A Measurement-Aided Model-Based Admission Control Scheme for IEEE 802.11e EDCA Wireless LANs

Conroy A. Smith, Neco Ventura
Department of Electrical Engineering, University of Cape Town,
Rondebosch, Cape Town, South Africa
{csmith, neco}@crg.ee.uct.ac.za

Abstract—The IEEE 802.11e standard was introduced to overcome the lack of Quality of Service (QoS) support for the legacy IEEE 802.11 Wireless LANs. However, channel overloading still remains a major problem, as the QoS of traffic flows are degraded with a heavy load on the wireless channels. This paper proposes a measurement-aided model-based admission control scheme for IEEE 802.11e Enhanced Distributed Channel Access (EDCA) Wireless Local Area Networks (WLANs). It presents an overview of an Admission Control Unit (ACU) that is capable of providing quantitative QoS guarantees to all existing flows. The ACU in the Access Point (AP) makes use of measured collision statistics to estimate the achievable throughput that stations can achieve at saturated network conditions. The achievable throughput estimations are based on a 2-state markov chain model of the IEEE 802.11 contention based channel access scheme. Simulation results indicate that the analytical model is fairly accurate.

Index Terms—Admission Control, IEEE 802.11e, Quality of Service (QoS), Wireless LAN.

I. INTRODUCTION

In recent times, 802.11 hotspots have become increasingly popular. By using the unlicensed ISM frequency spectrum, Wireless LANs (WLANs) are able to provide relatively cheap wireless internet connectivity while maintaining a relatively high throughput. With the growth of the Internet, home and enterprise WLANs are now being used freely for applications such as file sharing, video conferencing and Voice over IP (VoIP) telephony. Additional devices, including cellular phones, are being equipped with WiFi capabilities bringing more revenue for Wireless Internet Service Providers (WISPs). It is envisioned that further growth for IEEE 802.11 WLANs will take place and will continue to have a major impact on the lifestyles of society.

The trends of exciting new applications and network services are putting greater demands on Next Generation Networks (NGNs). An important aspect of NGNs is dealing with the complexity of QoS, as applications have diverse performance needs. Static bandwidth reservations may not always be implemented at the access networks to aid QoS support. This is especially the case with IEEE 802.11 Wireless LANs which are traditionally a best effort medium access technology [1]. For this reason, end users for WLANs may not experience true end-to-end QoS support.

The IEEE 802.11e standard [2] was introduced to overcome the lack of QoS support of legacy WLANs. IEEE 802.11e includes a modified MAC layer that is capable of providing service differentiation. This enables the network to provide reasonable throughput and delay guarantees at the MAC layer. However, when the network becomes heavily overloaded, it becomes less capable of satisfying QoS guarantees. When a new flow is admitted while the network is saturated, it may not achieve its required QoS. It may also jeopardize the QoS of other admitted flows.

Formulating an admission control approach that is based on static bandwidth partitioning of WLAN cannels is a complex task, as it is difficult to quantify resources of the shared WLAN medium. This paper presents a method for estimating the achievable throughput for WiFi stations based on an analytical model of the WLAN contention based channels. The analytical model is aided by the measurement of collision statistics at each wireless station. The throughput estimations are then used to make effective admission control decisions that are capable of protecting existing traffic flows, as well as utilizing the full channel capacity.

Section II presents an overview of IEEE 802.11e WLANs. Section III gives a description on some previous work done that relates to the work presented in this paper. Section IV outlines the proposed admission control scheme for IEEE 802.11e WLANs. Section V presents simulation results to indicate the accuracy of the analytical model that is fundamental to the proposed admission control scheme. Section VI draws conclusions and proposes future work.

II. IEEE 802.11E WIRELESS LANS

As of late 2005, IEEE 802.11e became an approved standard that defines a set of QoS enhancements for WLAN applications [2]. The standard is of great importance to delay-sensitive applications, such as VoIP and other streaming media.

The IEEE 802.11e standard specifies enhancements to the legacy IEEE 802.11 MAC layer, as shown Fig 1. It specifies a new coordination function called the Hybrid Coordination Function (HCF) that is under the control of a Hybrid Coordinator (HC). The HC is situated in the QoS Access Point (QAP). The HCF specifies two channel access modes,

The authors would like to thank Telkom SA, NSN, Intel, the National Research Foundation (NRF), the Technology and Human Resources for Industry Programme (THRIP) and the Department of Trade and Industry (DTI) for supporting this research project.

the Enhanced Distributed Channel Access (EDCA) and the HCF Controlled Channel Access (HCCA). Both EDCA and HCCA define Traffic Classes (TC) that provides service differentiation. The PCF is an optional element providing a contention-free service for those stations that are unable to conform to the HCF of the IEEE 802.11e standard. The Distributed Coordination Function (DCF) is used to provide a reliable transport medium using the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) mechanism.

The HCCA still requires some major improvements, as it does not cope well with overlapping QoS Base Service Sets (QBSSs) and is only efficient when handling data streams that are strictly constant bit rate (CBR) [3]. For this reason the EDCA is mostly used to provide QoS support due to its simplicity and relatively good performance.

