

## Feasible HCCA Polling Mechanism for Video Transmission in IEEE 802.11e WLANs

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**Abstract** IEEE 802.11e standard defines two Medium Access Control (MAC) functions to support Quality of Service (QoS) for wireless local area networks: Enhanced Distributed Channel Access (EDCA) and HCF Controlled Channel Access (HCCA). EDCA provides fair prioritized QoS support while HCCA guarantees parameterized QoS for the traffics with rigid QoS requirements. The latter shows higher QoS provisioning with Constant Bit Rate (CBR) traffics. However, it does not efficiently cope with the fluctuation of the Variable Bit Rate (VBR) video streams since its reference scheduler generates a schedule based on the mean characteristics of the traffic. Scheduling based on these characteristics is not always accurate as these traffics show high irregularity over the time. In this paper, we propose an enhancement on the HCCA polling mechanism to address the problem of scheduling pre-recorded VBR video streams. Our approach enhances the polling mechanism by feed-backing the arrival time of the subsequent video frame of the uplink traffic obtained through cross-layering approach. Simulation experiments have been conducted on several publicly available video traces in order to show the efficiency of our mechanism. The simulation results reveal the efficiency of the proposed mechanism in providing less delay and high throughput with conserving medium channel through minimizing the number of Null-Frames caused by wasted polls.

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## 1 Introduction

Recently IEEE 802.11 has become one of the massively deployed technology in the residential and public places such as apartments, stock markets, campuses, airports, etc. Due to some of its key features like deployment flexibility, infrastructure simplicity and cost effectiveness, there has been a recent trend toward providing an ubiquitous wireless access environment. This tendency leads to the presence of many multimedia applications with various traffic characteristics. In the future, it is widely expected that next generation wireless networks will be carrying a large portion of encoded video streams, two-third of all traffics in the networks will be video by 2017 according to Cisco Visual Networking Index [1]. IEEE 802.11 WLANs [2] were designed for the transmission of the best effort services which are no longer sufficient to meet the vast growth of time-bounded services that require rigorous QoS requirements such as channel bandwidth, delay and jitter [3,4]. Since MAC layer functions are not QoS-oriented, guaranteeing QoS in a such layer has become a challenging task. IEEE 802.11 Task Group E (TGe) has presented IEEE 802.11e standard to improve the QoS support of multimedia streaming over WLANs.

The IEEE 802.11e introduced differentiated QoS services through a novel Hybrid Coordination Function (HCF) which is included into the recent standard, released on 2007 [5]. A new revised version with technical enhancements on MAC and Physical layer has been launched on 2012 [6]. The HCF promotes the channel access modes of IEEE 802.11, Distributed Coordination Function (DCF) and Point Coordination Function (PCF) into EDCA and HCCA respectively. EDCA provides prioritized QoS support by defining multiple Access Categories (ACs) with AC-specific Contention Window (CW) and Arbitration Inter Frame Space (AIFS) to identify different levels of priority. QoS is achieved through classifying delay-sensitive application such as video and voice into the highest priority ACs so they experience smaller backoff times. However, EDCA mechanism is unsatisfactory for supporting real-time applications with rough QoS requirements, especially in heavily loaded networks, where collision possibility is high. Recently, a number of efforts have been presented to discuss the deficiency of supporting QoS in EDCA mode such as [7, 8, 9].

In HCCA, parameterized QoS support is achieved through scheduling QoS-enabled Stations (QSTAs) traffics in a The Basic Service Set (BSS) based on their negotiated QoS with the Hybrid Coordinator (HC) which is usually collocated with the Access Point (AP). Newly joined QSTAs are admitted to the system, asserting that previously admitted services are not jeopardized. HCCA is promising scheme for supporting QoS for delay-constrained applications such as VoIP and video streams compared to its counterpart (EDCA). This is due to the fact of eliminating the backoff counter overhead and the

collision caused by the hidden node which is inherent in distributed access mode.

Although, the reference HCCA schedules traffics upon their negotiated QoS requirements in the first place, it is only efficient for CBR applications such as CBR G.711 [10] audio streams and H.261 [11] video (MPEG-1). However, it is not convenient to deal with the fluctuation of the VBR traffic such as H.263 [12] video streams and G.718 [13] audio traffic, where neither the packet size nor the packet generation time is constant. This consequently leads to a remarkable increase in the end to end delay of the delivered traffics and degradation in the channel bandwidth utilization as well.

The HC which resides in QoS-enabled Acces Point (QAP) maintains separate queues for the downlink traffic streams while the uplink streams are maintained in QSTAs' queues. For this reason, the HC can allocate time resources for its queues easily, yet it is unable to predict the amount of the VBR uplink traffics due to the fact that it is physically separated from the QSTAs. Several mechanisms such as [14, 15, 16] have been recently proposed to remedy the deficiency of the HCCA reference scheduler in supporting QoS for VBR video traffics. However, these enhancements still not sufficient to cope with the fast fluctuating nature of high compressed video applications due to the difficulty of accurately predict the VBR traffic profile. Recently, [17] presents a multi-polling approach to enhance the QoS provision of the VBR videos that show variability in packet size with fixed packet inter-arrival time such as MPEG-4.

With the increase of Internet web applications in the wireless mobile devices, the User-Generated Content (UGC) such as pre-recorded video streams have become more prominent nowadays. To the best of our knowledge, the scheduling of uplink pre-recorded continuous media in HCCA has not been addressed efficiently despite the fast growth of uplink streams of the UGC on the Internet such as pre-recorded video streams. In this paper, we present an enhancement on the HCCA polling mechanism. The proposed mechanism adjusts the legacy polling based on the feedback information sent to the HC in order to accommodate to the fast changing of the VBR traffics which show variability in packet generation interval such as H.263 streams. This mechanism makes use of the queue size field of QoS data frame in the MAC header of the IEEE 802.11e to carry this information to the HC, this is discussed in details in Section 3.

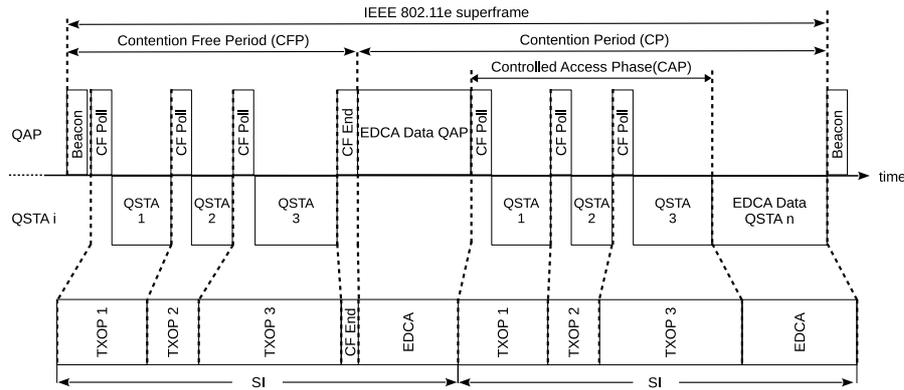
The rest of this paper is organized as follows: Section 2 explains the reference HCCA mechanism and demonstrates its deficiency in supporting VBR Video streams and discusses some enhancements on its polling mechanism. Section 3 explains the proposed algorithm. The performance evaluation and discussion is presented in Section 4. Section 5 concludes the study presented in this paper.

## 2 Background and Related Work

In this section, the reference scheme of the IEEE 802.11e HCCA along with some characteristics of the VBR video application are reviewed. The deficiencies of HCCA in supporting VBR and some related work in enhancing its performance are also discussed.

### 2.1 IEEE 802.11e HCCA Mechanism

In IEEE 802.11e, a beacon is transmitted periodically to all stations in the BSS for synchronization purpose. The time between two subsequent beacons forms a so-called superframe. Service delivery occurs during the superframe in two periods, Contention Free Period (CFP) and Contention Period (CP). A station shall transmit its traffics within a duration of time called Transmission Opportunity (TXOP) which is a time duration reserved for a QSTA to deliver its MAC Service Data Units (MSDUs). The TXOP obtained via contention-based access referred to EDCA-TXOP, while in controlled medium access the TXOP granted to the QSTA by the HC so that it called polled TXOP. Figure 1 illustrates an example of the alternation of one controlled medium access followed by a contention-based period with one QAP and three QSTAs. Note that the controlled medium access not only occur during the CFP



**Fig. 1** Example of an 802.11e Superframe, Optional Contention-free Period and Contention Period

but also during the CP when the medium is sensed idle for a period of PCF Inter Frame Space (PIFS). For this reason, supporting QoS in HCCA mode is improved compared to its ancestor, PCF, where the controlled transmission only occurs during CFP. The station in HCCA mode can only transmit its data packets for a duration declared in the poll frame.

