W-CBS: A Scheduling Algorithm for Supporting QoS in IEEE 802.11e

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ABSTRACT

This paper presents a new scheduling algorithm, the Wireless Constant Bandwidth Server (W-CBS) for the Access Points of an IEEE 802.11e wireless networks to support traffic streams with Quality of Service guarantees, in particular in the case of multimedia applications which present variable bit rate traffic. The performance of W-CBS is compared to that of the reference scheduler defined in 802.11e standard using the ns2 simulator. The results show that the W-CBS outperforms the reference scheduler with VBR traffic, in terms of resource utilization and maximum admitted flows.

Keywords

Quality of Service, Scheduling algorithm, Wireless LAN.

1. INTRODUCTION

In recent years Wireless Local Area Networks (WLANs) are became very popular and the IEEE802.11 [1] has established itself as the world wide standard. At the same time, the continuous growth in the use of mobile devices that support multimedia applications and real-time services with strict latency/throughput requirements, such as multimedia video, VoIP (Voice Over IP), videoconference over a wireless channel, involves a great interest in the study of appropriate mechanisms to manage the wireless medium in order to achieve the expected *Quality of Service* (QoS). Furthermore, QoS applications imply increasing bandwidth requirements and exhibit differentiated behavior due to the presence of *Constant Bit Rate* (CBR) and *Variable Bit Rate* (VBR) traffic, which need an appropriate approach which can guarantee different QoS services. In order to introduce QoS guarantees, the 802.11 Working Group has recently developed an enhancement to this protocol, IEEE 802.11e [2], to provide differentiation mechanisms at the *Medium Access Control* (MAC) layer, using two additional access functions: the Enhanced Distributed Channel Access (EDCA) function, which is based on a distributed control and enables prioritized channel access, and the HCF Controlled Channel Access (HCCA) function, which instead requires centralized scheduling and allows the applications to negotiate parameterized service guarantees. The IEEE 802.11e standard does not specify a mandatory HCCA scheduling algorithm, while it offers a *reference* scheduler that is compatible with the use of link adaptation and that respects a minimum set of performance requirements. Many research studies have evaluated the new standard employing analytical techniques [3] and simulations [4, 5], and they have demonstrated the usefulness of the proposed mechanisms of 802.11e. Subsequent works have proposed several scheduling algorithms to improve the QoS provisioning [6–9].

This improvement is necessary in particular in the case of VBR traffic for which the *reference* scheduler shows its limit. In fact it is particularly tailored for constant bit rate traffic.

In this article we propose a novel scheduling algorithm, namely the Wireless Constant Bandwidth Server (W-CBS). It does provide those flows that have been admitted to use the HCCA function with rate base guarantees. We propose a scheduling methodology which reserves a fraction of network bandwidth to each flow, assigning a suitable deadline to the server flow whenever the reserved time is consumed. Differently from the *reference* scheduler, W-CBS is not based on periodic scheduling of fixed allocations but it manages dynamically the allocated capacity. Moreover the latter is made available for contention based access when it is not used by the HCCA flows.

The rest of the paper is organized as follows. Section 2 gives an introduction of the IEEE 802.11 standard and IEEE 802.11e enhancement. Section 3 contains the related work. In Section 4 the CBS scheduling algorithm is described. Section 5 presents the performance analysis, illustrating the simulation environment and the results obtained. Section 6 concludes the paper.

2. PROTOCOL DESCRIPTION

This section briefly describes the IEEE 802.11 MAC protocol and the enhancements proposed in the IEEE 802.11e amendment.

2.1 IEEE 802.11 MAC

The IEEE802.11 MAC defines two transmission modes for data packets: the mandatory *Distributed Coordination*

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Function (DCF), based on *Carrier Sense Multiple Access / Collision Avoidance* scheme and the optional contention-free *Point Coordination Function* (PCF), where the *Access Point* (AC) controls all transmissions, based on polling mechanism. The DCF and PCF are multiplexed in a superframe, which is formed by a PCF *contention-free period* (CFP) followed by a DCF *contention period* (CP), positioned at regular intervals.

