PLUS-DAC: A Distributed Admission Control Scheme for IEEE 802.11e WLANs

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***Abstract*— The IEEE 802.11e standard provides many mechanisms for Quality of Service (QoS) support at the MAC layer level. However, the service differentiation provided in IEEE 802.11e is not enough to meet the QoS requirements of time bounded multimedia traffic. These can be better satisfied, if we employ Admission Control and Bandwidth Reservation mechanisms. In this paper, we discuss a measurement based distributed admission control mechanism, for the IEEE 802.11e Wireless Local Area Network (WLAN) functioning in infrastructure mode. We call the scheme PLUS-DAC (Priority, Load and Utilization based Scheme for Distributed Admission Control). PLUS-DAC measures the load and utilization in the BSS and adapts the Transmission Opportunity (TXOP) allocation dynamically. Our results show that, PLUS-DAC can achieve quasi-optimal utilization and continue to satisfy QoS guarantees given to multimedia flows.**

***Index Terms*— Quality of Service, Admission Control, Wireless LANs, Enhanced Distributed Channel Access.**

I. Introduction

The IEEE 802.11 standard has become a de-facto standard for Wireless LANs. With the trend of converged networks, the use of WLANs for multimedia communication has also grown. Thus, there is a compelling need for Quality of Service (QoS) provisioning in WLANs. The IEEE 802.11e task group is finalizing work on IEEE 802.11e, a MAC level QoS standard, which can be used to provide service differentiation between traffic classes.

IEEE 802.11e supports a new Coordination function called *Hybrid Coordination Function* (HCF), which includes a contention based channel access known as *Enhanced Distributed Channel Access* (EDCA) as well as a polling based channel access known as *HCF Controlled Channel Access* (HCCA). EDCA extends the *Distributed Co-ordination Function* (DCF) of the 802.11 MAC, by allowing traffic streams to have priorities. The service differentiation is implemented by choosing backoff parameters and inter-frame spaces in such a way as to give one traffic stream priority over the other [1], [2], [3]. We give an overview of IEEE 802.11e in Section II.

For any network that tries to ensure QoS, simply implementing QoS-enabling scheduling algorithms is not enough. *Admission Control* mechanisms are also required, so that the offered load to the network can be kept under control. This is especially true about contention based access mechanisms such as EDCA. At high load, the performance of EDCA degrades considerably, and QoS guarantees of even high-priority traffic may not be met. Thus admission control mechanisms for EDCA are necessary.

Several admission control mechanisms for the 802.11e EDCA have been proposed recently [4], [5], [6], [7]. Xiao and Li [4], [5] have proposed a scheme by which bandwidth is partitioned among traffic categories. Each traffic category is a set of streams in the same priority class. When the bandwidth allocated to a category is used up, no more streams from that category are allowed. We briefly discuss work done so far in admission control for IEEE 802.11e WLANs in Section III. Most of the existing schemes do not give enough attention to bandwidth reservation, which is very much essential for giving QoS guarantees. Another important concern in WLANs is channel utilization, hence any QoS provisioning scheme for WLAN should also try to achieve optimal channel utilization.

In this paper, we propose a mechanism, called PLUS-DAC (*Priority, Load and Utilization-based Scheme for Distributed Admission Control*), which is partly based on the admission control mechanism proposed by Xiao and Li. We specifically address one drawback of partitioning schemes: the static division of bandwidth. When bandwidth is divided statically, often, more bandwidth can get allocated to a category which is currently not offering much traffic to the network, resulting in under-utilization of the bandwidth resources.

