key requirement of a clock for network measurement. Thus, the synchronization method described in [Pas02] will be used in the HCRM routers. In addition, it is very important that measurement probes are sent into the network as soon as possible, so that the probing design remains effective. Such task is possible only on real-time systems. For this purpose, it will be used RealTime Linux, as proposed in [Pas01]. This being so, an inexpensive active probing solution will be utilized.

The common premise for the methods cited so far is that the network offers a best effort service. This fits well in the HCRM environment because no assumptions are made about the underlying DN technology and its capacity to support resource reservations and service differentiation. However, if the DN does implement service differentiation (with DiffServ over MPLS, for instance), the probing scheme has to be adapted in order to estimate end-to-end path parameters to each traffic class separately. In this case, there has to be a service level agreement between the HCRM router and the DN access router.

To the knowledge of the authors, the concept of an edge-based CAC based on explicit measurements of the DN's parameters is original and this is one of the contributions of this article. The basic idea is to view the DN as a "black box" whose parameters can be estimated. It is worth to cite that there are other interesting applications for network characterization like the development of tools for traffic engineering and congestion control algorithms.

V. INTERFERING TRAFFIC GENERATION

The ability to correctly test the HCRM architecture is fundamental given the ambitious overall goal of delivering the best possible QoS for the HCRM aware applications. Testing it on the Internet (or any other DN) is certainly a necessary step, but testing it first in a controlled environment, such as a simulator or a testbed, is certainly a better idea to validate the CAC algorithms. Since HCRM uses a measurement-based CAC approach, it is essential to test it with an interfering traffic that has the same statistical properties of the traffic observed on the Internet.

A lot of previous research has tested models (either through simulation or emulation in a testbed) using simple traffic sources that do not reflect the fractal (self-similar) nature of data traffic that many studies have confirmed ([Lel94], [Pax95a]), or even its multifractal characteristics [Rie97], as confirmed by more recent studies. These characteristics may lead to erroneous conclusions if simpler models are used.

In an effort to generate self-similar traffic, some studies have used a number of independent traffic sources modeled such as Pareto on/off sources or HTTP sessions running simultaneously to achieve an aggregated traffic that resembles some self-similar characteristics. However, these methods have a number of problems, such as non-scalability (since a huge number of sources may have to be running at the same time to generate only one aggregate flow, wasting system resources), generation of "shaped" traffic (due to trace-driven methods, such as described in [Flo01]) that loose their self-similar characteristics, and so on. Hence, there is a need to generate an aggregated traffic in a simple, scalable way, having self-similar characteristics.

A first proposal to efficiently generate such aggregated traffic is presented in [Pax95b]. This paper presents a fast algorithm for generating sample paths of a fractional Gaussian noise (fGn), which is a type of self-similar process. The method is somewhat accurate, and the author still addresses some key issues that must be taken into account when using it for network traffic studies. However, although being fast and simple, a main drawback is its lack of ability to generate multifractal traffic.

A method for generating multifractal traffic is presented in [Rie99], [Rib99]. This is a wavelet-based method that uses a multiplicative structure on the top of the Haar wavelet transform to generate nonGaussian, long-range dependent (LRD) network traffic. The authors show evidence that this model is a much more flexible one, since it is not based only on the Hurst parameter, which is not sufficient to capture the complicated correlation structure of real network processes. Besides, it gives a much better approximation to the queuing behavior of traffic data, compared to

Gaussian models, a feature that is of great relevance when studying the efficiency of CAC algorithms.

However, a complete method for effectively generating traffic contains not only the time-series generation phase, but also the actual traffic generation phase. This is not a problem if one considers generation of background traffic for simulation purposes. But if this traffic is supposed to load a testbed, than practical issues arise. Such issues include scalability to high speed links, transforming the time series as a traffic stream whose measured bit rate matches that of the time series as close as possible, and so on. These issues were addressed in [Vei00], in an attempt to describe a general framework for generation of fractal and multifractal traffic. Once again, one can see that a system running RealTime Linux is a very affordable way of generating this traffic and sending it to the wire very closely to the time series specification.

The literature on MBACs usually avoids discussions related to aggregate traffic generation and this is a serious flaw. Generation of interfering traffic with fractal or multifractal characteristics is a key component in the evaluation of CAC algorithms on both simulation and testbed environments, and this motivated the development of this section. Although a considerable research has been done in the area of self-similar traffic modeling and some significant results have been achieved, Internet traffic modeling remains an open research area.

VI. CONCLUSION AND FUTURE WORK

This paper introduced a framework for the admission control algorithm of the CAC2 domain. CAC2 runs at ingress routers and it is a simple algorithm. The actual complexity of the proposed framework is due to network characterization, which demands advanced mathematical theory and methods in order to achieve accurate inference of network's parameters. The QoS signaling is achieved through extended SIP. The extension is fairly simple: traffic descriptors and QoS parameters associated to each new requested flow are transported in the format transport attribute of SDP. Some of the issues regarding the difficulties in dealing with real-time measurements and traffic generation, as well as the key importance of them to the proposed scheme, were addressed. The future steps of this work include simulation and implementation of the proposed scheme.

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