2.1.1 Distributed Coordination Function (DCF)

The basic 802.11 MAC protocol is the Distributed Coordination Function (DCF) that works as a listen-before-talk scheme, based on CSMA/CA mechanism to determine the medium state and to avoid collisions. According this access scheme, if a station that has packets to send senses the medium is busy, it will defer its transmission and initiate a random backoff procedure. The backoff time, which is loaded in the backoff timer, is a uniformly distributed random number between 0 and *Contention Window* (CW). Once the station detects that the medium has been free for a duration of *DCF Inter-Frame Space* (DIFS), it starts a backoff procedure (i.e., it starts decrementing its backoff counter as long as the channel is idle). If the backoff counter has reduced to zero and the medium is still free, the station begins to transmit. If the medium becomes busy in the middle of the decrement, the station freezes its backoff counter and resumes the countdown after deferring for a specific period of time. It is possible that two or more stations begin to transmit at the same time. In such a case, a collision occurs. Collisions are inferred by no acknowledgment (ACK) from the receiver. After a collision occurs, all the involved stations double their CWs (up to a maximum value, CWmax) and compete to gain control of the medium next time. If a station succeeds in channel access (inferred by the reception of an ACK), the station resets its CW to CWmin.

DCF does not provide QoS support but supplies best effort service as all stations operate with the same channel access parameters, they have the same medium access priority and there is no stream differentiation.

2.1.2 Point Coordination Function (PCF)

PCF provides contention-free transmission into a CFP. During the CFP, the AP polls its associated stations according to a predetermined order indicated through the polling list (usually in a round-robin manner). No station is allowed to transmit unless it is polled. If there is no pending transmission in a polled station, the response is a null frame containing no payload. The CFP ends when the AP sends a CF-end message. If the CFP terminates before all stations have been polled, the polling list will be resumed at the next CFP cycle from the previous stopping point. If the AP receives no response from a polled station after waiting for a PIFS, it will poll the next station or end the CFP. PCF Inter-Frame Space (PIFS) is the time interval used by PCF; it is longer than a Short Inter-Frame space (SIFS) but shorter than DIFS, used in DCF, to provide point coordinators higher priority in medium access than DCF stations. In this way, no idle period longer than a PIFS occurs during a CFP.

PCF does not make available adapted QoS guarantees.

2.2 THE IEEE 802.11e STANDARD MAC

The new standard IEEE 802.11e introduces a new coordination function called the *Hybrid Coordination Function* (HCF) which multiplexes between two medium access modes: a distributed scheme called *Enhanced Distributed Channel Accesss* (EDCA) and a centralized scheme called *HCF Controlled Channel Access* (HCCA). To ensure compatibility whit legacy devices, the standard allows the coexistence of DCF and PCF with EDCA and HCCA.

2.2.1 Enhanced Distributed Channel Access

EDCA is a channel access mode which provides prioritized QoS and it enhances the original DCF by classifying traffic through the introduction of *Access Categories* (ACs), corresponding to different level of traffic priority. Each AC has its own transmission queue and its own set of channel access parameters. The most important ones are Contention Window (CWmin and CWmax), which sets backoff interval, and *Transmission Opportunity* (TXOP) limits which is the maximum duration for which a node can transmit after obtaining access to the channel. Using these parameters, when data arrives from higher layers it is classified and placed in the appropriate AC queue. Then an internal contention algorithm is used to calculate the total backoff time for each AC. The AC with the smallest backoff time wins the internal contention and uses this backoff value to contend externally for the wireless medium. Nodes with higher priority can access the channel earlier than other nodes and prioritized flows have the advantage of longer channel access with their TXOP.