For example, the highest priority traffic is generally voice traffic, whose bandwidth requirements with added overheads are less than 100 Kbps (e.g. G.711, G.723 codecs). Even video conferencing applications (H.261 and H.263 codecs) have bandwidth requirements between 100 Kbps to 400 Kbps. MPEG video streams have bandwidth requirements of 1-4 Mbps, but they are generally used for broadcast. As the physical transmission rates of the WLANs are increasing (IEEE 802.11a/g - 54 Mbps), the fraction of bandwidth required by high priority traffic compared to low priority traffic is low, but reserving bandwidth for high priority flows is required for meeting their QoS requirements. However, an approach solely based on priority is not efficient in all the scenarios and will lead to under utilization of the network. PLUS-DAC is a flexible mechanism, which monitors load and priority and continuously adjusts the fractions of bandwidth reserved for each category to reflect actual requirement (Section IV). Our simulation results (Section V) show that PLUS-DAC indeed outperforms static bandwidth reservation-based mechanisms - it is able to admit more streams, while still meeting QoS requirements.

II. IEEE 802.11e

The major enhancement of IEEE 802.11e is *Hybrid Coordination Function* (HCF), which specifies two mechanisms - HCCA (HCF Controlled Channel Access) and EDCA (Enhanced Distributed Channel Access). Details of these can be found in [1], [2], [3]. We briefly review some required background here.

a) TXOP: The IEEE 802.11e introduces the notion of *Transmission Opportunity* (TXOP), which is the interval of time during which a station has a right to initiate transmissions. A TXOP is defined by a starting time and a maximum limit on the interval. TXOP can be obtained by either contention based channel access (called EDCA-TXOP) or controlled channel access.

b) EDCA: EDCA provides service differentiation by introducing the notion of *Access Category* (AC) and parallel back-off entities within each *QoS enabled Station* (QSTA) as shown in Fig 1. There are four different ACs, with priorities from 0 to 3, which are mapped to best-effort, video probe , video and voice traffic respectively. These priorities can be

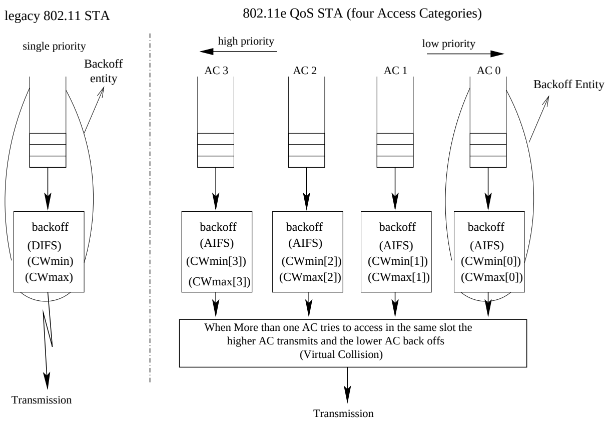

Fig. 1. Queue model in the IEEE 802.11e QSTA

realized by modifying the back-off procedure with EDCA parameter sets. Each back-off entity within a QSTA, which can be thought of as a virtual station, contends for TXOP independently. If the counters of two or more back-off entities reach zero at the same time, the scheduler inside the QSTA resolves this by granting the TXOP to the back-off entity with higher priority (virtual collision).

In IEEE 802.11e, the EDCA parameter values to be used by each of the back-off entities are defined by a centralized coordinator called the *Hybrid Coordinator* (HC) and broadcast via information fields in the beacon frame. This HC is generally co-located with the *QoS-enabled Access Point* (QAP) The default set of EDCA parameters are the *Arbitration Inter-Frame Space* (AIFS[TC]), the *Contention Window* ($CW_{min}[AC], CW_{max}[AC]$) and the *maximum* TXOP (TXOPLimit[AC]).

c) QoS Control: IEEE 802.11e frame header has also been enhanced to allow distribution of QoS Information. Specifically, it contains an additional 2 byte field, called *QoS Control* that, among other things, identifies the *Traffic Category* (TC) to which the frame belongs. The QoS Control field of a frame sent by a non-AP station includes an 8-bit subfield for the *queue size* that specifies the amount of traffic buffered for a given TC, at that particular station.

d) TSPEC: This element contains the set of parameters that identify the characteristics and QoS expectations of the traffic flow. Most of the fields are ported from RSVP, and are optional. The TSPEC parameters include typical QoS parameters such as Mean Data Rate (λ bps), peak data rate (PR bps), delay bound (D μs), maximum burst size (MB bytes). In addition, it defines the following parameters:

- Nominal MSDU Size (L): nominal size of MAC Service Data Units (MSDU), in octets. The size of the MSDU may be fixed and equal to this size, which is indicated by the most significant bit of the field.
- Maximum MSDU Size (M): maximum size of MSDUs belonging to the traffic category, in octets.

