A Low Complexity IEEE802.11e Scheduling Scheme for Efficient Wireless Delivery

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Abstract— **In this work, a novel algorithm is presented, suitable for deriving effective service scheduling schemes under the Hybrid Controlled Channel Access (HCCA) method employed as the centralized polling mechanism for parameterized channel access in the IEEE802.11e specification. Compared to existing service schedulers, the proposed novel algorithm demonstrates a significant bandwidth management improvement and optimal QoS performance, especially for high-quality audio/video streaming applications.**

Keywords-Quality of Service, WLAN, Multimedia Bandwidth Scheduling

I. INTRODUCTION

The IEEE 802.11 Wireless Local Area Networks (WLANs) standard represents a rapidly emerging technology for a wide range of applications, such as broadband wireless access and digital media distribution within home environments [1]. The major benefit from WLANs is the convenient access in hard-to-wire locations and the increased mobility, using low-cost, fully interoperable wireless equipment. Hence, the integration of WLANs with audio/video playback devices is expected to produce wireless home products with significant benefits, mainly in terms of setup simplicity/flexibility and limited interconnecting cost.

Figure 1 illustrates the general application framework of a typical wireless home theatre setup. A WLAN Access Point (AP) is connected to (or integrated within) the central audio/video control system (i.e. a digital audio/video receiver) which wirelessly distributes the encoded digital audio/video content concurrently to multiple points (typically to six loudspeakers and one TV display).

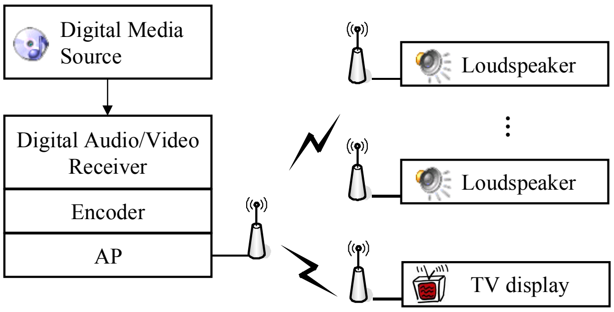

Figure 1. General architecture of wireless home theatre applications

Although a number of 802.11 WLAN amendments already exist (focusing for example on enhanced security [2] and higher transmission rates [3]), no reliable Quality of Service (QoS) support can be potentially achieved, in order to support digital audiovisual content streaming in real-time, as the basic access mechanisms defined in the legacy 802.11 standard (namely the Distributed Coordination Function – DCF and the Point Coordination Function – PCF) fail to provide strict transmission guarantees to time critical traffic flows [4]. Towards this aim, an additional 802.11 amendment was recently ratified [5] named 802.11e for defining a set of QoS enhancements to the Medium Access Control (MAC) layer under a novel access coordination strategy termed Hybrid Coordination Function (HCF). This novel access scheme is realized by the Hybrid Coordinator (HC) located within the Access Point (AP) and employs two different channel access schemes: a) the contention-based Enhanced Distributed Channel Access (EDCA) for differentiated QoS services and b) the polling-based Hybrid Controlled Channel Access (HCCA), which provides parameterized QoS services.

Under HCCA, the HC controls the channel access and allocates the available bandwidth resources using a traffic scheduling mechanism that coordinates the polling process among all serviced wireless stations (STAs). This algorithm, usually referred as “service scheduler”, represents one of the basic research areas for the 802.11e technology, as its functionality affects the overall QoS performance. The 802.11e specification encourages the development of optimized service schedulers, such as the FHCF introduced in [11]. In practice, the choice of a specific scheduler design and implementation should be based on the targeted application.

In this work, a novel HCCA scheduler called WAVES (Wireless Access using Variable Expansion Scheduling) is introduced that aims to optimize the overall bandwidth management for real-time, high-quality digital audio/video applications. The rest of the paper is organized as follows: Section II outlines the 802.11e mechanisms for QoS support. In Section III, a brief description of previously published transmission scheduling techniques is provided, and an analysis of the proposed WAVES scheduler is introduced in Section IV. Finally, in Section V, the test methodology followed for obtaining the results is described, leading to the conclusions summarized in Section VI.