2.2.2 HCF Controlled Channel Access

HCCA provides a centralized polling scheme to allocate guaranteed channel access to traffic flows based on their QoS requirements. It uses a QoS-aware *Hybrid Coordinator* (HC) which is usually located at the *QoS Access Point* (QAP) in infrastructured WLANs and it provides polled access to the wireless medium. In order to be included in the polling list of the HC, a *QoS Station* (QSTA) must send a QoS reservation request to the QAP, using the special QoS management frame, *Add traffic Stream* (ADDTS), which contains flow information, such as mean data rate, mean packet size, MAC service data unit size and maximum tolerable delay. Each individual flow needs one particular reservation request and it is classified and assigned to one of eight *Traffic Streams*(TS) of that QSTA. In this manner TSs are guaranteed a parameterized QoS access to the medium. TS can be unidirectional (uplink or downlink) or bi-directional (both of them). TS parameters are collected by using a *Traffic Specification* (TSPEC), which is negotiated between the QSTA and the QAP. Mandatory fields include mean data rate, the Delay Bound and, the nominal *Service Data Unit* (SDU).

HC aggregates every TSPEC of QSTA TSs and determines the values of parameters needed by the transmission itself: *Service Interval* (SI) and TXOP. SI is the time duration between successive polls for the node and it is a submultiple of the 802.11e beacon interval duration. TXOP is the transmission duration of each node based on the mean application data rates of its requested flows. Before the calculation of the latter parameters, AP has to verify if the admission of each TS does not compromise the service guarantees of the already admitted TSs and, if the specified TS is accepted, QAP sends a positive acknowledgement which contains also the service start time that indicates the time from when the QSTA is allowed to transmit frames relative to considered TS.

When there are admitted QSTAs which desire to access the medium, the QAP listen to the medium itself and, if it is idle for a PIFS, HC gains control of the channel and, within the *Controlled Access Phase* (CAP), it polls a single QSTA at turn, according to its polling list, generated by a scheduler. It is necessary to distinguish between downlink TXOP, during which the QAP sends burst of QoS Data to QSTA and uplink TXOP, that starts when the polled QSTA takes the medium control. If the polled QSTA does not have packets for the considered TS (TS of the polled QSTA is not backlogged) or if the head-of line packet does not fit into the remaining TXOP duration, the QSTA sends a QoS CF-Null frame to the QAP.

The maximum time spent in HCCA for each SI is limited by the `dot11CAPMax` variable and the total controlled access time in a beacon interval is limited by `dot11CAPRate`. The duration of the controlled access period can be limited using these parameters and the effect of controlled access mode on traffic flows in contention access mode can be bounded.

3. RELATED WORK

Scheduling algorithms addressed to wireless networks have to take into account some limits due to the wireless environment [10]. In particular, the wireless medium itself presents space and time varying characteristics, unlike what happens in wired networks, so wireless networks are subject to fast changes in *Signal to Interference plus Noise Ratio* (SINR) due to phenomena like *path loss*, *shadowing*, *multipath fading*, *signal attenuation* and *interference* [11].

This implies that the concept of fairness is difficult to apply. Furthermore, wireless resources (e.g., bandwidth and energy) are limited and that, jointly to the need of lower computation complexity due to the use of low-performance hardware, adds other constraints in the choice of algorithms.

Several studies have been done to verify performances of the reference scheduler [5, 9, 12]. According to them, for every QSTA, fixed SI and TXOP based on mean values of the transmission parameters are useful for Constant Bit Rate TS, while they do not reflect the fluctuation of Variable Bit Rate TS. Particularly reference scheduler performances are evaluated using heterogeneous traffic stream like VoIP (G.711 codec), video stream (MPEG4 codec) and burst *best effort* data stream.

Some alternative algorithms introduce the following features: a) variable SI and/or TXOP, b) feedback based mechanism, c) queue length model.

3.1 Scheduling Estimated Transmission Time - Earliest Due Date

In [13] the authors propose the SETT-EDD scheduling algorithm which limits the amount of time during which the stations control the wireless medium, it improves the performance of the scheduler and it enhances its flexibility. It uses the mean TXOP as a guideline for allocating time and uses a token bucket scheme of time units or TXOP timer to allow nodes to vary their TXOP over time according to their needs. The TXOP timer of station j increases at a constant rate equal to TD_j/mSI_j (where mSI_j is minimum SI of j^{th} QSTA), which corresponds to the total fraction of time the station can spend in polled TXOPs. The TXOP timer has a maximum value equal to MTD_j (where MTD_j is the Maximum Time Duration of j^{th} QSTA). The time spent by a station in a polled TXOP is deducted from the TXOP timer at the end of the TXOP. The station can be polled only when the value of the TXOP timer is greater than or equal to mTD_j, which ensures the transmission of at least one packet at the minimum PHY rate.