III. Admission Control

Although the EDCA mechanism of the 802.11e MAC enables service differentiation for different traffic categories, it can provide QoS only if the load on the network is reasonable. If the traffic on the LAN increases beyond control, QoS guarantees to even high-priority traffic will be violated [3], [4]. *Admission control mechanisms* prevent the network from being congested, by "accepting" or "rejecting" flows depending on whether QoS guarantees can be met.

More precisely, the problem of admission control can be defined as: *Given that there are N[AC] flows of each AC existing in the QoS enabled basic service set (QBSS), determine whether the new flow belonging to a particular AC should be admitted or not. An admitted flow should not affect the guarantees given to the existing flows and should get its own QoS requirements satisfied.*

Any admission control mechanism requires an indicator of the current load on the network, in order to decide whether a new flow can be admitted under the current conditions. However, in the case of distributed media access mechanisms, such as the EDCA, none of the stations may have the knowledge of exact state of the network. Hence, it is necessary to define a notion of available bandwidth, and to devise a frame work for distributing network state information within the BSS.

Several admission control mechanisms have been proposed recently to address these challenges. Pong and Moors [7] use an analytical model based on collision probabilities for the admission control. Choi [8] proposes a centralized admission control algorithm that models a traffic stream by the arrivals of bursts with constant inter-arrival time. Both these schemes use sophisticated admission criteria, but rely heavily on the underlying analytical models, which do not evaluate the IEEE 802.11e standard thoroughly. These models make simplifying assumptions and are prone to approximation errors. Schemes that are more empirical in nature and work only with direct measurements of the state of the network have also been proposed.

Xiao and Li [4], [5] propose a distributed measurement based admission control scheme. This scheme partitions the available time in the beacon interval among different ACs, which forms the *Available TXOP Limit* ($ATL[i]$) for each AC. The algorithm depends on a parameter called $TXOPBudget[i]$, the amount of TXOP that has not been used by an AC $i$in the last beacon interval, which is available for new flows in the current beacon interval. The AP calculates the $TXOPBudget$ for each AC and sends to all the stations through the beacon frame at the start of the beacon interval. If the $TXOPBudget[i]$ is zero, no new flows of AC i are admitted. The $TXOPBudget[i]$ is calculated as follows.

$$TXOPBudget[i] = \max(ATL[i] - TxTime[i] \times SF[i], 0)$$

here $TxTime[i]$ is the transmission time of AC i, and $SF[i]$, the *surplus factor* represents the ratio of over the air bandwidth reserved for AC i to the bandwidth of the successful transmission of the AC. $ATL[i]$ and $SF[i]$ are fixed values to be configured by the administrator at AP.

Consider a scenario in which $70\%, 20\%, 10\%$ of the bandwidth is reserved for voice, video and data traffic respectively. Now let the length of beacon interval is $100ms$, then ATL[3] (voice) will be $70ms$. Suppose that the voice traffic has occupied $20ms$ in the previous beacon interval, then $TXOPBudget$ will be $50ms$.

Xiao and Li's approach [4] essentially performs admission control based on bandwidth requirement. The advantages of this approach are its simplicity, and the absence of any assumptions. However, one drawback is the static partitioning of bandwidth that is implied by the choice of the $ATL[i]$ values that the network administrator has to make, which could lead to under-utilization of the channel. In the next section, we present our approach in which we dynamically select the bandwidth partitioning factor, based on the bandwidth requirement of the traffic categories, as well as their priorities.

IV. PLUS-DAC: Proposed Distributed Admission Control Scheme

In this section, we describe PLUS-DAC, a QAP assisted distributed admission control mechanism. As we have already mentioned, the goal of PLUS-DAC is to maximize the utilization, while simultaneously providing QoS guarantees to high priority traffic.