## 2.2 Reference Design of HCCA

When a QSTA desires to deliver its real-time Traffic Stream (TS) during the contention free phase it sends an ADDTS-Request to the QAP declaring its desired QoS requirements for the particular TS. The required QoS parameters are carried in the traffic specification TS Specification (TSPEC) fields. Accordingly, QAP will try to satisfy these requirements with an attempt to conserve the QoS of the already admitted flows. The accepted ADDTS-Request will be replied by an ADDTS-Response and the particular station will be added to the polling list in the QAP. A list of the mandatory TSPEC parameters is presented in Table 1.

**Table 1** TSPEC and Scheduling Parameters Symbols

Symbol	Unit	Description
$\rho$	bit/sec	Mean Data Rate
$L$	bytes	Nominal MSDU Size
$M$	bytes	Maximum MSDU Size
$D$	sec	Delay Bound
$SI$	sec	Service Interval
$mSI$	sec	Minimum Service Interval
$MSI$	sec	Maximum Service Interval
$R$	bit/sec	Physical Transmission Rate
$BI$	sec	Beacon Interval
$O$	sec	PHY and MAC Overhead
$N$	Number	Number of packets
$T$	sec	Superframe duration
$T_{CP}$	sec	Contention-based duration

Upon receiving an ADDTS-Request from a QSTA, the HCCA reference scheduler goes through the following steps:

1. *SI Assignment*

In the HCCA reference scheduler, Service Interval (SI) is computed as a submultiple of the beacon interval  $BI$  which is the minimum of the maximum SIs for all previously admitted traffics including the incoming traffic as shown in Equation (1)

$$SI = \frac{BI}{\left\lceil \frac{BI}{MSI_{min}} \right\rceil} \quad (1)$$

where  $MSI_{min}$  is calculated in Equation (2)

$$MSI_{min} = \min(MSI_i), i \in [1, n] \quad (2)$$

and  $n$  is the number of admitted QSTAs' traffic streams and  $MSI_i$  is the maximum  $SI$  of the  $i^{th}$  stream.

### 2. TXOP Allocation

HC allocates different TXOP to each admitted station so as to transmit their data with respect to the declared TSPEC parameters. This TXOP is calculated for each station as follows:

Firstly, for the  $i^{th}$  station, the scheduler calculates the number of MSDUs that may arrive at  $\rho_i$  as in Equation (3) :

$$N_i = \left\lceil \frac{SI \times \rho_i}{L_i} \right\rceil, \quad (3)$$

where  $L_i$  is the nominal MSDU for the  $i^{th}$  station. Then the TXOP duration of the particular station,  $TXOP_i$ , is calculated as the maximum of the time required to transmit a number  $N_i$  of MSDUs or time to transmit one maximum MSDU at a physical rate  $R_i$ , as stated in Equation (4):

$$TXOP_i = \max \left( \frac{N_i \times L_i}{R_i} + O, \frac{M}{R_i} + O \right) \quad (4)$$

where  $O$  is the overhead, including MAC and physical headers, Interframe Spaces (IFSs), the acknowledgment and poll frames overheads.

### 3. Admission Control

Admission Control Unit (ACU) manages the admission of the TSs with insuring that the QoS of the already admitted TSs is maintained. When a new TS demands an admission, the ACU : 1) obtains a new  $SI$  as shown in step 1 and calculates the number of MSDUs expected to arrive at the new  $SI$  using Equation (3). 2) the ACU then calculates the  $TXOP_i$  for the particular TS as in Equation (4). Finally, the ACU admits the TS only if the following inequality satisfied:

$$\frac{TXOP_{n+1}}{SI} + \sum_{i=1}^n \frac{TXOP_i}{SI} \leq \frac{T - T_{CP}}{T} \quad (5)$$

where  $n$  is the number of admitted traffic streams,  $n + 1$  is the index of the incoming TS,  $T$  is the beacon interval and  $T_{CP}$  is the duration reserved for EDCA, contention-period.

The HC sends an acceptance message, ADDTS-Response, to the requested QSTA if the Equation (5) is true or send a rejection message otherwise. The accepted TS will be added to the polling list of the HC.

## 2.3 VBR Video Traffic Application

Video compression has been widely used in today's wireless system transmissions due to the limitation of transmission rate in the wireless networks. Several encoding techniques have been adopted to produce compressed video with different quality levels like Motion Picture Experts Group type 1 (MPEG-1) and MPEG-2. A high picture quality can be obtained by encoding video at several

megabits per second bit rate, yet it is not appropriate for transmitting over the limited wireless medium [12]. Thus, encoding schemes providing lower bit rate has been emerged to produce video with an acceptable picture quality at even lower than 64 kpbs bit rate.

H.263, is an example of low rate, video compression, achieves more than 50% reduction in the bit rate required to represent the equivalent video quality compared to H.261. H.263 encodes the video sequence at a reference frame rate, e.g. 25 frames/Sec, i.e. every 40 ms. However, in order to meet the smaller bit rate, H.263 encoder skips some frames which consequently results in a variable frame interval. A fragment of 10 frames of H.263 trace file of *Silence of the Lambs* film exhibits the fact of frame skipping is shown in Table 2. The number of the skipped frames tends to be higher as the target bit rate goes smaller, which means the higher varying feature of video traffic. Such kind of video streaming served poorly by HCCA based on fixed TSPEC parameters negotiated at the traffic setup. The following section discusses the issue of overpolling the stations in the reference design of the HCCA.

**Table 2** A Fragment of Silence of the Lambs Trace File Encoded Using H.263 at 256kbps Target Bit Rate [18]

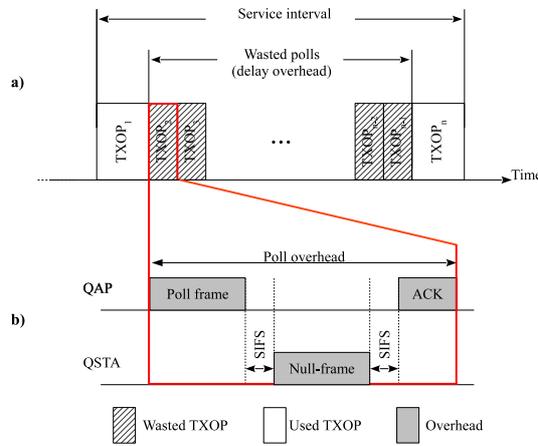
Frame period (ms)	Frame type	Frame size (bits)
0	I	12539
360	P	3981
600	PB	6203
760	PB	5884
1000	PB	6749
1160	PB	6425
1400	PB	7849
1640	PB	5983
1800	PB	6183
2040	PB	7052

#### 2.4 Preliminary Study of HCCA Polling Mechanism

Since HCCA schedules QSTA based on negotiated TSPECs which represent their mean traffic characteristics, it is not efficient to cope with the variable profile of VBR traffic streams. Polling all QSTAs at the same SI period may cause degradation in the channel utilization since some QSTAs are not ready to send data and thus reply to poll by Null-Frames. Consider Figure 3 where number of VBR traffics are scheduled in one SI. The beacon interval is 200 ms and three QSTAs are scheduled every 40 ms. Assume that the first SI begins at time 0 and all QSTAs commence their traffics at that time. In this example, all QSTAs will use their TXOP duration at the first SI since they start their traffic and must have packets to send. However and due to the varying feature of the VBR traffics, at some SIs there might be one or more QSTAs with no packet to send thus they are considered as over-pollled. Consider the second

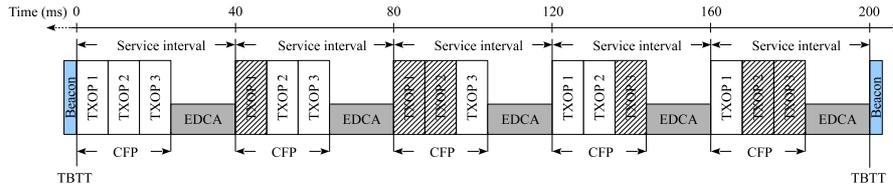
SI at time 40 ms  $QSTA_1$  has no data which will reply by Null-frame. In the third SI it is even worse where only  $QSTA_3$  utilizes the poll and transmit data packets while  $QSTA_1$  and  $QSTA_2$  will reply by Null-frames and so on. Polling a QSTA with no data will remarkably increase the poll overhead which consists of transmitting one poll frame, a Null-frame and an Acknowledgement (ACK).