The authors also propose to change the service interval for each node based on the traffic profile and use Earliest Deadline First (EDF) to determine the polling order. If the due time to poll a station is t, the next poll shall be issued on a time t' that satisfies the relation: $t+mSI < t' < t+MSI$. Time instant $t+mSI$ is the instant after which the next poll can be done, equivalent to the release time in the real-time scheduling theory. Time instant $t+MSI$ is the maximum time by which the next poll has to be done, or deadline time.

It has been shown that the proposed flexibility in the scheduler for voice and video traffic leads to significant reduction in average transmission delay (up to 33 percent) and packet loss ratio (up to 50 percent).

3.2 Fair HCF

FHCF [14] tries to improve the fairness both of CBR and VBR flows by assigning variable TXOPs. These are computed using queue length. Actually FHCF is composed of two schedulers: the QAP scheduler estimates the varying queue length for each QSTA before the next SI and compares this value with the ideal queue length. The QAP scheduler uses a window of previous estimation errors for each TS in each QSTA to adapt the computation of the TXOP allocated to that QSTA. Because sending rate and packet size can change, this estimation can not be accurate. After this comparison QAP computes the additional requested time (positive or negative) for each TS of each QSTA and reallocates the corresponding TXOP duration. Then, the node scheduler located in each QSTA can redistribute the unused time among its different TSs since the TXOP is always allocated to a whole QSTA. It computes the number of packets to transmit in the TS and time required to transmit a packet according to its QoS requirements. Later, according to its allocated TXOP, it evaluates the remaining time that can be re-allocated. This is possible since each QSTA knows its TS queue size at the beginning of polling phase and it is able to estimate its queue length at the end of TXOP and the requested additional time for TS.

A performance study indicates that FHCF provides good fairness while supporting bandwidth and delay requirements for a large range of network loads and, because it uses to allocate TXOPs the mean sending rate of VBR applications instead of the maximum sending rate usable for the standard HCF scheme, it may recover much time and more flows can accepted in HCCA. Furthermore, it is more efficient than the reference scheduler, admitting an higher number of traffic streams.

3.3 Feedback Based Dynamic Scheduler

FBDS [15] assigns dynamically the TXOP according to queue length estimation while SI remains fixed. All the QSTAs which compose the communication system and its transmission queues are regarded as a system whose balance is perturbed by new incoming flows. The FBDS periodic scheduler, which uses HCF, behaves as a closed loop controller which restores this balance by bandwidth recovering. This is possible due queue length information sent by each QSTA through a 8-bit subfield of QoS Control Field. Moreover the closed loop system uses a discrete time model which permits to estimate queue length at beginning of new CAP phase and so it acts as compensation system against errors produced by channel perturbations not previewed by the scheduling algorithm.

This algorithm guarantees the delay bounds required by audio/video applications in presence of very broad set of traffic conditions and networks loads by using a control system action which ensures a maximum delay for queuing new frames.

4. W-CBS

The QAP schedules traffic streams using an algorithm derived from the soft real-time scheduling literature, namely the Constant Bandwidth Server (CBS) scheduling algorithm [16]. The latter was modified to suit the needs of wireless traffic and named Wireless-CBS.

4.1 Scheduler description

For each traffic stream the QAP has to keep the following information:

- Q_i the budget of the stream.
- P_i its period.
- c_i its current capacity.
- d_i its absolute deadline.
- p_i its polling time.

Q_i and P_i have the same meaning as in the CBS, with Q_i being the maximum capacity, expressed in time units, that a stream i can consume in a period P_i; the choice of those values is based on the TSPEC for the stream i, and is done during the admission control phase. They do not change during normal execution flow.

