Traffic Scheduling for Multimedia QoS over Wireless LANs

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***Abstract*—In this paper we present a novel traffic scheduling algorithm for IEEE 802.11e, referred to as *ARROW* (Adaptive Resource Reservation Over WLANs), able to handle multimedia traffic. The novel characteristic of ARROW is that it performs channel allocations based on the actual traffic (not estimated traffic) buffered in the various mobile stations. Additionally, a variation of ARROW is studied for improving the performance for constant bit rate traffic. The ARROW algorithm and its enhancement are evaluated against two other schedulers found in the literature, namely the Simple Scheduler and SETT-EDD. Results from a detailed simulation model show that much better channel utilization and considerably improved performance can be provided.**

A. INTRODUCTION

The IEEE 802.11 standard [1] is considered today the dominant technology for wireless local area networks (WLANs). Besides great research interest, 802.11 has enjoyed widespread market adoption in the last few years, mainly due to low-price equipment combined with high bandwidth availability. However, one of the main weaknesses of 802.11, towards efficient support of multimedia traffic, is the lack of its Medium Access Control (MAC) protocol to provide enhanced Quality of Service (QoS) features. In order to eliminate these weaknesses, IEEE established a dedicated task group with the aim to provide an amendment to the standard 802.11, referred to as IEEE 802.11e, that enhances the existing MAC protocol towards multimedia QoS provision.

In IEEE 802.11e [2], the QoS mechanism is supervised by the Hybrid Coordinator (HC), and utilizes a combination of a contention-based scheme, referred to as Enhanced Distributed Coordination Access (EDCA), and a polling-based scheme, referred to as HCF Controlled Channel Access (HCCA), to provide QoS-enhanced access to the wireless medium.

This paper focuses on HCCA which provides parameterized QoS services to traffic streams based on the traffic specifications and QoS requirements of these streams. To perform this operation, the HC incorporates a scheduling algorithm that decides on how to allocate the available radio resources to the polled stations called *QoS Stations (QSTAs)*. In what follows we describe and study a new scheduling algorithm referred to as *ARROW (Adaptive Resource Reservation Over WLANs)* that aims at improving the performance attained so far with existing scheduler proposals.

B. ACCESS MODES IN IEEE 802.11E

In 802.11e access to the wireless channel is composed of Contention-Free Periods (CFPs) and Contention Periods (CPs), controlled by the HC. EDCA is used in CPs only, while HCCA is used in both periods. A basic concept in 802.11e is the *Transmission Opportunity (TXOP)*, defined as an interval of time when a QSTA has the right to initiate transmissions. A TXOP is described by a starting time and a maximum duration. TXOPs are assigned via contention using EDCA or granted through HCCA.

Although proper differentiation with EDCA can lead to improved performance especially for high priority traffic, its contention-based operation cannot guarantee specific levels of QoS at all times. HCCA, on the other hand provides the HC with the ability to assign contention-free TXOPs during both the CP and the CFP. Through these polls, the HC can explicitly assign a TXOP to a particular QSTA for a specific duration of time. The major responsibility of the HC is to assign TXOPs in such a way that ensures the traffic and QoS characteristics of all *Traffic Streams (TSs)*, as expressed through their *Traffic Specifications (TSPECs)* [2], [3].

The draft amendment of IEEE 802.11e [2] includes an example scheduling algorithm, referred to as the *Simple Scheduler*, to provide a reference for future, more complicated algorithms. The idea of this algorithm is to schedule fixed batches of TXOPs at constant time intervals. Each batch contains one fixed length TXOP per QSTA, based on mean data rates as declared in the TSPECs. With this discipline the Simple Scheduler respects the mean data rates of all TSs and performs well when the incoming traffic load does not deviate from its mean declared value; however it is inefficient when it comes to bursty or variable bit rate traffic.

Identifying the weaknesses of the Simple Scheduler mentioned earlier, several proposals for Schedulers have been developed trying to improve the attained performance [3], [4], [5], [6]. The scheduling algorithm proposed in [3] provides improved flexibility by allowing the HC to poll each QSTA at variable intervals, assigning variable length TXOPs. The algorithm is referred to as *"Scheduling based on Estimated Transmission Times - Earliest Due Date"* (SETT-EDD), indicating that TXOP assignments are based on earliest deadlines, to reduce transmission delay and packet losses due to expiration. SETT-EDD is a flexible and dynamic scheduler, but it lacks an efficient mechanism for calculating the exact required TXOP duration for each QSTA transmission. TXOP duration is calculated based on estimations derived from the mean data rate of each TS and the time interval between two successive transmissions, a scheme that is not efficient for bursty traffic.