Consider the case illustrated in Figure 2 where there are  $n$  number of QSTAs are polled in the current SI in order. Assume that only  $QSTA_1$  and  $QSTA_n$  have packet in their transmission queue and the rest of the stations have no packets. In this case,  $QSTA_n$  will have to wait for all stations ahead to transmit their Null-frames. This inherent issue in HCCA occurs because QAP is unaware about the current change in VBR traffic profile. It worth noting that



**Fig. 2** Unwanted Delay Caused by Wasted Polls by Unready QSTAs with VBR Traffics in The Reference Design of HCCA.

minimizing the number of wasted polls may reduce the delay in both EDCA and HCCA and boosts the channel utilization as well. For instance, at the third SI preventing polling  $QSTA_1$  and  $QSTA_2$  will lead to poll  $QSTA_3$  earlier and thus reduce the end-to-end delay. On the other hand, at time 160 ms the wasted time of polling  $QSTA_2$  and  $QSTA_3$  can be transferred to EDCA period, which enhance the system channel utilization and the packet delay. The QAP over-polls QSTA because of lack of information about the backlogged packets on QSTAs queues. This is normal in a controlled-access mode where the station only transmits upon receiving a poll from QAP. Many approaches have been conducted to alleviate the overhead caused by sending polls to unready stations with VBR traffics we present some of them in the following section.



**Fig. 3** Wasting Polls in VBR Traffics, Example of Three QSTAs Each of Which Has one VBR Traffic

## 2.5 Enhancements on HCCA Scheduler for Supporting VBR Traffics

It is hard for the HC to accurately schedule the uplink TSs for the reason that HC is physically separated from the QSTAs and because of the stochastic behavior of the VBR traffics. Several approaches proposed in the literature to assist the HCCA scheduler accommodate with the VBR traffic fluctuation over the time. In this section, we discuss some of the enhancements on the SI assignment and the polling mechanism of VBR traffics in the reference design.

Scheduling Based on Estimated Transmission Times-Earliest Due Date (SETT-EDD) [19] is deemed one of the exemplary solution proposed in the literature. SETT-EDD schedules the TSs in the system considering the delay of the head-of-line packets of the scheduled TSs by the mean of using the well known algorithm in multimedia, Delay Earliest Due Date (EDD). In the case of the downlink traffics, the HC directly obtains the delay of the TSs head-of-line packet delay since it maintains these traffics at its transmission queues. In the case of the uplink traffics, the SETT-EDD is unable to read these values, thus it estimates them using a token-bucket algorithm affiliated with each TS.

This scheme succeeds in reducing the packet delay and the packet loss. Notwithstanding in high bursty traffics the average TXOP is not efficient and may lead to high transmission delay, since it considers only average TXOP transmission. Besides, inaccurate estimation of network status may lead to degradation in bandwidth utilization.

Adaptive Resource Reservation Over WLANs (ARROW) scheme [20] has received considerable attention in the literature since it considers the actual packets buffered at stations rather than estimate the buffered data. ARROW utilizes the Queue Size (QS) by QSTA, which is part of QoS Data frames introduced by 802.11e standard [5]. Thus to inform the HC about backlogged packets in the their transmission queue at the previous SI. A scheduler exploits this information and allocates TXOPs to QSTAs in such a way that attempt to clear their queues as long as they comply with the declared TSPEC. ARROW achieves more bandwidth utilization and higher throughput compared to SETT-EDD. However, calculation of SIs based on the mean parameters declared in TSPEC might cause high packet loss when high variable packet interval is used, such as low bit rate H.263 video streams [21].

A four-way-polling [22] is a feedback approach in which information about the backlogged information is inquired by QAP about the buffer occupancy

of the uplink TSs. Unlike ARROW, where the feedback information and the respective SI assignment is done separately in two consequent SI, in this approach the QAP explicitly inquires the backlogged information through transmitting a request packet and the QSTA reports its buffer in a response packet. Accordingly, QAP sends an allocation packet with the TXOP duration enough to serve the buffered load at that station. The Four-way-polling algorithm succeeds in minimizing the packet delay and loss. However, exchanging additional packets may raise the risk of being attacked and lead to wasting channel time, especially when the SI is small, in such case the polling happened more frequently.

In [23], the authors proposed a modification on HCCA named Non-polling based HCCA Non-Polling based HCCA (NPHCCA) to alleviate the inherited issue on wasted polls on the reference design. The key idea is to let stations report their transmission requirement (buffered packets) during reserved channel called Req-Time after QAP broadcasts the beacon frame. Stations that succeed to send their request frames will be notified in the next beacon for transmission. NPHCCA involves modifications in the reference design data structure by adding a new frame, called transmission request frame which conveys information about the station backlogged packets to the QAP. In addition, in the QAP, a new table is defined to maintain information about the station's transmission status to help QAP decide an appropriate scheduling sequence of stations with respect to their QoS needs. Besides, additional field extends the beacon frame which is used by QAP for transmission notification.

Results reveal that NPHCCA has reduced the access delay of the stations by avoiding polling stations that have no data. Average transmission delay is also minimized due to the fact that AP assigns a real-time TXOP to stations to transmit their frames with regards to their requests. However, the performance of HCCA and NPHCCA are almost equivalent when the network is heavily loaded. Accordingly, references [24,25,26,27,28] tend to reduce the poll overhead by sending a multiple poll frame to all stations instead of periodically transmitting one poll to each.

The Enhanced Earliest-Due-Date (EDD) [14]. The TXOP is dynamically allocated based on the data rate reported to QAP in TSPEC of each TS. Information about the backlogged packets is delivered at the previous SI just like ARROW. The TXOP of a station  $i$  can be computed as in Equation (6). The scheduler also adaptively advances the start of the SI when it determines that 1) there are backlogged packets at QSTA transmission queues which implies that packets generated at the previous SI have not served hence the new SI will be advanced by a time enough to clear the queue as in Equation (7). 2) the allocated TXOP is not fully utilized by the QSTA in this case the SI will be postponed by the residual time of the previous TXOP as in Equation (8).

Simulation results reveal that Enhanced EDD scheduler has outperforms both HCCA and SETT-EDD schedulers in terms of end-to-end delay. This is due to preventing backlogged packets from unnecessarily waiting caused by

fixed mSI and Maximum Service Interval (MSI).

$$TXOP_i = TXOP_{avg}^i + TD_i \quad (6)$$

where  $TXOP_{avg}^i$  is the TXOP calculated for the station  $i$  considering the data rate since the previous SI until the current time whereas the  $TD_i$  is the TXOP required to transmit the backlogged packets of the TS.

$$mSI_{new}^i = mSI^i - TD_{cur}^i \quad (7)$$

where the  $mSI_{new}^i$  is the new SI for the station and  $TD_{cur}^i$  is the TXOP duration required to send the backlogged packets at station  $i$ .

$$mSI_{new}^i = mSI^i - TD_{free}^i \quad (8)$$

where  $TD_{free}^i$  is the unused TXOP duration of at the previous SI.

### 3 Feasible Polling Scheme (F-Poll)

In F-Poll, the exact arrival time of the next frame of the uplink stream is obtained at the MAC layer of the station from its application layer through cross layering concept. For this reason we call it Feasible Polling Scheme (F-Poll), in which accurate information about the next inter-arrival time is transmitted to the QAP for enhancing the scheduling of the TSs. Upon the reception of the data frame a decision is made about either polling the respective station in the next SI or not, to prevent polling stations that are not ready to transmit and consequently minimize the packet access delay and maximize the channel utilization.

F-Poll enhances the polling scheme of the HCCA reference design to accurately poll stations with encoded video streams. We present in this section the description of the scheduling process of the F-Poll in both station and access point.