On the other hand c_i, d_i and p_i represent the actual stream status. While c_i and d_i retain the same meaning they have in the CBS algorithm, c_i being the current capacity a stream has, and d_i its current deadline, a new state variable is introduced, p_i, that is, if the stream is an uplink one, the next time it will be polled when it has no more data to transfer or it has exhausted its TXOP.

Each stream can be in one of the following states:

Active : if it is a downlink stream it has packets to send, otherwise, if it is an uplink one, it has to be polled.

Idle : if it is a downlink stream, it has no packets to send.

Polling : if it is an uplink stream, it has to be polled, but it is still too early to poll it.

Active streams are scheduled by their deadline, that is dynamically updated as described in the following sections.

4.2 Admission Control

From the real-time theory we know that the CBS can schedule tasks if the following condition is met:

$$\sum_{i=0}^{N} \frac{Q_i}{P_i} \leq 1. \tag{1}$$

So, when admitting a stream i, the QAP has to calculate its Q_i and P_i, and to check if eqn. (1) holds. Given the TSPEC for i we define:

$$Q_{min} := \lceil \frac{R_i \cdot T_i}{Nss_i} \rceil, \quad Q_{max} := \lceil \frac{PR_i \cdot T_i}{Mss_i} \rceil$$

where R_i is the mean data rate, T_i is the period, Nss_i is the nominal SDU size, PR_i is the peak data rate, Mss_i is the maximum SDU size for the i^{th} TSPEC.

For W-CBS, we use: $Q_i = Q_{min} + CWF(Q_{max} - Q_{min})$. For P_i we use the maximum service interval (MSI).

As shown in Listing 1 the QAP keeps track of the allocated capacity, and when doing admission control it checks if a new stream would require more capacity than the system can provide. If it can be admitted and it is a downlink stream no more actions than updating the currently used capacity have to be performed, otherwise, if it is an uplink one, the stream is added to the polling list, with a poll time p_i equal to the current time, so that it will be polled as soon as possible, on the next call to the scheduler.

```
bool admit(tspec ts) {
  P = ts.max_SI;
  Q = calc_budget(ts);

  if (Q/P + used_bandwidth >
      MAX_BANDWIDTH)
    return false;
  used_bandwidth += Q/P;
  stream s = alloc_stream(ts);
  if (is_uplink(s)) {
    s.state = POLLING;
    s.poll_time = now();
    poll_enqueue(s);
  }
}
```

Listing 1: Admission Control

4.3 Enqueueing a Packet

When a packet arrives, the QAP has to check if its associated stream i was already active. If it was not, it has to check if the remaining c_i can be given to the stream without exceeding the Q_i/P_i utilization of the medium, otherwise it has to postpone the deadline of the stream, replenishing its capacity. The pseudocode for that operation is shown in Listing 2. If we are not in a CAP we have to start a new one as soon as possible.

```
enqueue(packet pkt, stream s) {
  if (is_idle(s)) {
    if (s.dline < now() ||
          s.capacity >
           (s.dline - now())*s.Q/s.P)
      postpone(s);
    pkt_enqueue(s, pkt);
    edf_enqueue(s);
    if (!is_cap())
      start_cap();
  }
}
```

Listing 2: Packet Enqueue

4.4 Dequeueing a Packet

When in a CAP the QAP has to chose the next packet to send, if first updates the status of the stream being served, changing its capacity as needed, and updating its deadline if necessary. Then it checks if there are polling streams that can be added to the active list (i.e., their p_i is passed,) changing their state and requeueing them if necessary.

It then requeues the active stream if it has switched to a polling or idle state or if it is no more the one with the earliest deadline, selecting the next task in Earliest Deadline First (EDF) order.