C. Description of ARROW Scheduler

In Simple and SETT-EDD schedulers discussed in the previous section, TXOP durations are calculated by using some kind of estimation of the amount of data waiting to be transmitted by every QSTA. The scheduling algorithm described in this section is referred to as *"Adaptive Resource Reservation Over WLANs"* (ARROW), and an earlier version of this algorithm, without the enhancement to improve performance for CBR traffic, has been presented in [7]. ARROW adapts TXOP reservations based on real-time requirements declared by the QSTAs. To achieve this, ARROW utilizes the ***Queue Size (QS)*** field, introduced by 802.11e [2] as part of the new *QoS Data* frames, not supported by legacy 802.11 systems. The QS field can be used by the QSTAs to indicate the amount of buffered traffic for their TSs, i.e., their transmission requirements. A scheduler that utilizes this information should allocate TXOPs to QSTAs in such a way that satisfies these transmission requirements, as long as they comply with the traffic specifications declared through the TSPECs.

1st. Scheduling Parameters

Before proceeding with the description of ARROW it is essential to refer to some parameters that are utilized by the HC in order to calculate an aggregate service schedule for a $QSTA_i$ having n_i active TSs. These parameters can be derived from the individual TSPEC parameters [8]:

Minimum TXOP duration (*mTD*): This is the minimum TXOP duration that can be assigned to a QSTA.

Maximum TXOP duration (*MTD*): This is the maximum TXOP duration that can be assigned to a QSTA.

Minimum Service Interval (mSI): It is the minimum time gap required between the start of two successive TXOPs assigned to a specific QSTA.

Maximum Service Interval (MSI): It is the maximum time interval allowed between the start of two successive TXOPs assigned to a QSTA.

Delay Bound (D): maximum delay allowed to transport a packet across the wireless interface (including queuing delay), in milliseconds.

Minimum physical rate (R): physical bit rate assumed by the HC for transmission time and admission control calculations, in units of bits per second.

2nd. Operation of ARROW Scheduler

An example of the use of QS in ARROW is depicted in Figure 1. The allocation procedure will be described later in this section. For simplicity, one TS per QSTA is assumed. At time $t_i(x)$, $QSTA_i$ is assigned $TXOP_i(x)$, according to requirements declared earlier through the QS field. Using a *QoS Data* frame, $QSTA_i$ transmits its data together with the current size of its queue in the QS field ($QS_i(x)$). At time $t_i(x+1)$ the scheduler assigns $TXOP_i(x+1)$ to $QSTA_i$, in order to accommodate part or all of $QS_i(x)$. During the interval $[t_i(x), t_i(x+1)]$ new data are generated in $QSTA_i$, therefore $QSTA_i$ uses the *QoS Data* frame transmitted at $TXOP_i(x+1)$ to indicate the new queue size ($QS_i(x+1)$). In the same manner, at $t_i(x+2)$ the scheduler assigns $TXOP_i(x+2)$ to $QSTA_i$, accommodating part or all of the data declared in $QS_i(x+1)$ and gets the new queue size from $QSTA_i$ ($QS_i(x+2)$). As clearly shown, by utilizing the QS field, ARROW has very accurate information about the time varying properties of each TS, and is able to adapt the TXOP duration accordingly. This is considered essential, especially in the case of bursty and VBR traffic, where transmission requirements are time varying.