978-1-4244-1688-2/08/$25.00

II. OVERVIEW OF 802.11E QOS SUPPORT

According to the 802.11e protocol, QoS-enabled stations (QSTAs) obtain access to the medium within specific time intervals termed as transmission opportunities (TXOPs). Each TXOP is defined by an implicit starting time and a maximum-allowed transmission length. Using EDCA, the QSTAs contend for TXOPs during the Contention Period (CP), using a set of contention parameters organized in four independent, prioritized backoff entities called Access Categories (ACs). Each AC contends for medium access using a priority-based access scheme similar to the legacy DCF backoff mechanism, combined with a specific set of EDCA backoff parameters (e.g. interframe space, contention window, etc), which corresponds to the specific AC and realizes the AC prioritization. For AC differentiation, it is very important that the same EDCA parameters' values are used by all backoff entities that belong to a specific AC. Hence, the EDCA parameters are defined and announced by the HC and must be followed by all contending QSTAs.

Although EDCA achieves improved QoS performance (especially for high-priority traffic), its contention nature cannot provide strict service guarantees under all channel and network conditions [6] (i.e. for high rate, variable traffic loads, traffic congestion, etc). To overcome this, under HCCA, TXOPs are centrally allocated by the HC through a polling mechanism, during both the Contention and Contention Free Period (CFP). The polling instances and sequence, as well as the maximum TXOP lengths represent a complete service schedule, which is calculated by the HCCA service scheduler based on the Traffic Specification (TSPEC) parameters sent by the requesting traffic. The admission of a requesting stream is subject to an Admission Control Unit (ACU), provided that the QoS guarantees already granted to all previously admitted streams will be satisfied after the new admission.

It must be noted that according to the 802.11e specification, EDCA-based transmissions may be also subject to certain channel access restrictions in the form of a similar TSPEC-based admission control mechanism, which provides guarantees on the amount of time an admitted traffic will access the wireless medium. Hence, the TSPEC values represent a very critical parameter for accepting traffic requests, thus they must be carefully selected for accurately representing a traffic flow. A typical set of TSPEC values for well-known types of traffic is provided in [7]. The main TSPEC parameters are presented in Table I.

Moreover, from the above description it is clear that HCCA requires the presence of a contention-based method (e.g. legacy DCF or EDCA) at least in order to establish and control the polling mechanism between the HC and the QSTAs during the CP. Hence, a small portion of the complete beacon interval length must be reserved for contention based traffic. Although HCCA is allowed to expand over the CP, the above restriction must be taken into account by the ACU and the HC during the service schedule calculation. An algorithm for reserving time / bandwidth only for contention-based access is defined in [8].

TABLE I. MAIN TSPEC PARAMETERS

Parameter name	Units	Description
Mean data rate (p)	bps	the average data rate produced by the traffic source
Peak data rate (pk)	bps	the maximum data rate produced by the traffic source
Delay Bound (DB)	msec	the maximum allowed delay for successful packet delivery (including all queuing delays)
Nominal MSDU size (L)	Octets	the nominal size of the MAC Service Data Units (MSDUs)
Maximum MSDU size (M)	Octets	the maximum size of the MSDUs produced by the traffic source
Maximum Burst Size (MBS)	Octets	the maximum size of a data burst produced at the peak data rate
Minimum Service Interval (minSI)	msec	the minimum allowed time length between two TXOPs
Maximum Service Interval (maxSI)	msec	the maximum allowed time interval between two TXOPs
Minimum physical rate (R)	bps	the minimum physical (PHY) transmission bit rate
User Priority (UP)	-	the traffic priority

III. HCCA SERVICE SCHEDULERS

Although the 802.11e specification encourages the development of application specific service scheduling schemes, it clearly defines the minimum requirements that must be met by any scheduler by introducing the Simple scheduler reference design. The Simple scheduler uses all the mandatory TSPEC parameters that must be employed by any scheduling technique, namely the Mean Data Rate (p), the nominal (L) and maximum (M) MSDU size, as well as the maximum service interval (maxSI), and calculates the i-th QSTA TXOP length as:

$$TXOP_i = max\left(\left\lceil \frac{SIxp_i}{L_i} \right\rceil \frac{L_i}{R_i} + O, \frac{M}{R_i} + O\right) \tag{1}$$

The value O in the previous equation represents all the MAC layer overheads introduced by the 802.11e signaling. SI is the Service Interval (in msec) calculated as the first sub multiple of the beacon interval that is less than the minimum of all maxSIs for all admitted streams. This calculation approach ensures that all calculated service schedules will conform to the maxSI values declared by all the serviced flows.

Obviously, when using the Simple scheduler, the TXOP starting times are constant within each SI, as the polling operation is performed in a serial manner. An example of TXOP allocation using the Simple scheduler is illustrated in Figure 2, where SI=50ms and 2 polled QSTAs hosting 1 TS each are considered.