If there are no active streams a CP is started. If the selected stream i is an uplink one the corresponding station is given a TXOP of c_i, otherwise the packet to be sent is extracted from the QAP queues.

```
packet dequeue() {
  te_capacity(current);
  activate_polling_streams();

  if (is_polling(current))
    poll_enqueue(current);
  if (edf_preempted(current))
    edf_enqueue(current);
  if (!current || !is_active(current)
      || !edf_first(current))
    current = edf_dequeue();
  if (!current)
    return nil;
  if (is_uplink(current))
    return alloc_poll_pkt(s.capacity);
  pkt = pkt_dequeue(current);
  if (!more_packets(current))
    current.state = IDLE;
  return pkt;
}
```

Listing 3: Packet Dequeue

5. PERFORMANCE ANALYSIS

In this section we analyze W-CBS through simulation. We first define the traffic models and the metrics used in the performance analysis and the settings under which the latter is carried out and then describe the simulation scenarios. Finally we present simulation results.

5.1 Traffic model

We consider two types of QoS traffic transmitted through HCCA: VoIP and videoconference (VC).

We simulate a VoIP traffic stream as an ON/OFF source: during ON (talkspurt) periods the traffic is CBR with parameters that depend on the encoding scheme. The encoding scheme that we employ is the G.711 [17], which produces 50 packets of 160 bytes (including IP/UDP/RTP headers) per second. Talkspurt and silence periods are distributed according to Weibull distributions [18] with mean of 0.87 s and 1.58 s respectively.

We simulate Video Conference traffic according to a pre-encoded MPEG trace file (LectureHQ) from the Internet archive of traces [19]. MPEG4 encoders produce streams of frames of variable size at fixed intervals [20]. In our simulation analisys, the frame rate is 30 fps which corresponds to a frame interarrival time of about 33.3 ms, the average rate is about 158 Kb/s and the peak rate is about 2.7 Mb/s. In both VoIP and Video Conference (VC) traffic models the downlink and uplink traffic flows of a bi-directional TS are not correlated.

Data traffic, which posses non specific QoS requirements, is also considered. It transmits using DCF. Stations with data traffic operate in asymptotic conditions, i.e. they always have a frame to transmit. The packet length of data traffic is constant and equal to 1500 bytes.

5.2 Simulation settings

The physical layer parameters are those specified by the High Rate Direct Sequence Spread Spectrum (HR-DSSS) [21], also known as 802.11b, and are reported in Table 1.

Table 1: MAC/PHY simulation parameters

Parameter	Value
SIFS (μs)	10
PIFS (μs)	30
DIFS (μs)	50
SlotTime (μs)	20
PHY header(μs)	192
Data rate (Mb/s)	11
Basic rate (Mb/s)	1
Bit error rate (b/s)	0

We focus on the system performance in ideal conditions so we assume that the channel is error-free, while MAC level fragmentation and multirate support are disabled. Furthermore we assume that all nodes can directly communicate with each other. Therefore, the hidden node problem and the packet capture are not taken into consideration and the RTS/CTS protection mechanism is disabled.

We have implemented the proposed W-CBS in the ns-2 network simulator [22], using the HCCA implementation framework described in [23]. Then we compared the results with respect of reference IEEE 802.11e standard scheduler. The analysis has been carried out using the method of independent replications. Specifically we ran independent replications of 600 seconds each with 100 seconds warm-up period until the 95% confidence interval is reached for each performance measure. Confidence intervals are not drawn whenever negligible.

5.3 Admission control analysis

We first evaluated the performance of W-CBS in terms of the admission control limit.

Fig. 1 shows the number of admitted videoconference TSs, as a function of the number of admitted VoIP G.711 TSs. In both cases, the sample scheduler curve lies significantly below the W-CBS curve. This behavior confirms that the sample scheduler cannot efficiently accommodate TSs with different TSPECs. In fact, firstly, it polls TSs with $\Delta i > SI$ more often than needed, by setting the scheduling duration to the smallest TS period. Secondly, it overestimates the capacity needed by TSs.

In Figs. 2 and 3 we evaluate a scenario with up to six stations with VoIP or videoconference traffic and we report the data throughput reached by the stations with data traffic.