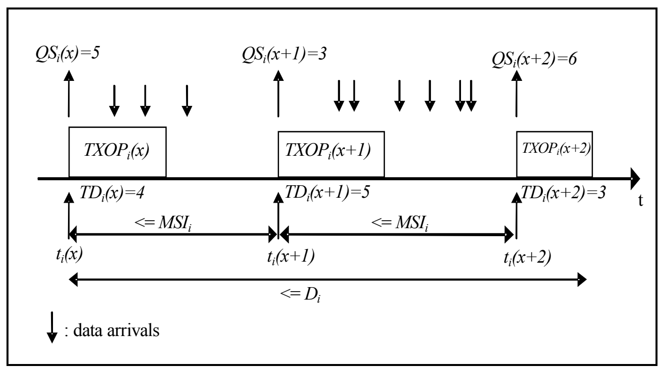


Figure 1. TXOP assignment with ARROW

As can be observed in Figure 1, for every $QSTA_i$, data arriving within the interval $[t_i(x), t_i(x+1)]$ can be transmitted no earlier than $TXOP_i(x+2)$ starting at $t_i(x+2)$. Therefore, in order not to exceed the delay deadline of MSDUs, assuming the worst case that service intervals are equal to MSI_i and $TXOP_i(x+2)=MTD_i$, it should hold that:

$$D_i \geq 2MSI_i + MTD_i \Leftrightarrow MSI_i \leq \frac{D_i - MTD_i}{2} \qquad (1)$$

Based on the above discussion, the operation of ARROW is as follows:

1. The scheduler waits for the channel to become idle.

2. When the channel becomes idle at a given moment t, the scheduler checks for QSTAs that can be polled without violating mSI and MSI, i.e., for a $QSTA_i$ that was last polled at time t_i, it should hold that:

$$t_i + mSI_i \le t \le t_i + MSI_i \qquad (2)$$

3. If no QSTAs are found, the scheduler proceeds to the next time slot and returns to step 1.
4. In different case, the scheduler polls the QSTA with the earliest deadline. The deadline for a $QSTA_i$ is the latest time that this QSTA should be polled, i.e., t_i+MSI_i, where t_i is the time of the last poll for $QSTA_i$.
5. Assuming $QSTA_i$ having n_i active TSs is selected for polling, the scheduler calculates the TXOP duration TD_i, in two steps:

   a. First, for every TS_{ij} of $QSTA_i$ ($j=1\ldots n_i$), the scheduler calculates TD_{ij}, as the maximum of (a) the time required to accommodate the pending traffic, as indicated by the queue size of that TS (QS_{ij}), plus any overheads, and, (b) mTD_{ij}, to ensure that the assigned TXOP will have at least the minimum duration:

$$TD_{ij} = \max\left(\frac{QS_{ij}}{R_{ij}} + O, mTD_{ij}\right) \qquad (3)$$

   In the special case where QS_{ij} is equal to zero, TD_{ij} is set equal to the time for the transmission of a Null-Data MSDU [2], to allow $QSTA_i$ to update the queue size information for TS_{ij}.

   b. TD_i for $QSTA_i$ is calculated as the sum of all TD_{ij}:

$$TD_i = \sum_{j=1}^{n_i} TD_{ij} \qquad (4)$$

6. After the scheduler assigns the TXOP, it returns to step 1:

3rd. Enhancement for CBR Traffic

The exploitation of queue size information for calculating accurate TXOP durations is particularly effective for both Constant Bit Rate (CBR) and Variable Bit Rate (VBR) traffic, but introduces some extra delay and increases the transmission overhead percentage. For VBR traffic this seems to be unavoidable, since its behavior cannot be accurately predicted. On the other hand, due to its periodic nature, CBR traffic has a much more predictable behavior. An enhanced version of ARROW scheduler can take advantage of this characteristic to reduce overhead and delays. To differentiate the two versions of the algorithm, we refer to *"basic ARROW"* and *"enhanced ARROW"*. The idea behind the enhancement is that, instead of waiting for the QS information or use Null-Data TXOPs to get the current queue size, the scheduler can estimate the current queue size of a CBR TS. Every time a TXOP is assigned to a QSTA with CBR TSs, the scheduler calculates the TXOP duration for each of these TSs by adding the queue size value indicated by the previous MSDU transmission of the same TS and the estimated (using Mean Data Rate, ρ) generated traffic in the time interval between the previous and the current transmission. Accordingly, for CBR TSs equation (3) can be replaced by:

$$TD_{ij} = \max\left(\frac{QS_{ij} + \left(\frac{\rho_{ij}}{t - t'}\right)}{R_{ij}} + O, mTD_{ij}\right) \quad (5)$$

Assuming a CBR TS in Figure 1, the duration of $TXOP_i(x+1)$ is calculated based on the $QS_i(x)$ and the estimation for the generated MSDUs within the interval $[t(x), t(x+1)]$. This estimation is very accurate for CBR TSs, leading to considerably lower transmission delays, since the MSDUs generated in the interval $[t(x), t(x+1)]$ are transmitted at $t(x+1)$, instead of $t(x+2)$ with basic ARROW. This strategy also reduces transmission overheads and leads to lower average channel occupancy (i.e., better channel utilization) since, by picking a suitable value for mSI_i, adequate for the generation of at least one MSDU, no Null-Data TXOPs for CBR TSs are required.