PLUS-DAC is a scheme similar to upper limit admission control schemes [9], [10], which considers the amount of TXOP that has been utilized by a traffic category in the previous beacon interval as the lower limit on the reserved TXOP. We calculate $TXOP\_Grant[i]$, the excess capacity that could be reserved for each access category by partitioning the unused time in the previous beacon interval based on the *effective weight (*$ew[i]$*)s*. The $TXOP\_Grant[i]$ value defines the upper limit on the reservation for each access category in the current beacon interval. Considering the similar scenario as described in Section III, let total unused time left in the previous beacon interval is $50ms$. Now $TXOP\_Grant[3]$ for the current beacon interval will be $35ms$ (assuming ew[i] is calculated as 0.7).

The effective weight, $ew[i]$ is calculated from other weights namely, *priority weight (pw[i]), load weight (lw[i]) and utilization weight (uw[i]),* which are normalized fractions of the measured values. Through effective weight calculation we give importance to traffic categories which have sufficient load and priority but have not utilized the channel to the required extent.

We first explain how QAP calculates various parameters and how the total available TXOP is partitioned among the access categories. Then we discuss how each QSTA use the information sent by the QAP to make admissibility decisions.

A. TXOP Partitioning and Reservation

The QAP works as a centralized coordinator, which measures the load and utilization in the network and calculates $TXOP\_Grant[i]$ to be allocated to each access category as explained in the algorithm shown in Fig 2.

We define the priority weights as the configurable weights that can be set at the QAP by the administrator depending on the previous traffic profiles. Initially the total available TXOP in the beacon interval is partitioned based on these priority weights.

```
calculate utilization weights();
{ fraction of time used by particular access category to total time utilized in the previous beacon interval
  uw[i] = TX_TIME[i] / Total_TXOP_Used
}
Total_TXOP_Available=Time_in_CP - Total_TXOP_Used
calculate load weights();
{ fraction of time required for queue length of particular access category to total time required by the queues as measured by Access Point
  lw[i] = TX_Load[i] / Total_TXOP_Needed
}
if Total_Time_Needed is Zero then
  for Each Access Category do
    TXOP_Grant[i]=Total_TXOP_Available * pw[i]
    {pw[i] is the priority weight of the Access Category, fraction of Time reserved by the policy controller.
    }
  end for
else
  for Each Access Category do
    ew[i] = pw[i] · ((0.5 + α · lw[i]) / (1 + α · uw[i]))
    TXOP_Grant[i] = Total_TXOP_Available*ew'[i]
    {ew'[i] is the normalized effective weight.}
  end for
end if
```

Fig. 2. TXOP Grant Calculation

The QAP can measure the TXOP utilized by each of the access category (TX_Time[AC]) by looking at the *Duration ID* field in the MAC header of the frames being transmitted in the BSS. We can calculate the total TXOP utilized in the last beacon interval as,

$$Total\_TXOP\_Used = \sum_i TX\_Time[i]$$

We define *utilization weight,* $uw[i]$ as the normalized fractions of the TXOP utilized by the particular access category traffic to total time utilized in the previous beacon interval, which can be calculated as,

$$uw[i] = \frac{TX\_TIME[i]}{Total\_TXOP\_Used}$$

We consider the buffered queue length of each access category at each QSTA as a measure of load, which is transmitted to

QAP, through the *queuesize* sub-field of the QoS Control field in the MAC header. We can calculate the nominal time, $\tau[i]$ required for the transmission of an MSDU belonging to an AC i as,

$$\tau[i] = \frac{MSDU[i]}{R} + t_{ACK} + SIFS + AIFS[i]$$

here $MSDU[i]$ is nominal MSDU size of AC i, t_{ACK} is the time required to transmit an acknowledgment and R is the physical transmission rate.