If there are not any stations with CBR or VBR TSs, the data throughput is maximum and the W-CBS behaves in a very similar way to the reference scheduler. Otherwise, if there are TSs with significantly different delay bound requirements, such as the VoIP and VC TSs, the MAC over-

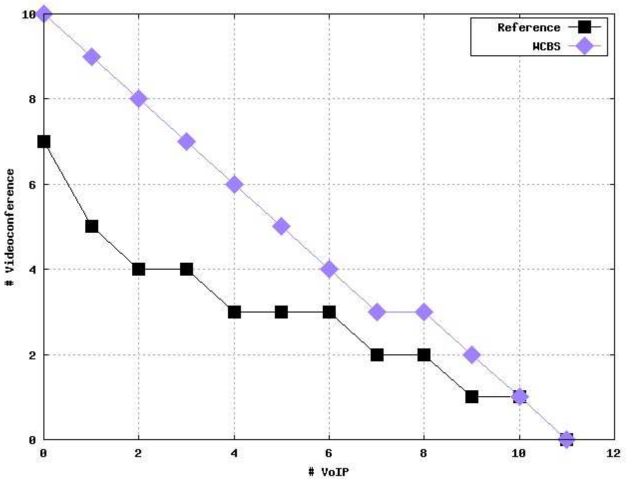

Figure 1: Admission control. Number of admitted videoconference TSs against the number of admitted VoIP G.711 TSs.

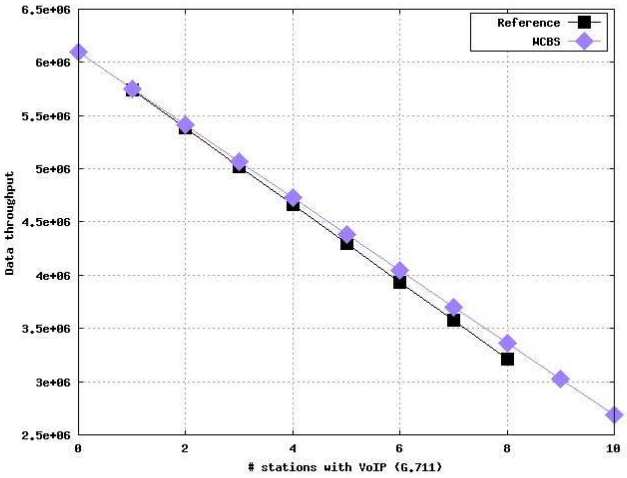

Figure 2: Data Throughput vs. number of VoIP G.711 stations.

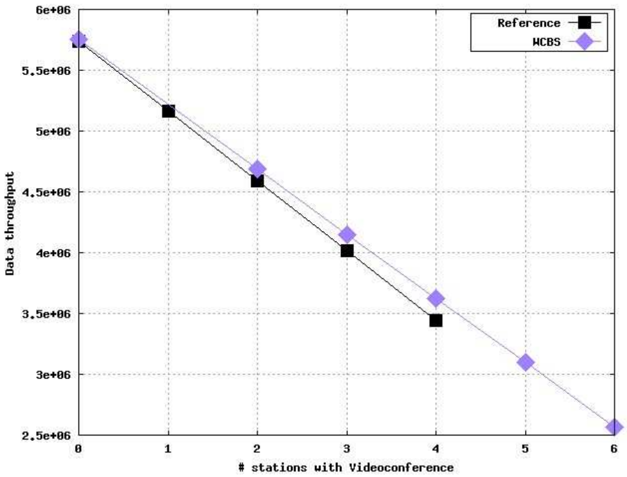

Figure 3: Data Throughput vs. number of VC stations.

head of the reference scheduler is higher than that with W-CBS and, therefore, the throughput achievable by data traffic is much lower.

5.4 Uplink VBR traffic only

Here we analyze the performance of VBR traffic, in terms of delay, with an increasing number of QSTAs each having un uplink VC TS. TSs are provided with a reserved rate equal to the average of the application, which is much lower than its peak rate. The average polling interval, reported in Fig. 4 increased when the number of QSTAs increased. When the average polling interval is higher than 33 ms, which is the frames generation interval, in most cases, the duration of the TXOP granted by the QAP is enough for the QSTA to clear its backlog. Hence, the QSTA indicates to the QAP an empty TS queue. The QAP, in turn, will poll the TS after 33 ms have elapsed. This fixed contribution to the polling interval sums up to the increasing average round duration, which accounts for the increasing delay curve.