#### 3.1 Scheduling Actions at the Station

At the station, information about the next frame arrival time is obtained from the application layer via cross-layering. The information of the next frame arrival time can be obtained based on the deployment at the application layer. For instance, in Real-time Transport Protocol (RTP) defined in [29] which is suitable for applications transmitting real-time data each RTP packet has a sequence number and timestamp. The timestamp represents the packet arrival time to be used in F-Poll scheme, as the whole or prefetched part of the video is known before the streaming commences. At the MAC layer, the feedback information is carried in the *Queue Size (QS)* field introduced by IEEE 802.11 standard [5] which is a part of the QoS Control field of the QoS data frame. The *QS* field is exploited in this scheme for sending information about the next frame arrival time to the QAP for scheduling purpose.

**Algorithm 1:** F-Poll Scheme Pseudo Code

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```

1 Input:
2 stations, a list of  $N$  stations in the polling list of the HC
3 arrivals, a list of next packet arrival time for each  $station_i$  in stations where
    $i = 1..N$ 
4 WHEN receiving a data packet from a  $station_i$ 
5  $arrival_i \leftarrow arrival_i - SI$ 
6 for each CAP do
7   WHEN no data packet received from  $station_i$ 
8      $arrival_i \leftarrow -1$ 
9      $i \leftarrow 1$ 
10    while  $i \leq N$  do
11      if first CAP of stationi then
12        | Poll  $station_i$ 
13      else if  $arrival_i \leq 0$  then
14        | Poll  $station_i$ 
15      else
16        |  $arrival_i \leftarrow arrival_i - SI$ 
17      end
18       $i \leftarrow i + 1$ 
19    end
20 end

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## 3.2 Scheduling Actions at the Access Point

After the traffic setup, the QAP sends the first poll frame granting the QSTA a TXOP duration and the station will accordingly transmit the first packet of its traffic to the QAP. Note that the inter-arrival time between encoded video traffic frames is a multiple of a fixed interval (e.g. 40 ms) depends on the encoding parameters. That is to say, it is expected to receive only one packet at a multiple of the designated interval.

At the beginning of each Controlled Access Phase (CAP), the QAP goes through the polling list, which maintains a list of all admitted QSTAs in the system and behaves according to two cases. The first case is when a data packet received from the  $QSTA_i$  in the previous CAP/SI period, the arrival time ( $arrival_i$ ) of the next frame is obtained. Then, a value of SI is deducted from it to compute the time left to the next frame at the  $QSTA_i$ . The station is polled only if the  $arrival_i$  is less than or equal to zero which implies that the next frame is generated at  $QSTA_i$  and is waiting for a poll to transmit. The second case is when no data packet received due to loss, the QAP will keep polling the QSTA at the original SI rate regardless if it has data to transmit or not. The information about the arrival time of next frame held in the first received packet from the correspond QSTA after loss will be ignored and F-Poll scheme will resume its operation when the second packet after loss received. Algorithm 1 reports the pseudo code of F-Poll scheme and Figure 4 depicts F-poll framework. Figure 5 illustrates the polling overhead introduced by polling QSTAs that have no data to transmit and how F-Poll tackle this issue. The HCCA Polling scheme in Figure 5(a)  $SI_i$ , polls QSTAs regardless