Let $queue\_length[j][i]$, be the queue length of the AC i, at STA j. We calculate the $TX\_Load[i]$ as,

$$TX\_Load[i] = \sum_j queue\_length[j][i] * \tau[i]$$

The total TXOP needed across ACs can be calculated as,

$$Total\_TXOP\_Needed = \sum_i TX\_Load[i]$$

Now, we define *load weight*, $lw[i]$ as the normalized fraction of TXOP load of a particular access category to total TXOP required to service the load as measured by the QAP. It can be calculated as follows.

$$lw[i] = \frac{TX\_Load[i]}{Total\_TXOP\_Needed}$$

Now, the *effective weight*, $ew[i]$ of each AC is calculated as a function of *load weight (*$lw[i]$*)*, *utilization weight (*$uw[i]$*)*, and *priority weight (*$ew[i]$*)* of the AC as,

$$ew[i] = pw[i] \cdot \left(\frac{0.5 + \alpha \cdot lw[i]}{1 + \alpha \cdot uw[i]} \right)$$

where α is the *balance factor*, which can be set by the administrator, depending on how much importance to be given to load in the network. When a particular priority is not using the TXOP allocated for it, the unused TXOP will be allocated to access categories which have enough load (indicated by a higher $lw[i]$), but not utilized the channel optimally (indicated by lower $uw[i]$) in the last beacon interval. The increase in the α value, enhances this effect. During initialization, the entire TXOP is partitioned based on the priority weights. As and when new flows come into the network the $lw[i]$ of medium and low priority traffic will increase, resulting in an increase in $ew[i]$. When the medium and low priority traffic are getting sufficient TXOP, which can be indicated by the increased uw[i] values, again more weight will be given to high priority traffic. The value 0.5 in the numerator indicates that approximately 50% weight will be given to priority even when the load in the network is negligible.

We estimate the $TXOP\_Grant[i]$ for each AC i at the start of each BI as,

$$TXOP\_Grant[i] = Total\_TXOP\_Available * ew'[i]$$

where $ew'[i]$ is the normalized effective weight. The QAP sends this $TXOP\_Grant[i]$ for each AC i to all the stations as a part of the beacon frame.

B. Distributed Admission Control at each QSTA

Each of the QSTA notes the announced $TXOP\_Grant$ at the start of each beacon interval. We can estimate $\Delta[i]$, the nominal TXOP required by a new flow belonging to AC i, from the Traffic Specification negotiated. The nominal TXOP required for a traffic stream can simply be calculated as,

$$\Delta[i] = \frac{\lambda[i] \times T_{Beacon}}{R}$$

where $\lambda[i]$ is the arrival rate, T_{Beacon} is the length of beacon interval and R is the PHY transmission rate.

Thus a request for a new flow belonging to AC i can be admitted if the following inequality is satisfied.

$$TXOP\_Grant \geq \Delta[i]$$

Note that we are assuming that there may not be more than one flow arrival of each category in a beacon interval. Even if occasionally multiple flows arrive, the effect will not be severe as the $TXOP\_Grant[i]$ value will be immediately adjusted in the next beacon interval, with decrease in unused time. If $TXOP\_Grant[i]$ is not sufficient, no new QSTA can gain transmission time for AC i, and all the existing QSTAs continue to use the allocated TXOP. Thus the guarantees given to existing flows are protected.

V. Simulation and Results

In this section we study the performance of PLUS-DAC scheme in comparison with, the static admission control scheme that gives max channel utilization and pure EDCA with no admission control. We have implemented the PLUS-DAC mechanism in *ns-2* [11]. The FHCF ns-patch [12] is extended to support the admission control.

A. Traffic Description and Simulation Scenario

The design of the network we have considered in our simulation follows the conventional approach. Our topology consists of several wireless stations and an access point. The QAP serves as a direct sink for all the flows from various stations. Each station can have a high priority exponential on-off audio flow $(64Kb/s)$, a H.261 VBR video flow $(200Kb/s)$ with medium priority, a CBR MPEG video flow $(3.2Mb/s)$ with medium priority and a low priority poission data traffic $(1000Kb/s)$. The traffic streams are described in TABLE I.