D. SIMULATION MODEL AND RESULTS

To measure the performance of ARROW and its enhancement against Simple and SETT-EDD, a proprietary 802.11e simulation tool provided by ATMEL Hellas was used. The tool consists of a core application implementing the MAC functionality and a set of plug-ins implementing the Scheduler, Admission Control and Channel modules. All 802.11e MAC features relevant to the HCCA mechanism are supported, with the exception of the 802.11e fragmentation, which is referred to as optional in the standard amendment. Fragmentation is considered as a low priority feature by 802.11e vendors, due to the implementation complexity it introduces.

The simulation study focused on the performance comparison of the examined algorithms, under the same set of scenarios. The main objective was to investigate the maximum system capacity attained by HCCA with the use of each algorithm, provided QoS characteristics are preserved.

The simulation scenarios considered an increasing number of QSTAs attached to an AP. All QSTAs and the AP were supporting the extended MAC layer specified in IEEE 802.11e [2] and the PHY layer specified in IEEE 802.11g [9], with a transmission rate of 12Mbps. An ideal, error-free wireless channel was assumed, as the focus was on the scheduling procedure. In order to investigate the limits and the maximum scheduling capability of each algorithm under heavy traffic conditions, no admission control was applied. Each QSTA had two active sessions, a bi-directional G.711 voice session (CBR traffic), mapped into two TSs (one per direction), and an uplink (from QSTA to AP) H.261 video session at 256 Kbps (VBR traffic), mapped into one uplink TS.

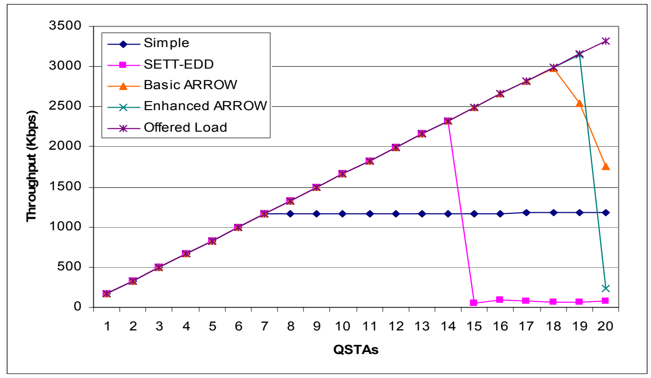
Table 1 summarizes the TSPEC parameters for the various types of TSs considered. For the G.711 TSs, the TSPEC defined by Wi-Fi Alliance [9] was used. For the H.261 TSs, the input traffic and the respective TSPECs were derived using video traces from two films, available at [11].

TABLE I. TSPEC PARAMETERS

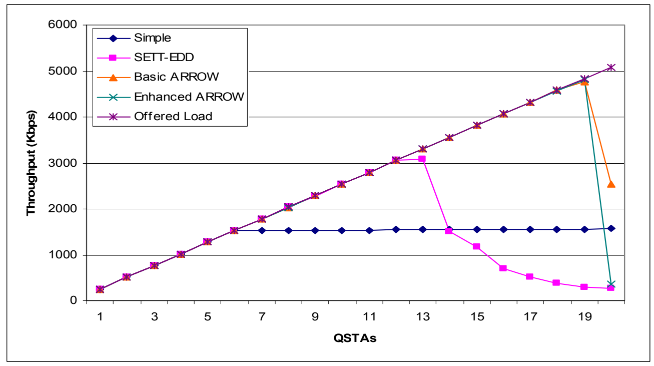
TSPEC Parms.	G.711 Voice	H.261 Video	H.261 Video
ρ (Kbps)	83	256	256
D (ms)	60	40	40
R (Mbps)	12	12	12
mSI (ms)	20	0	0
MSI (ms)	30	40	40