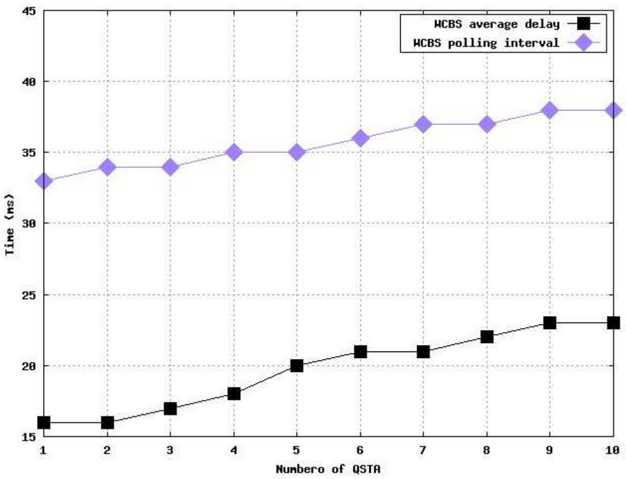

Figure 4: Delay and average polling interval with uplink VBR traffic.

5.5 Bi-directional CBR and VBR traffic

In this scenario we compare the performance of the framework scheduler with mixed CBR and VBR traffic. To do so, we set up an increasing number of QSTAs, from 1 to 6, each having a bi-directional VoIP TS and a bi-directional VC TS. The delay bound value of VoIP TSs is set to 20 ms, and that of VC TSs to 33 ms. Figure 5 shows the the delay of VoIP and VC traffic, respectively.

VoIP traffic:

the downlink curve lies significantly below the uplink one, on the one hand, each node associated to a downlink TS is added to the round robin list as soon as the TSs queue becomes backlogged; therefore, the service delay is only due to the time that it takes for the server to cycle through the backlogged nodes.

VC traffic:

the same line of reasoning holds for VC traffic, as well. In fact, in downlink, the VC curves are almost overlapping with the VoIP ones. On the other hand, in uplink, the delay percentile is always larger than the VC packet generation interval, i.e., 33 ms.

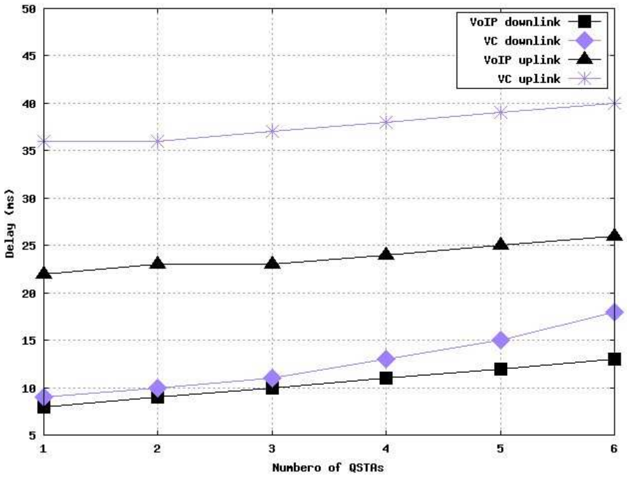

Figure 5: Delay with bi-directional CBR and VBR traffic.

6. CONCLUSIONS

In this paper we have presented a new scheduling algorithm alternative to the reference scheduler to integrate a QoS support in wireless networks under time-varying network conditions and different traffic specifications. It is based on CBS Real-Time algorithm which permits to dynamically manages the medium resources. The adopted scheduler supports real-time applications, variable packet size and variable bit rate traffic streams. Even if the centralized system of HCCA results in the deterministic nature of admission control, we show that many improvements to the reference scheduler can be obtained, especially for VBR streams. The simulation analysis shows that WCBS outperforms the reference scheduler in term of resource utilization and maximum admitted flows.

7. ACKNOWLEDGEMENTS

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