TABLE I
Description of Traffic streams

Application	Arrival Period(ms)	Packet Size (bytes)	Sending rate(Kb/s)
Audio	4.7	160	64
H.261 video	26	660	200
MPEG4 video	2.5	1000	3200
Data	12	1500	1000

The MAC and PHY parameters used for the simulation are given in TABLE II. We mapped the traffic streams to three access categories: voice (AC 3), video (AC 2), data (AC 0). We have the following parameters: $AIFS[3] = 25\mu s$; $AIFS[2] = 25\mu s$; $AIFS[0] = 34\mu s$; $CW_{min}[3] = 7$; $CW_{min}[2] = 31$; $CW_{min}[0] = 127$; $CW_{max}[3] = 15$; $CW_{max}[2] = 63$; $CW_{max}[0] = 1023$; beacon interval is $500ms$.

We have considered various scenarios to test the proposed mechanism, but due to space limitations we include the results of only one scenario here. In this scenario, we have simulated audio and video traffic over a duration of 200 seconds. We have 20 audio, 20 H.261 VBR video flows and 15 CBR video flows. Audio and VBR flows start at 0 seconds and

TABLE II
PHY AND MAC PARAMETERS

SIFS	16 μs	MAC header	38 bytes
DIFS	34 μs	PLCP header	4 bits
Slot Time	9μs	Preamble	20 bits
PHY Rate	54 Mb/s	Min. bandwidth	24 Mb/s

new flows arrive periodically every 5 seconds till 50 seconds, then from 50 seconds to 100 seconds there are no new flows, and again from 100 seconds to 150 seconds the flows come in periodically. CBR video flows arrive periodically from 0 seconds to 150 seconds every 10 seconds. The priority weights are : $pw[3] = 0.7$ and $pw[2] = 0.3$, and balance factor selected for this scenario is 1;

B. Results and Discussions

We compare the three schemes: 1) pure EDCA, 2) EDCA with static admission control (SDAC), and 3) EDCA with PLUS-DAC. We have studied latency, bandwidth characteristics of different kinds of traffic with parameters such as, mean latency per stream, mean jitter per stream, packet loss ratio, throughput per stream, and total throughput per category. For a good quality multimedia service, unidirectional latency should be less than $150ms$ and packet loss should be less than 5%. The LAN component of these requirements should be more stringent. We can observe from the results that PLUS-DAC performs better and achieves quasi-optimal channel utilization in various situations.

e) ew[i] variation: As we can observe from Fig 3, the ew[i] value for voice is slightly decreased and gradually became constant giving importance to priority. In case of CBR video the value increased with increase in the load and stabilized once it accepted enough flows, resulting in better utilization of the channel. As for VBR flows, the requirement and priority weights are both low, ew[i] is almost constant.

f) Audio: Fig 3 show the latency characteristics of the different schemes. As we can observe, the latency characteristics of PLUS-DAC and SDAC are almost similar, and are well with in the QoS limits of the flows($< 0.5ms$). Even the latency and jitter experienced by EDCA alone is not very high ($< 3ms$), this is because audio flows are of highest priority and the bandwidth requirements are very less compared to other flows. For the same reasons, the schemes hardly differ in their throughput characteristics.

g) VBR Video: Fig 4 shows that PLUS-DAC achieves better utilization than the SDAC, though there is no difference in per stream throughput, SDAC accepted only half as many flows as that of PLUS-DAC leading to under-utilization. Through EDCA achieves the throughput by accepting all the flows, it started dropping packets from 100 seconds onwards.As we can observe from Figure 4, the latency experienced by pure EDCA without admission control is very high compared to admission control schemes.

h) CBR video: As we can observe from Fig 5, PLUS-DAC performs far better in case of CBR MPEG flows, which have significant bandwidth requirements. We can observe that EDCA is completely unacceptable for MPEG video transmissions, since mean latency is more than 100ms and packet loss is more than 10% even at low to medium load conditions. Admission control schemes have better latency characteristics, by admitting fewer flows and preventing heavy collisions due to overload. SDAC has admitted only one CBR flow leading to under utilization of the channel, whereas PLUS-DAC admitted four flows achieving better channel utilization, while still meeting the latency requirements similar to SDAC.