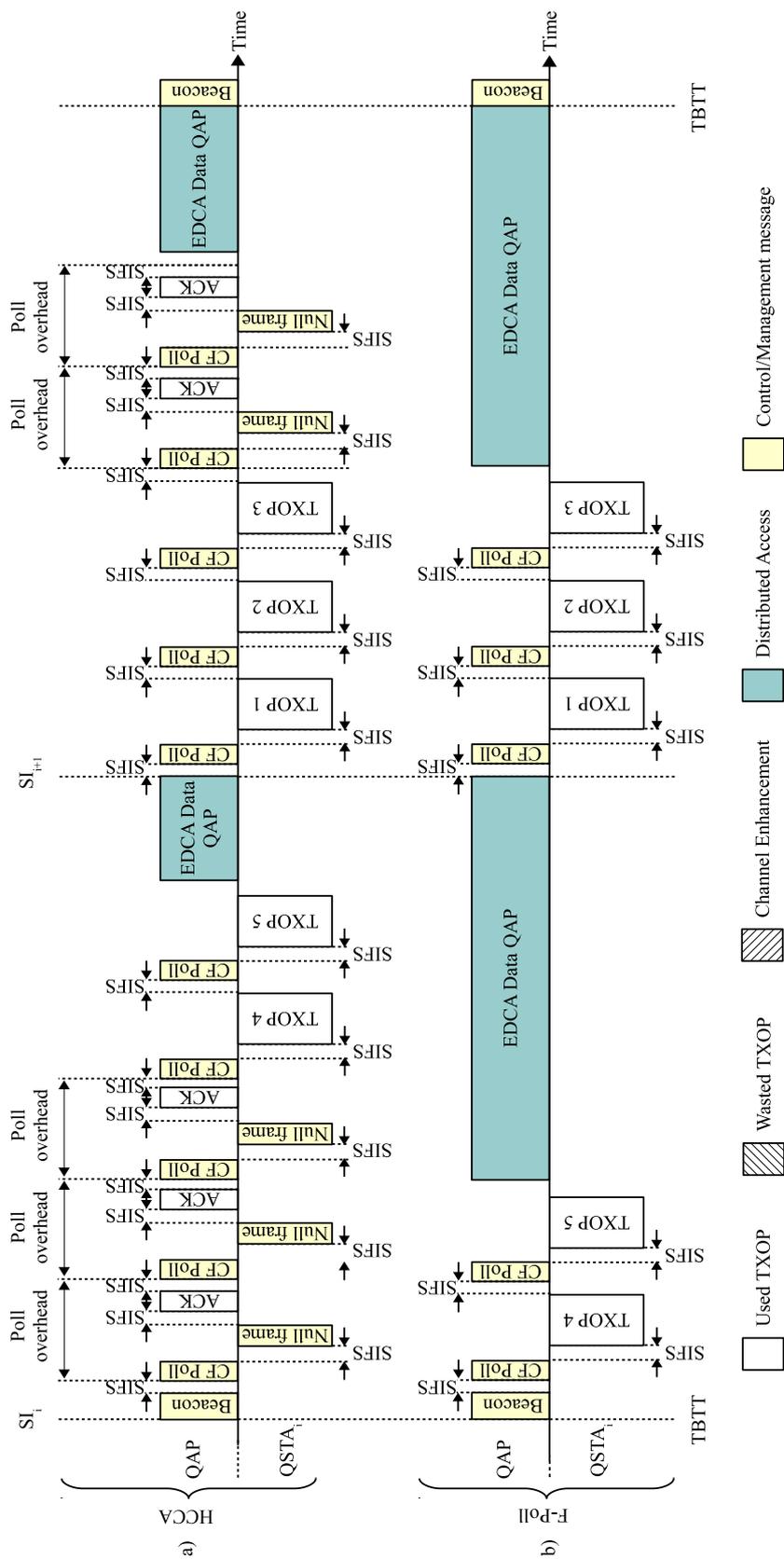


Fig. 5 F-Poll Scheme

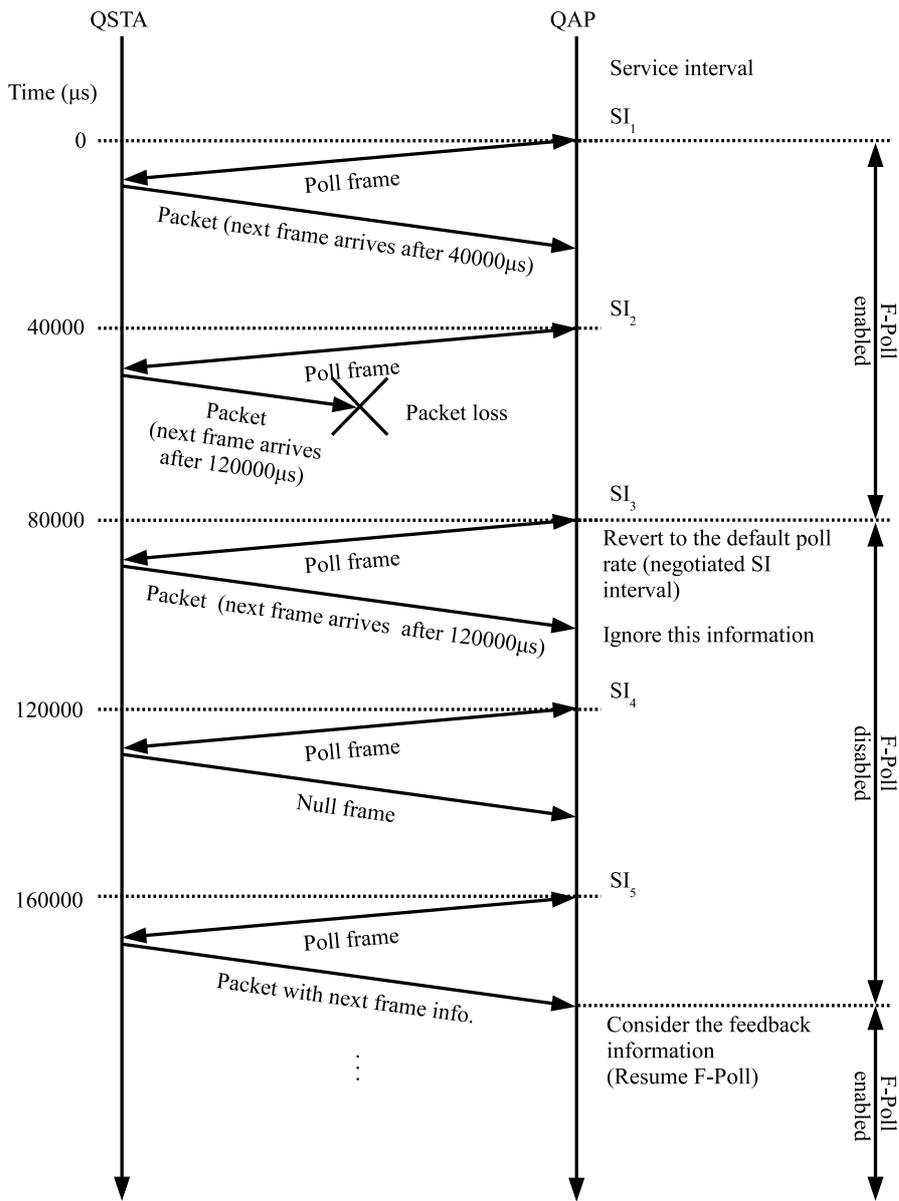
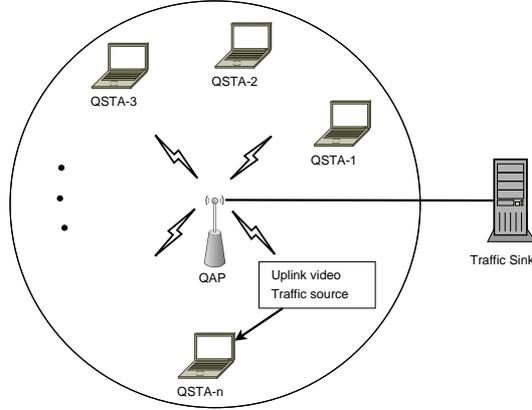


Fig. 6 F-Poll Scheme Example when Packet Loss Occurs

has been patched to provide the controlled access mode of IEEE 802.11e functions. The *ns-2* Traffic Trace agent[31] is used to generate payload bursts from the video trace file. The star topology in Figure 7 has been used for constructing the simulation scenario which form an infrastructure network of one QAP surrounded by varying number of the QSTAs ranging from 1 to 20. All QS-

TAs were distributed uniformly around the QAP with a radius of 10 meters. Stations were placed within the QAP coverage area, in the same basic ser-



**Fig. 7** Network Topology, One Access Point and Varying Number of Stations From One to Twelve.

vice set BSS, and the wireless channel assumed to be ideal. Since we focus on HCCA performance measurement, all stations operate only on the contention-free mode by setting  $T_{CP}$  in Equation (5) to zero. QAP is the sink receiver, while all stations are the video sources each sends only an uplink video traffic as only one flow per station is supported in *ns2hcca* patch. Therefore, for simulating concurrent video streams, multiple stations are added each with one flow.

Due to the fact that downlink TSs are maintained in QAP queues for this reason, HC can schedule them easily, we exclude the evaluation of the examined schemes in the presence of downlink traffics. In order to leave an ample time for initialization, stations start their transmission after 20 (sec) from the start of the simulation time and last till the simulation end. Wireless channel assumed to be an error-free. No admission control used for the sake of investigating the maximum scheduling capability of each examined algorithm under heavy traffic conditions. Simulation parameters are summarized in Table 3.

#### 4.2 Video Model Setup

For testing the performance of the examined schemes under different traffic variability, three video sequences have been chosen from a publicly available library for video traces [18]; Formula 1, Soccer and Mr Bean. All videos used in the simulation are H.263 format encoded at low bit rate target (16Kbps). The reason behind the selection of the low bit rate encoded videos is that although raw YUV videos are encoded at a fixed reference frame rate of 25 frames per

**Table 3** Simulation Parameters

Parameter	Value
Simulation time	500 sec
Physical layer	IEEE 802.11g
MAC layer	IEEE 802.11e
SIFS	10 $\mu$ s
PIFS	30 $\mu$ s
Slot time	20 $\mu$ s
Preamble length	144 bits
PLCP header length	48 bits
PLCP Data Rate	1 Mbps
MAC header	36 bytes
Physical Data rate	54 Mbps
Basic rate	6 Mbps

second. The encoder skips some frames so as to achieve the target low rate. Consequently, the inter-arrival time of the frames will be higher which better represents high fluctuating VBR traffic. Table 4 demonstrates some statistics of the examined traces. TSPEC parameters used for each video traffic is shown in Table 5 with regards to video QoS requirements.

**Table 4** Frame Statistics of MPEG-4 Video Trace Files [18]

Parameter	Formula 1	Soccer	Mr Bean
Comp. ratio (YUV:H263)	476.07	476.30	476.38
Mean size (byte)	519	655	403
Maximum size (byte)	4831	4647	3265
CoV of bit rate	0.21	0.17	0.34
Mean bit rate (bit/sec)	1.6e+04	1.6e+04	1.6e+04
Peak bit rate (bit/sec)	7.8e+04	7.3e+04	9.7e+04

**Table 5** Traffic Parameters for Video Streams.

Parameter	Formula 1	Soccer	Mr Bean
Nominal MSDU Size	519 bytes	655 bytes	403 bytes
Maximum MSDU Size	4831 bytes	4647 bytes	3265 bytes
Mean Data Rate	16 Kbps	16 Kbps	16 Kbps
Peak Data Rate	78 Kbps	73 Kbps	97 Kbps
Delay Bound	0.08 sec	0.08 sec	0.08 sec
Minimum Physical Rate	54 Mbps	54 Mbps	54 Mbps
Maximum Service Interval	0.04 sec	0.04 sec	0.04 sec

### 4.3 Results and Discussions

In our simulation study the aim was to improve the QoS provision of the HCCA algorithm. Simulation has been run to demonstrate the performance of

the examined schemes with the same simulation scenario. The main objective is to achieve better QoS support by avoiding polling stations that have no data backlogged at their transmission queues. Packet end-to-end delay of the uplink traffics has been evaluated in this research which considered as one of the important metrics for measuring QoS efficiency for supporting multimedia applications such as video streams. In order to validate the behavior of the examined schemes, the measurements have been done with increasing number of TSs. System throughput was also investigated to verify that the improvement in delay is achieved without jeopardizing the wireless channel efficiency.