Figure 2 depicts throughput of non-delayed MSDUs for voice and video traffic. For voice traffic (Figure 2a), basic ARROW accommodates up to 18 QSTAs, while SETT-EDD can manage up to 14 QSTAs and Simple up to only 7 QSTAs. Using the enhancement, the number of QSTAs can be increased to 19 with enhanced ARROW. For video traffic (Figure 2b), basic and enhanced ARROW outperform both SETT-EDD and Simple, accommodating up to 19 QSTAs, as opposed to 13 with SETT-EDD and 6 with Simple. The main reason for the considerably improved performance of basic ARROW is the accurate TXOP assignment it performs, as a result of the accurate queue size information. This is also shown in more detail later in this section. As for the enhanced ARROW, it appears that the admission capacity limit of the Scheduler compared to the Standard ARROW for Voice traffic is somewhat increased since, with Enhanced ARROW up to 19 G.711 TSs can be accommodated comfortably.

It is interesting to observe that throughput of SETT-EDD and ARROW (both basic and enhanced) reduces rapidly immediately after reaching its maximum value. The reason is that, due to the dynamic TXOP assignment performed by these algorithms, new TSs entering the system can participate equally in the channel assignment. Thus, when the scheduler exceeds its maximum scheduling capability, service for all TSs is degraded abruptly. The Simple Scheduler on the other hand, manages to provide a stable throughput regardless of the offered load, because static allocations for existing TSs are not affected as the traffic load increases. This effect highlights the need for an effective admission control scheme for SETT-EDD and ARROW, that would prevent the offered load from exceeding the maximum scheduling capability.



(a) G.711 Voice

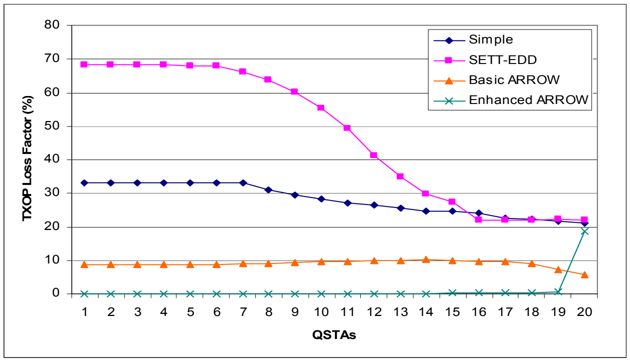


(b) H.261 video

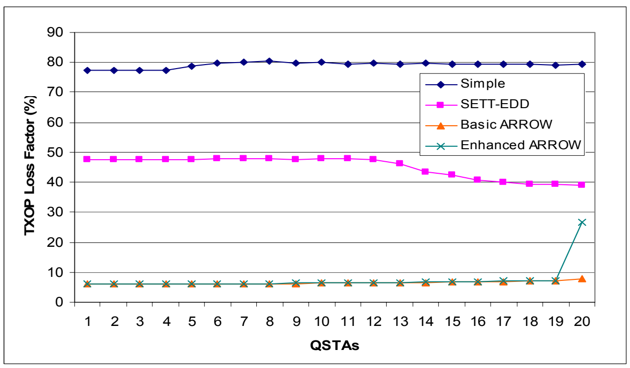
Figure 2. Throughput of Non-Delayed MSDUs

The TXOP loss factor, measuring the fraction of the total time (sum of TXOPs) assigned to a TS, but was left unused due to lack of data for transmission is shown in Figures 3a and 3b. The results clearly highlight the major advantage of ARROW, i.e., accurate TXOP assignments based on real-time requirements. For both voice and video traffic, the TXOP loss factor with both versions of ARROW for video traffic is below 8% while for voice enhanced ARROW attains a TXOP Loss Factor close to zero. Note that, although the allocation is based on real requirements, the loss factor is not 0% in all cases, because the queue size is given in multiples of 256 octets, leading to a slight deviation of calculations. On the other hand, both Simple and SETT-EDD experience high TXOP loss factors, due to the estimations they are using. These results explain the greater scheduling capability limit of both versions of ARROW, compared to Simple and SETT-EDD, as discussed earlier for Figure 2.