VI. CONCLUSION

In this work we have evaluated the performance of distributed admission control based on the upcoming IEEE 802.11e standard. We have shown that admission control is necessary to support real time traffic and given an overview of the features that can be used to support admission control in IEEE 802.11e standard. Our simulation results have shown that TXOP reservation and attention to load in the network are necessary. PLUS-DAC is able to achieve significant improvement in the channel utilization while satisfying the QoS guarantees of the real time traffic simultaneously.

The focus of our future work includes extending PLUS-DAC to integrate with HCF controlled channel access (HCCA). The policing and scheduling of packets at each station can be done by deferring the channel access to misbehaving flows in a manner similar to that of virtual collision.

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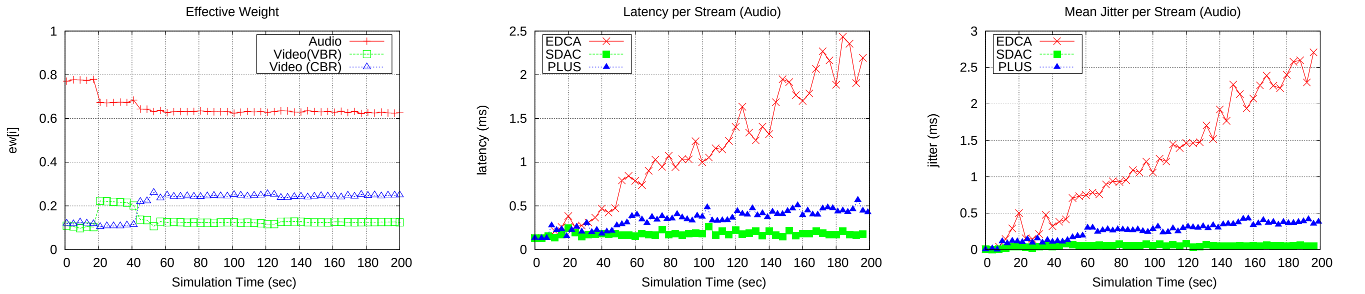