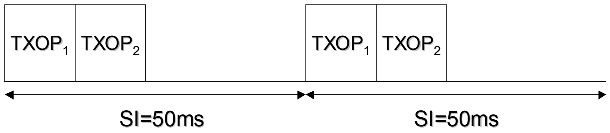

Figure 2. Typical TXOP schedule using the Simple scheduler

The resulting strict periodic TXOP allocation scheme derived by the Simple scheduler renders it insufficient under the presence of channel interference and / or for streaming bursty or variable bit rate traffic. An improved adaptive scheduling algorithm termed as Scheduling based on Estimated Transmission Times - Earliest Due Date (SETT-EDD) was introduced in [9], which achieves better QoS performance for variable rate streaming applications. However, as it will be shown in the following Section, especially for digital home theatre applications, this algorithm demonstrates low performance and introduces high implementation complexity.

IV. DESCRIPTION OF THE WAVES SCHEDULER

The proposed WAVES scheduling technique overcomes the above problems by dynamically adapting the service schedule according to the monitored network conditions. More specifically, using the WAVES technique a fixed service schedule (similar to the one derived using the Simple scheduler) is initially calculated using the following equation:

$$TXOP_i = \frac{p_i x BeaconInterval}{R_i x N} + O \tag{2}$$

where N is the number of the service intervals (SIs) existing in one beacon interval (denoted here as BeaconInterval and measured in msec). The HC then starts polling the QSTAs, following this schedule. Additionally, the HC continuously monitors the pending QSTAs traffic, using the Queue Size value in the QoS control field of the frame(s) transmitted within each TXOP. The HC aggregates this information obtained by the serviced QSTAs. If the pending queue for a specific QSTA is greater than the current TXOP data capacity, the HC attempts to expand the corresponding TXOP length by an appropriate time-length calculated as a function of the ratio of the Queue Size value with the aggregated pending traffic and the portion of SI not assigned to TXOPs.

The TXOP expansion is allowed only if it does not violate the maximum service interval of the TSs that are being polled within the same SI after the specific TXOP. Otherwise, the TXOP is not expanded, but instead, the HC attempts to re-poll the specific QSTA immediately after the end of all the scheduled TXOPs within the current SI. The duration of the additional TXOP equals to the expansion length calculated previously. Obviously, the HC re-polling transmission durations are limited up to the beginning of the next scheduled SI.

TXOP expansion/re-allocation can be calculated per SI or per beacon interval basis. In the first case, the bandwidth allocation adaptation is more accurate, at the expense of increased calculation load. In this work, the service schedule adaptation was performed per beacon interval basis.

A typical example of the bandwidth allocation scheme derived by the WAVES scheduler TXOP expansion/re-allocation algorithm is illustrated in Figure 3, where the instantaneous admitted capacity measurement is presented as a function of time, defined as the (%) portion of the beacon interval allocated for QSTAs transmissions through TXOPs. For demonstration purposes, heavy channel quality degradation is applied between the 30th and the 37th second of absolute simulation time.

In the same Figure, the admitted capacity derived by the Simple and the SETT-EDD schedulers is also depicted. In the first case, due to the constant TXOP allocation scheme applied, the instantaneous admitted capacity value is kept also constant, resulting in significant packet losses during the channel degradation time interval due to transmission buffer overflows. The same trends are also observed in the case of the SETT-EDD scheduling mechanism, which reserves nearly the 100% of the available bandwidth in order to implement the necessary signaling required for deriving the exact service schedule. However, in the case of the WAVES scheduler, the portion of bandwidth allocated for wireless transmissions is variable due to the TXOP expansion or re-allocation. Especially during the channel degradation period, all the bandwidth initially not admitted for transmissions can be additionally allocated to serve retransmissions in order to overcome the excessive packet losses and meet the initial QoS guarantees.