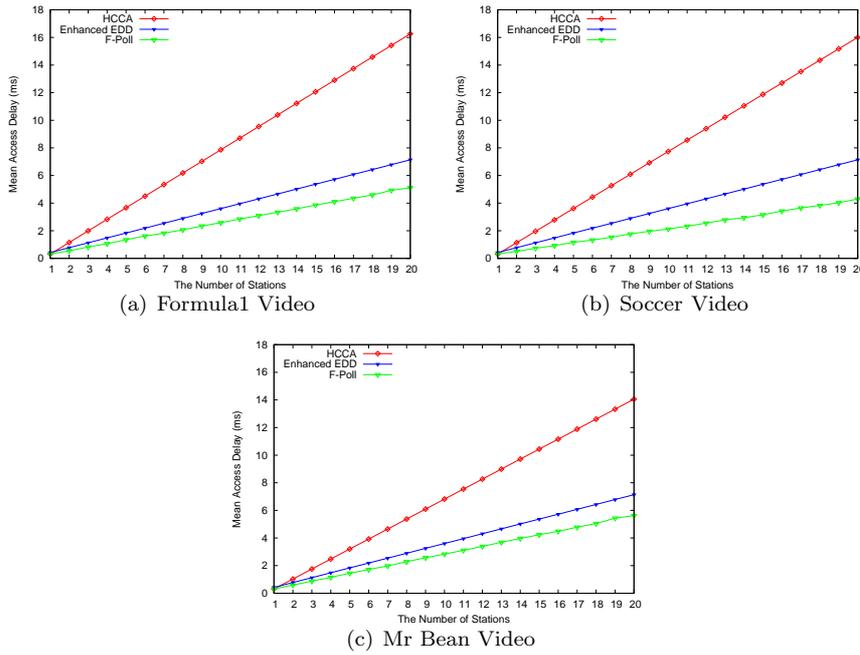
#### 4.3.1 Mean Access Delay Analysis

The packet access delay is referred to the time taken from the packet generation at the station until it's been transmitted from the MAC layer. The mean access delay is calculated in Equation (9)

$$MeanAccessDelay = \frac{1}{N} \sum_{i=1}^N (S_i - G_i), \quad (9)$$

where  $G_i$  is the generation time of packet  $i$  from the source station,  $S_i$  is the sending time of the particular packet (i) from MAC layer of the station and  $N$  is the total number of packets for all flows in the system. This metric reflects the delay time from a station being ready to transmit until it being served. In this experiment, we illustrate the efficiency of the F-Poll over HCCA polling and Enhanced EDD schemes in adapting to the fast changing of VBR traffic over the time. Figures 8(a), (b) and (c) show the average access delay of the data packets for the examined video traces. The proposed F-Poll scheme exhibits low access delay in all videos compared to both HCCA polling scheme and Enhanced EDD. The reason behind this low delay is that the F-Poll scheme is always aware about the change in uplink traffic profile and only polls the stations in need. Thus, the polls overhead is minimized which in turn shortens the time the packets wait in transmission queues. Note that Enhanced EDD accelerates the mSI according to the transmission queue status and the average TXOP assignment. This concept can minimize the delay when traffic shows variability in packet size only. However, in the case of traffics that show variability in packet inter-arrival time the delay caused by the wasted polls still persists since it is not being addressed. In contrary, HCCA polling scheme polls all stations regardless their actual needs which causes an increase in the queuing time awaiting a poll message. The maximum mean access delay experienced using the F-Poll scheme was as low as 5, 9 and 6 ms whereas in the reference poll scheme was 19, 14 and 20 ms for Formula 1, Soccer and Mr Bean video sequences respectively.

One can see the acute increase of the access delay by increasing the network load in the case of the HCCA polling scheme which can be justified by the high increase of the poll overhead in the network. The Enhanced EDD achieved up to 58% over HCCA in the three videos whereas F-Poll has achieved around

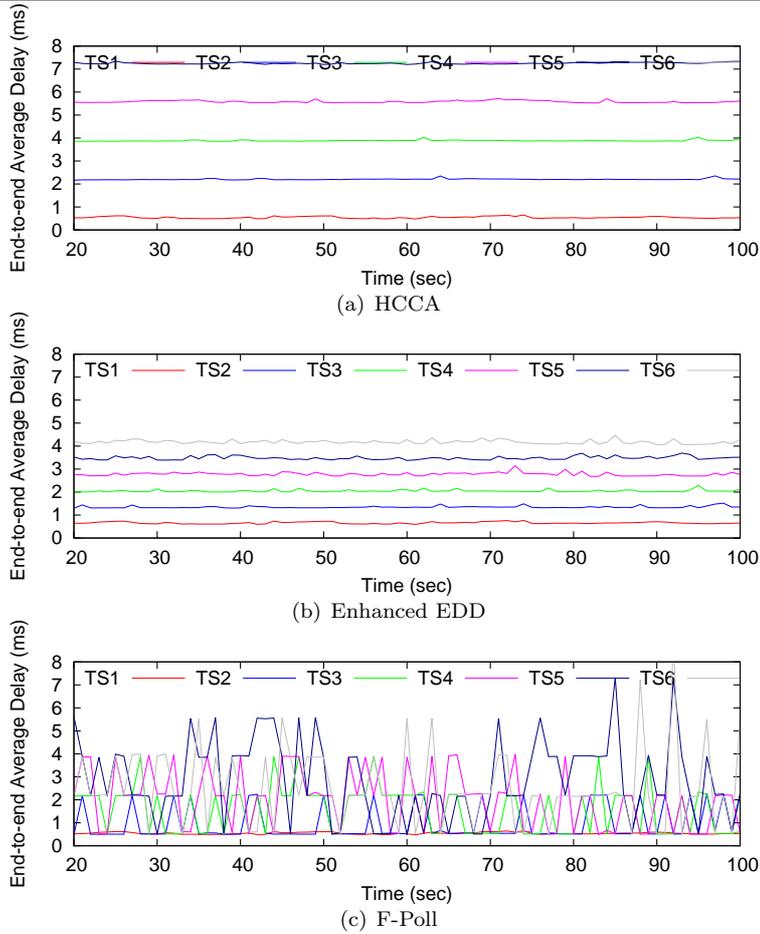


**Fig. 8** Packet Mean Access Delay as a Function of The Number of Stations.

27% over Enhanced EDD for Formula 1 and Mr Bean videos whereas, for Soccer video, F-Poll has enhanced the delay by up to 38% over Enhanced EDD.

#### 4.3.2 End-to-end Delay Analysis

The end-to-end delay is defined as the time elapsed from the generation of the packet in the application layer of the source QSTA until it's been received at the sink node, QAP. The end-to-end delay of the examined schemes has been measured using the three videos to study their efficiency over different traffic variability. Figures 9, 10 and 11 illustrate the effect of poll overhead on the delay of the packets of different TSs of 6 QSTAs in the system and for a duration of 100 seconds. Figures 9(a), 10(a) and 11(a) depict the delay experienced by data packets when using the legacy round-robin scheme of HCCA for each traffic stream. Figures 9(b), 10(b) and 11(b) reveals that Enhanced EDD has reduced the delay for all TSs yet it behave similar to HCCA as the delay of each TS remain the same during traffic lifetime as it does not address the issue of the over polling. Since traffics are VBR, in some SIs, TSs packets are likely to wait for all unready stations prior in the polling list to the particular station to reply null frames. Consequently, each TSs are likely to have near the same delay each SI. This issue becomes worse when the polling list increases where the stations in the last exposed to higher delay. It is worth noting that



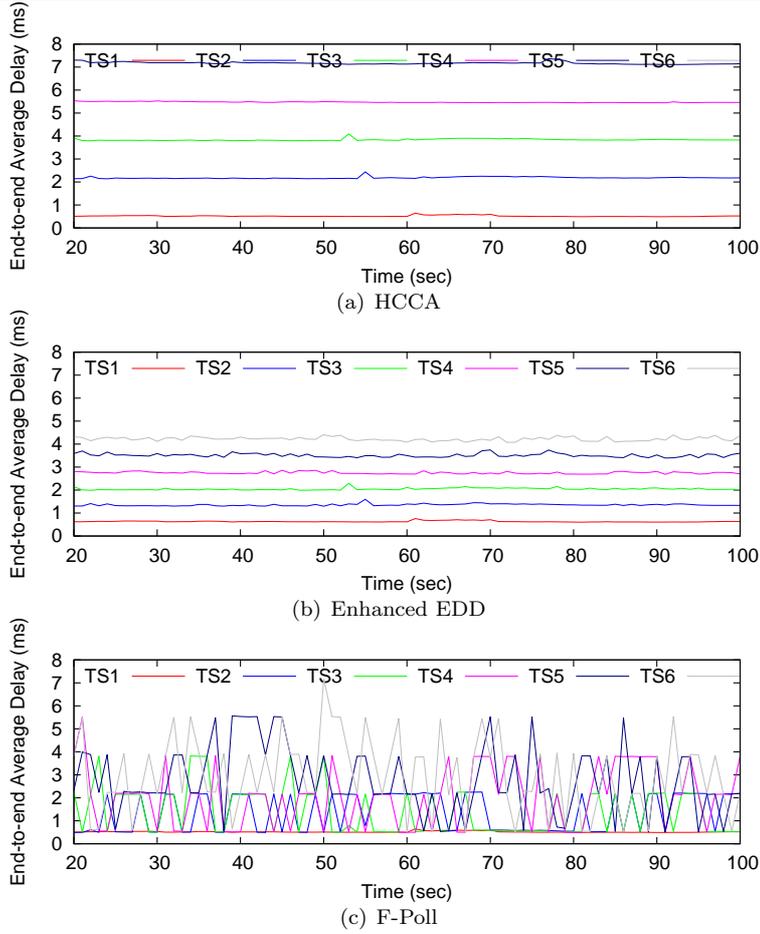
**Fig. 9** Packet End-to-end Delay for Formula1 Video

the preceding TSs are most likely to experience lower delay, in this case TS1 has the lowest packet end-to-end delay while TS6 shows highest delay among all video streams.