Fig. 3. Variation of *ew[i]* and Audio latency characteristics

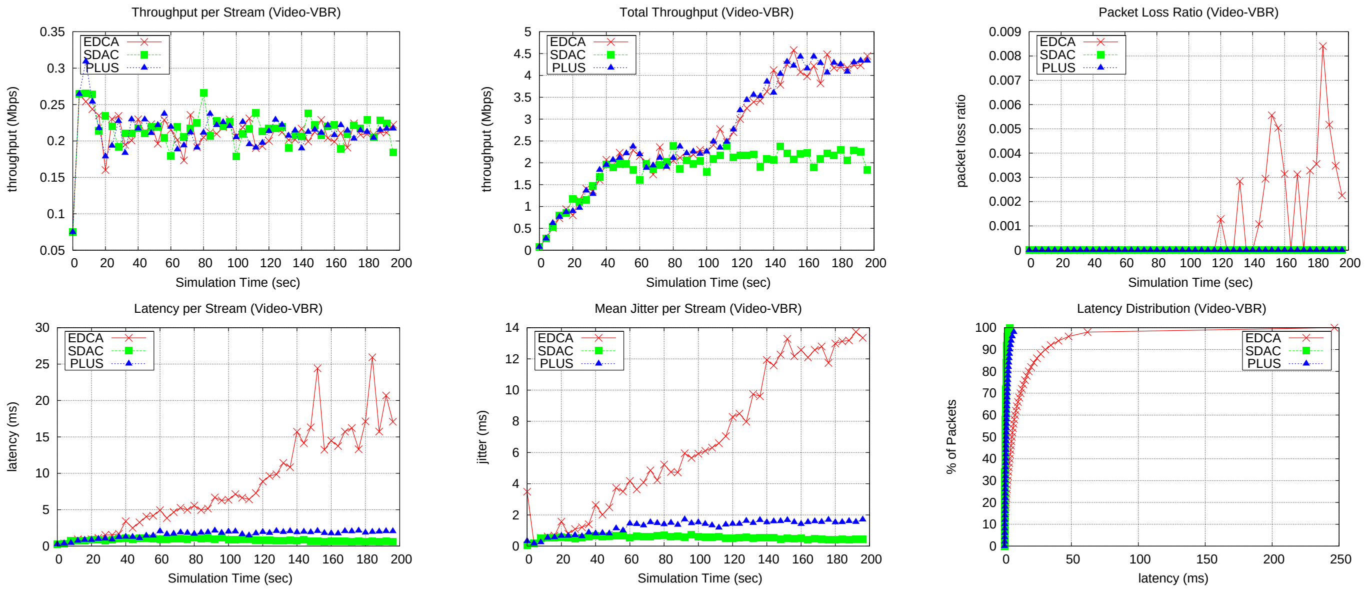

Fig. 4. VBR throughput and latency characteristics

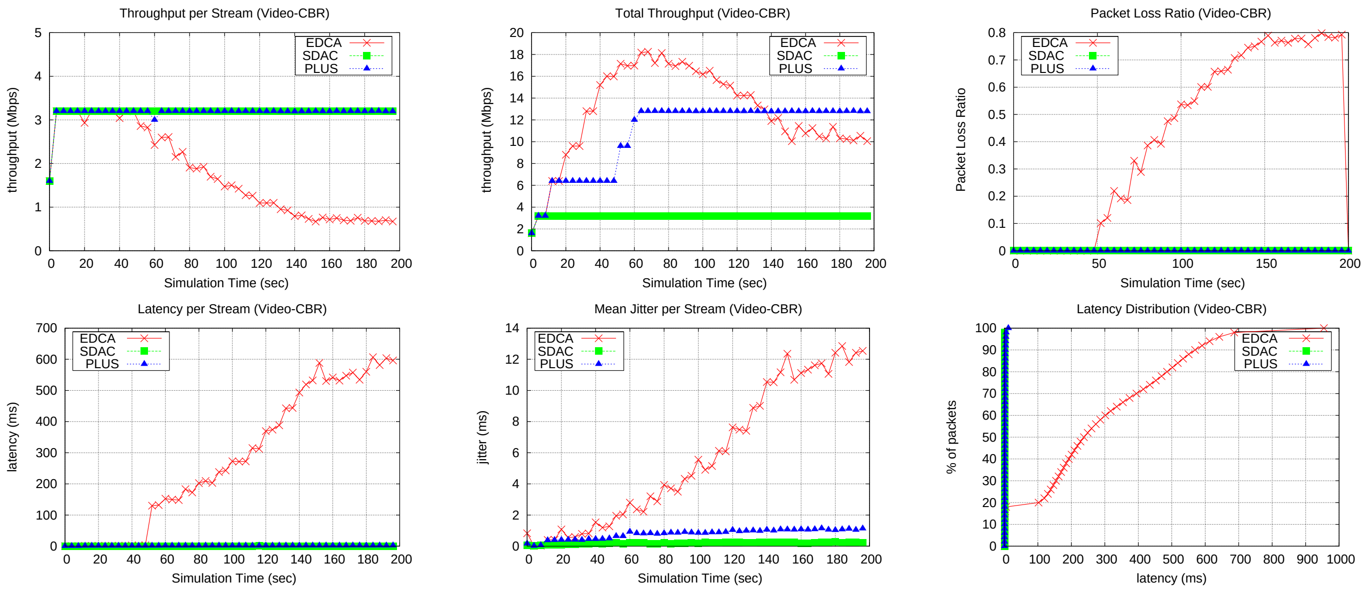

Fig. 5. CBR throughput and latency characteristics

EDCA: Enahanced Distributed Channel Access; **SDAC:** Static Distributed Admission Control; **PLUS:** PLUS-DAC;