As shown in Figure 4, the HCCA channel occupancy (i.e., the average fraction of time per Beacon Interval dedicated to HCCA) increases very quickly for both Simple and SETT-EDD, requiring high values of 96-97% to accommodate only 6 or 7 QSTAs, while both versions of ARROW achieve an almost linear increase, with enhanced ARROW attaining occupancy 10-12% less than basic ARROW. This linear behavior shows that the application of a simple admission control scheme is easier. Combined with the results of Figure 2, this metric show that the same throughput values can be achieved by ARROW utilizing a significantly smaller part of the wireless channel, compared to Simple and SETT-EDD.



(a) G.711 Voice



(b) H.261 video

Figure 3. TXOP Loss Factor

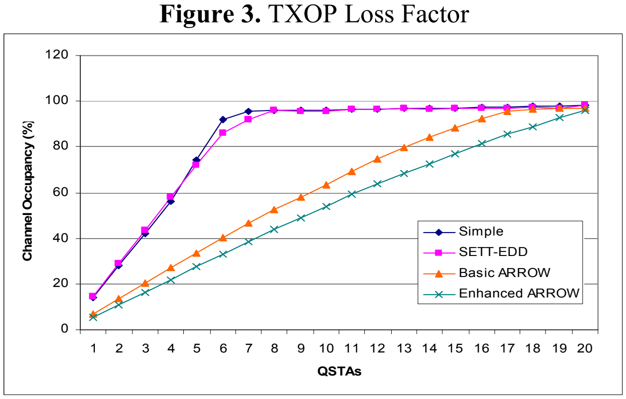


Figure 4. Average HCCA System Occupancy

E. CONCLUSIONS – FUTURE WORK

In this paper, the operation and evaluation of a traffic scheduling algorithm for the HCCA access mode of IEEE 802.11e, referred to as ARROW, was presented. The novel characteristic of ARROW is that it takes into account real-time requirements of QSTAs, in contrast to estimations used by previous proposals. Extensive simulation results show that ARROW achieves much more efficient use of the available bandwidth, compared to two existing schedulers, namely SETT-EDD and Simple, leading to better channel utilization and higher throughput. Additionally, an enhancement that takes into account the periodic nature of CBR traffic to accurately estimate traffic load presents considerable improvement in terms of channel utilization. Future plans include the development of an admission control algorithm to avoid fast deterioration of ARROW when input load exceeds the maximum affordable capacity, as indicated by simulations.

ACKNOWLEDGEMENTS

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REFERENCES

[1] IEEE Std 802.11, "IEEE Standard for Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications", 1999, P802.11.

[2] IEEE Std 802.11e/D8.0, "Draft Supplement to Standard for Telecommunications and Information Exchange between Systems – LAN/MAN Specific Requirements. Part 11: MAC and PHY Layer Specifications: Medium Access Control (MAC) Enhancements for Quality of Service (QoS)", Feb.2004

[3] Grilo A., Macedo M., and Nunes M, "A Scheduling Algorithm for QoS Support in IEEE 802.11e Networks", IEEE Wireless Communications, pp. 36-43, June 2003.

[4] P. Ansel, Qiang Ni, and T. Turletti, "An Efficient Scheduling Scheme for IEEE 802.11e" in Proc. IEEE WiOpt 2004, Cambridge, UK, March 2004.

[5] A. Annese, et al., "Providing Delay Guarantees in IEEE 802.11e Networks", in Proc. IEEE VTC Spring 2004, Milan, Italy, Amy 2004

[6] T. Korakis, L. Tassioulas, "Providing quality of service guarantees in wireless LANs compliant with 802.11e", in Computer Networks, Volume 47, Issue 2, February 2005.

[7] D. Skyrianoglou, N. Passas, A. Salkintzis, "ARROW: An Efficient Traffic Scheduling Algorithm for IEEE 802.11e" in Proc. IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks, Taormina, Italy, June 2005.

[8] S. Kandala et al., "Normative Text for TGe Consensus Proposal", IEEE 802.11-02/709r0, Nov. 2002.

[9] IEEE Std 802.11g, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications-Amendment 4: Further Higher-Speed Physical Layer Extension in the 2.4 GHz Band", June 2003.

[10] Wi-Fi Alliance web site at: http://www.wi-fi.org/

[11] Video Traces for Network Performance Evaluation available at: http://trace.eas.asu.edu/