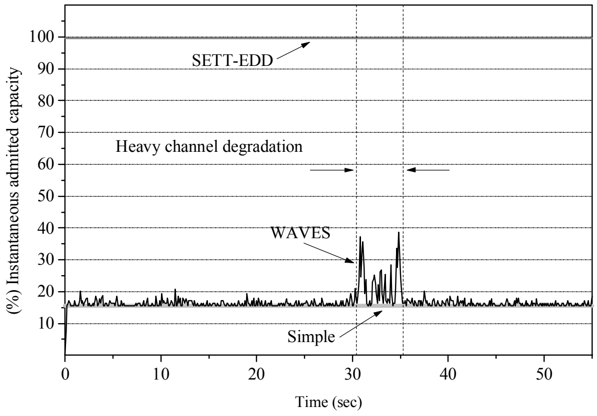

Figure 3. Measured instantaneous admitted capacity

V. TEST METHODOLOGY AND RESULTS

The functionality of the WAVES scheduler was simulated using the HCCA simulation environment presented in [10]. The simulation scenario considered a typical digital home theatre setup consisting of: a) six wireless QoS-enabled audio receivers/loudspeakers reproducing CD-quality linear PCM audio streams with 16bit resolution and sampling frequency equal to 44.1kHz and b) a wireless standard definition (SDTV) video receiver. The corresponding audio and video TSPECs are shown in Table II.

TABLE II. AUDIO/VIDEO TSPEC PARAMETERS

TSPEC parameter	PCM-audio	SDTV
Mean/Peak data rate	743.9kbps	6000kbps
Delay Bound	10 msec	64 msec
Nominal MSDU size	930 bytes	1364 bytes
Maximum MSDU size	930 bytes	1364 bytes
Maximum Burst Size	930 bytes	1364bytes
MinSI	0 msec	0 msec
MaxSI	10 msec	16 msec
Minimum physical rate	54Mbps	54Mbps

All QSTAs and the QAP were compatible with the 802.11g standard, operating at a PHY transmission rate equal to 54Mbps. Two different wireless channel models were considered: the ideal channel, which allows completely error-free wireless transmissions between all QSTAs/QAP and the non-ideal wireless link model, obtained from real world MAC-layer transmission error measurements. The simple and the SETT-EDD schedulers were also employed for a direct comparison with the proposed WAVES scheduling scheme.

Figure 4 compares the WAVES scheduling scheme to the Simple and the SETT-EDD schedulers in terms of the measured MAC layer mean throughput for the ideal wireless channel case. The mean throughput value for all six digital audio streams and the video stream separately is presented, as well as the corresponding mean value for the complete audio/video stream. The same measurements also appear in Figure 5 in the case of the non-ideal wireless link. Clearly, the WAVES scheduler achieves the optimal throughput performance in all three cases (audio only, video and mixed audio/video streams), which is almost equal to the aggregated offered traffic load.

It should be also noted that in the non-ideal wireless channel model, both Simple and SETT-EDD algorithms demonstrate a significant throughput degradation, due to the additional packet losses imposed by the link error model and the inability to adaptively provide adequate additional bandwidth for packet retransmissions. Hence, data transmission queue overflows occur, resulting into permanent data losses, increased transmission delay values and throughput decrement. However, in the case of the WAVES scheduler, as explained in the previous Section, the service adaptation mechanism efficiently re-allocates additional HCCA TXOPs or transmission lengths. Hence, adequate packet re-transmissions can be served.

The same trends are observed when measuring the mean MAC-layer packet delay (Figures 6 and 7) for the audio and video streams separately, as well as the mixed digital audio/video data. For all test cases considered, the non-ideal channel model employment slightly increases the measured mean delay value. However, the delay was lower when the WAVES scheduler was employed, due to the accurate transmission/retransmission scheduling achieved by the TXOP expansion/re-allocation scheme.