Figures 9(c), 10(c) and 11(c) exhibit that F-Poll scheme succeeded in minimizing the delay for all TSs and the reason is that our scheme minimized the poll overhead by avoiding poll unready stations. The fluctuation in the delay of each TS is subject to the number of transmitting stations ahead to that station in each SI. In general, the results demonstrate that the F-Poll scheme minimize the end-to-end delay even in the case of high network load.

#### 4.3.3 Poll Overhead Ratio

Figures 12(a), (b) and (c) illustrate the overpolling issue illustrated in section 2.4 for the studied video traces. Poll overhead ratio is calculated as the ratio

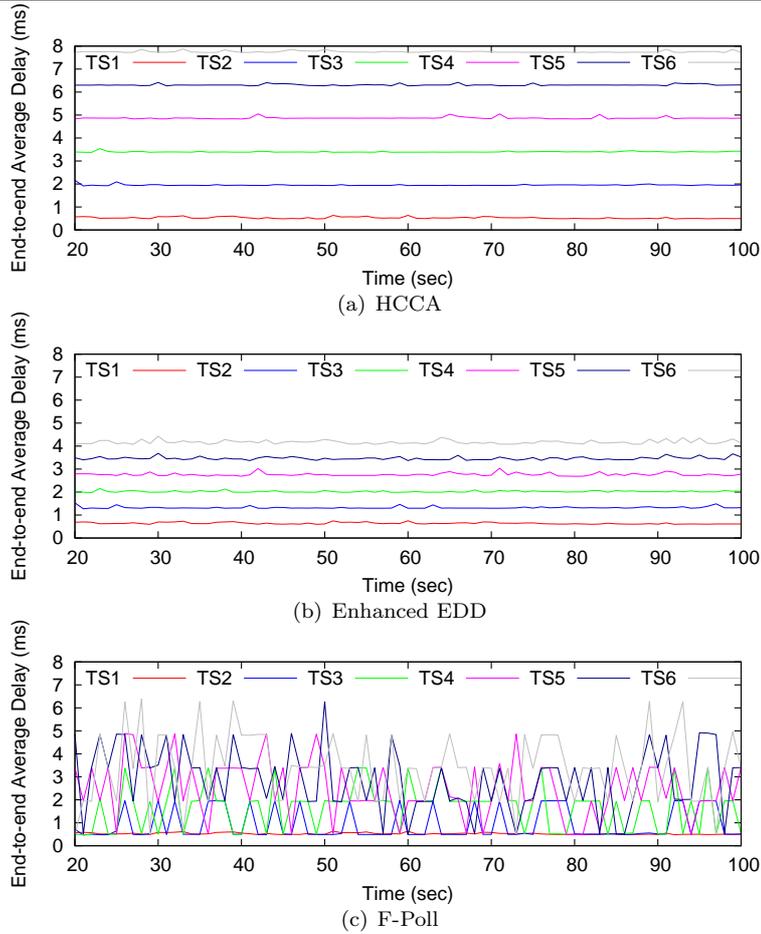


**Fig. 10** Packet End-to-end Delay for Soccer Video

of the number of Null-frames to the number of poll frame sent to the uplink TSs. Since the studied videos show high variability in their profile which lead to aggravate the Null-frame responses. In the reference HCCA scheme, the poll overhead ratio reaches about 85% for all the studied video traces with despite that the network is heavily loaded or not. F-Poll scheme as low as zero since the scheduler aware about the exact time for the next arrival packet.

#### 4.3.4 Number of Polls Versus Number of Packets

To further show the effect of the over-polling issue on the channel utilization we demonstrate the number of data packets sent versus the number of poll frames granted to the stations. We have chosen the case of 6 uplink traffics transmitting to the QAP of the tested videos. Figures 13(a), (b) and (c) as

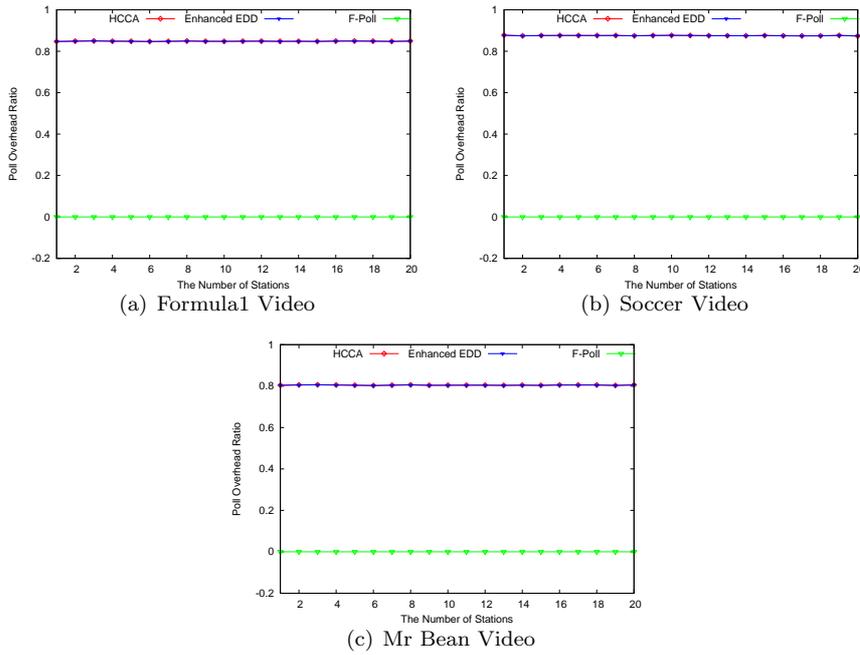


**Fig. 11** Packet End-to-end Delay for Mr Bean Video

well as 14(a), (b) and (c) show the high number of poll frames versus number of data packets using the reference HCCA design and Enhanced EDD for the examined video sequences. The massive increase in the number of polls against the actual need is discussed in Figures 15(a), (b) and (c). In contrary, Figure 1 shows the effectiveness of the F-Poll scheme in accurately poll stations using the feedback information about the next frame arrival time.

#### 4.3.5 Throughput Analysis

We have investigated the aggregate throughput of the examined schemes as a function of the number of stations to verify that our scheme is efficient in supporting QoS for VBR traffics and maintaining the utilization of the wireless



**Fig. 12** Poll Overhead as a Function of The Number of Stations.

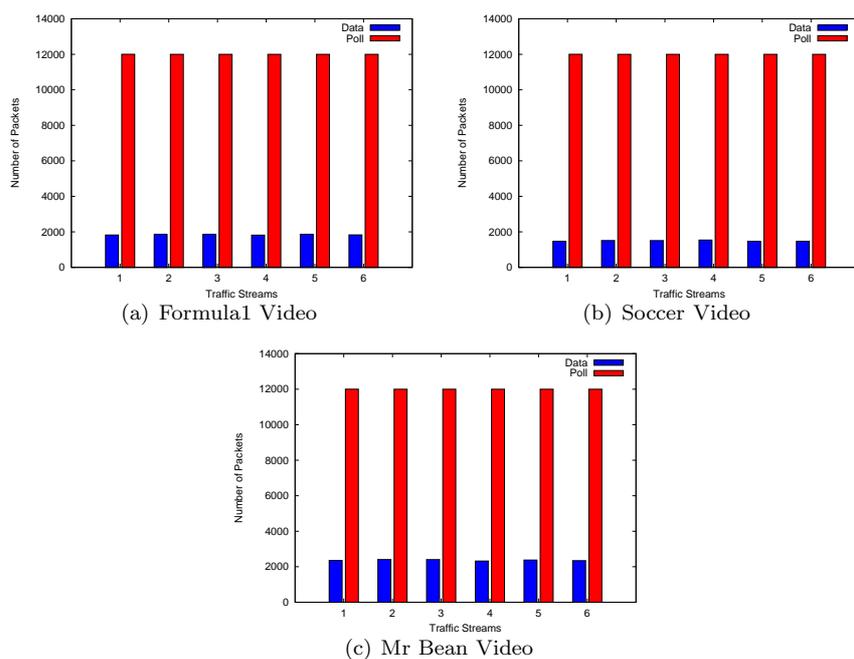
channel. Aggregate throughput is calculated in Equation (10).

$$AggregateThrp = \frac{1}{T} \sum_{i=1}^N (Size_i), \quad (10)$$

where  $Size_i$  is the total received packet size at the QAP,  $T$  is the simulation time and  $N$  is the total number of the received packets at QAP during the simulation time. Figures 16(a), (b) and (c) depict the aggregate throughput as a function of number of QSTA. Since the F-Poll scheme utilizes the  $QS$  field defined in the standard MAC header format to send information about the arrival time of the next frame, no extra overhead is added to the network. As a result, the F-Poll scheme minimized the packet delay while maintaining the throughput similar to that gained using reference HCCA design.

## 5 Conclusion

A new polling mechanism has been proposed in this paper to support pre-recorded VBR video stream transmission in IEEE 802.11e HCCA networks. F-Poll mechanism is a feedback-based mechanism in which the station sends information with each packet sent about the next arrival time of the next frame. Based on this, in each SI period, the QAP will selectively poll stations



**Fig. 13** Polls vs Packets of HCCA as a Function of The Number of Stations.

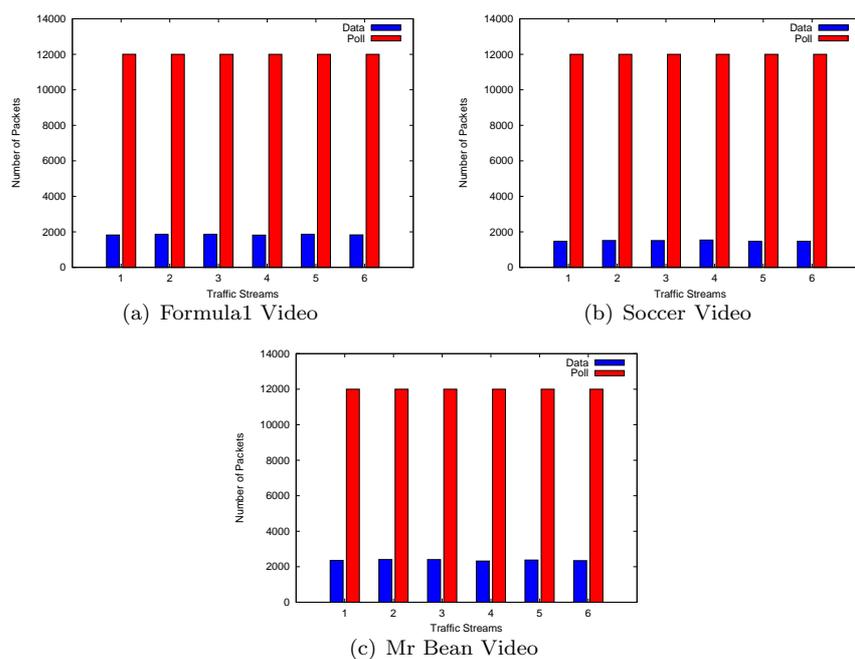
that are ready to transmit in order to reduce the poll overhead and thus minimized the delay in the system. Simulation results reveal the efficiency of the F-Poll mechanism over both HCCA and Enhanced EDD polling mechanisms in minimizing the data packet delay and conserve the channel bandwidth by remarkably reduce the poll overhead in the system.

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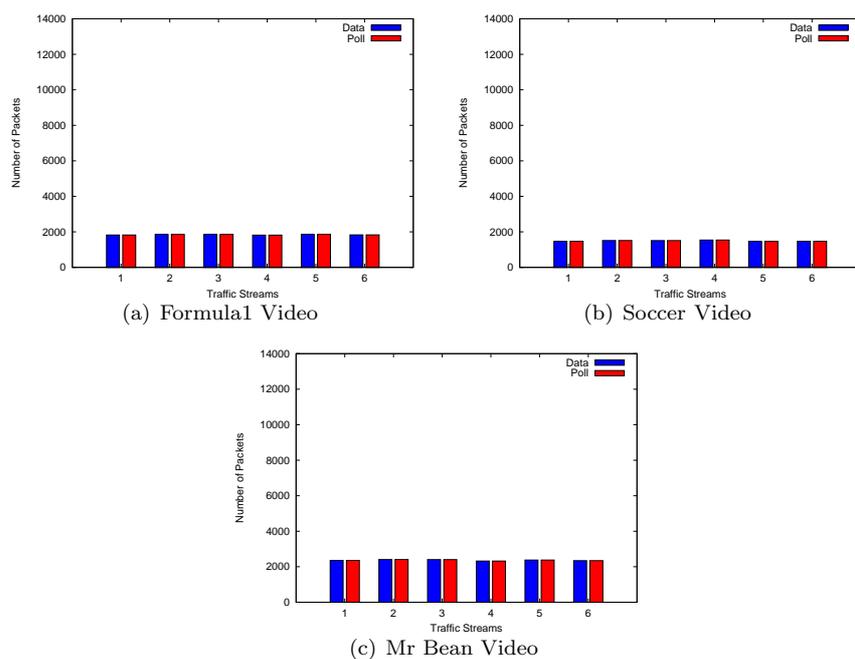
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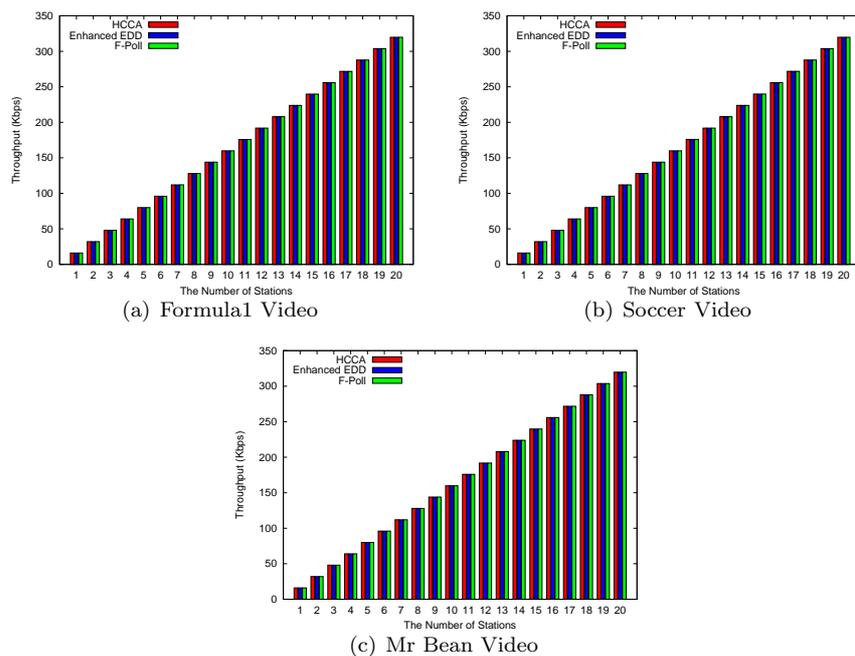
**Fig. 14** Polls vs Packets of Enhanced EDD as a Function of The Number of Stations.

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**Fig. 15** Polls vs Packets of F-Poll as a Function of The Number of Stations.

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**Fig. 16** Aggregate Throughput of as a Function of the Number of Stations.

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