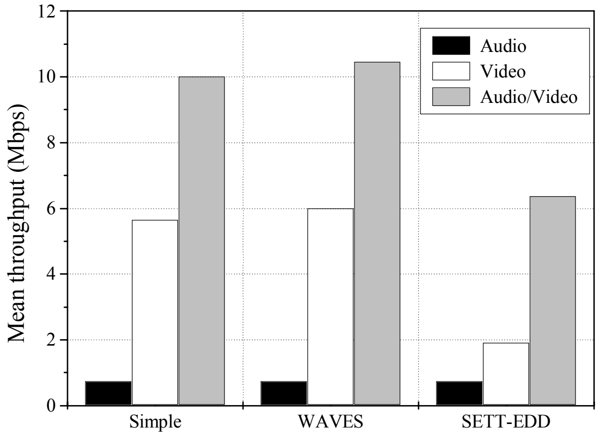

Figure 4. Mean throughput measurement for ideal channel

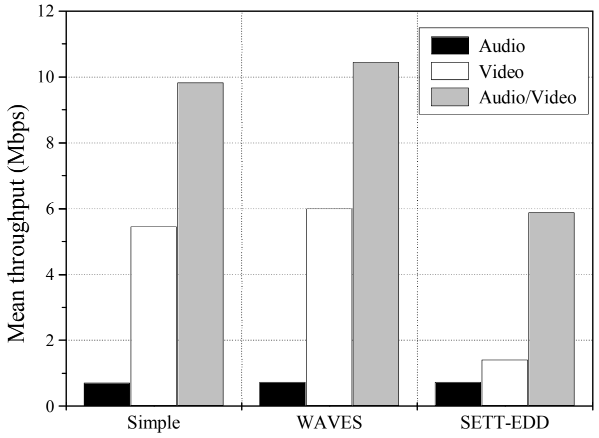

Figure 5. Mean throughput measurement for non-ideal channel

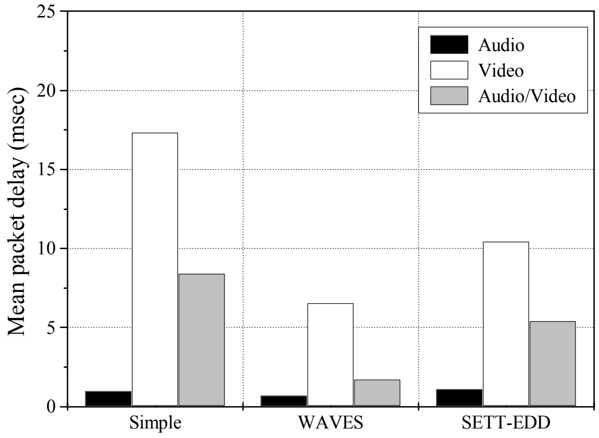

Figure 6. Mean packet delay for ideal channel

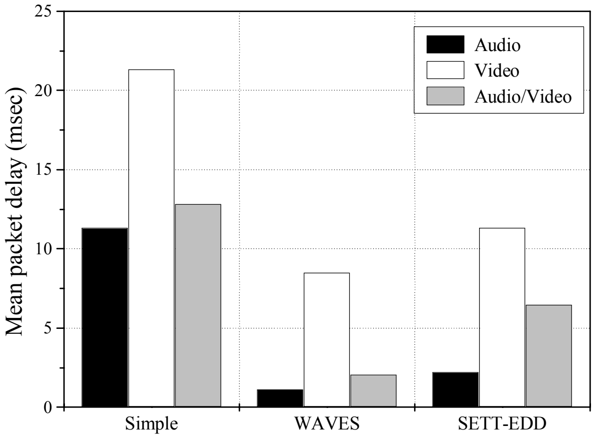

Figure 7. Mean packet delay for non-ideal channel

Apart from the improved QoS performance, another advantage of the WAVES algorithm is the low schedule calculation complexity, as illustrated in Table III, where the measured Computational Complexity is shown, defined here as the (%) ratio of the amount of time spent by the HC for calculating the service schedule to the total amount of the simulation duration. Provided that all simulations were performed on the same computer system, this metric represents a close approximation of the scheduling calculation complexity.

In Table III, the values in italics denote the Computational Complexity in the case of the non-ideal wireless channel. Clearly, the WAVES computational complexity is lower than the SETT-EDD algorithm. Compared to the Simple Scheduler, the WAVES scheduler introduces a small computational load increment, due to the TXOP re-allocation processes. However, this increment is very low and can be considered to be negligible for practical implementations in embedded systems.

TABLE III. MEASURED SCHEDULING COMPUTATIONAL COMPLEXITY

Computational Complexity	**Value**
Simple	0.4% *0.4%*
WAVES	0.6% *0.9%*
SETT-EDD	8.4% *9.6%*

VI. CONCLUSIONS

In this work, a novel HCCA service scheduler is introduced, optimized for the efficient delivery of audio/video high-quality, real-time streams. The proposed scheduler overcomes the bandwidth management problems induced by existing scheduling schemes and it is shown that it achieves high QoS performance, using an enhanced bandwidth management mechanism. This mechanism continuously monitors the network conditions and, if necessary, dynamically re-allocates a portion of the available bandwidth to the serviced traffic flows, provided that the QoS guarantees already granted to the admitted TSs are preserved. Hence, any network conditions degradations (e.g. heavy channel interference or degradation) that result into data losses and significant packet delays are transparent in terms of QoS performance.

The performance of the proposed scheduling scheme was evaluated in the case of servicing wireless high-quality audio/video delivery in a typical home theatre setup consisting of six full-bandwidth PCM-encoded audio streams and a concurrent digital video traffic. Using a sequence of tests it was found that the WAVES scheduler represents an optimized solution for managing the bandwidth available through typical WLAN environments.

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