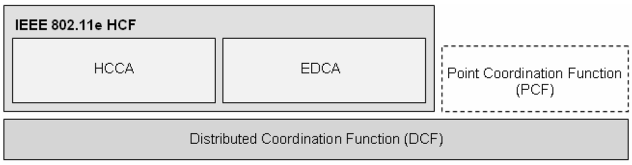

Fig 1: MAC enhancement of IEEE 802.11e.

A. Enhanced Distributed Channel Access (EDCA)

The EDCA allows service differentiation, by supporting 8 different priorities, which are further mapped to 4 Access Classes (ACs) as shown in Table I. Each AC behaves as a single Enhanced DCF (EDCF) contending entity with dedicated queues as shown in Fig 2. A single AC queue can be seen as an individual Virtual Station (VS), as they all contend for the shared wireless medium independently. Differentiation is achieved by varying the amount of time a VS will sense the channel to be idle and the length of the contention window during backoff. This is achieved by differentiating the Arbitration Interframe Space (AIFS), initial window size and maximum window size for each AC. This means that for each AC[i] (i = {0, 1, 2, 3}), the initial backoff window size is $CW_{min}[i]$, the maximum backoff window size is $CW_{max}[i]$, and the AIFS is AIFS[i]. The values of these parameters are announced by the QAP via periodically transmitted beacon frames. The virtual collision handler is used to resolve internal collisions by allowing the frame with higher priority to transmit, while the lower priority VS invokes a backoff algorithm. This means that a Lower priority internal VS will not cause a higher priority internal VS to backoff. This makes the IEEE 802.11e enhancement more efficient when handling internal collisions.

TABLE I:
PRIORITY ACCESS CATEGORY MAPPINGS

User Priority (UP)		**AC**	**Designation**
Lowest	1	0	Background
	2	0	Background
	0	1	Best Effort
	3	1	Best Effort
	4	2	Video
	5	2	Video
	6	3	Voice
Highest	7	3	Voice

Before data transmission, each VS has to contend for a Transmission Opportunity (TXOP). Data transmission begins when the medium is idle for more than the AIFS time. However, if the channel is sensed busy before attempting to transmit data, the VS must perform a backoff algorithm before attempting to resend the frame. The backoff algorithm involves the setting of a timer to a random value. The station will decrease this backoff timer when the channel is idle and stops when the medium is sensed busy. It resumes when the medium is sensed idle again for an AIFS time. A TXOP can be obtained when the backoff timer reaches zero. Fig 3 shows the EDCA timing diagram, where three ACs are shown. An AC with smaller AIFS, CW_{min} and CW_{max} has a better chance of accessing the wireless medium earlier and will receive better QoS.

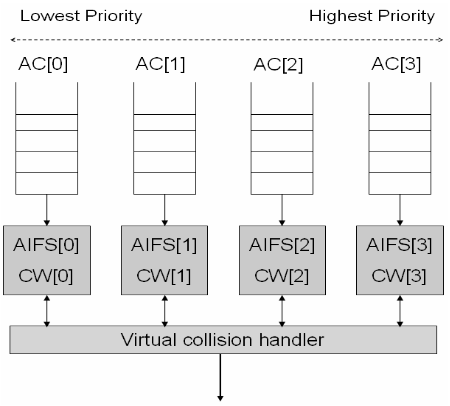

Fig 2: Queuing Architecture of EDCA.

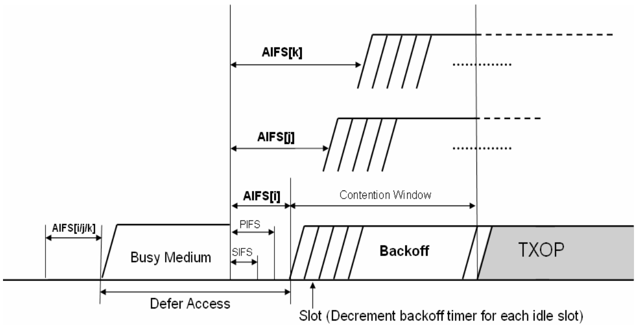

Fig 3: Timing diagram of EDCA.

For each AC queue, the initial backoff counter will be a random value that is uniformly distributed between 0 and CW_{min}, $random(0, CW_{min}[AC])$. When the destination station receives the frame, it waits for a Short InterFrame Space (SIFS) before sending back an ACK frame. The acknowledgement is necessary to inform the transmitting node that the transmission was successful. An unsuccessful transmission is assumed to be the cause of a collision with data from other transmitting stations. If a collision occurs, the transmitting station will first set its backoff timer to be $random(0,\ (CW_{min}[AC]+1)\times 2^{i}-1)$ for each retransmission attempt i. In other words, the contention window size is doubled for each retransmission to reduce the probability of collision. The Contention Window is also bounded by a maximum value of CW_{max}, thus there is only a finite number of backoff stages where the contention window is doubled.

The IEEE 802.11e standard also specifies an optional transmission mode, where multiple MAC Service Data Units (MSDU's) are allowed to be transmitted during a TXOP. This is known as TXOP bursting and the duration of the TXOP is limited by for each AC.

Unfortunately, the bandwidth of WLANs are limited, which means that QoS guarantees can only be satisfied when the network is not overloaded. For this reason, the need for admission control has become apparent.

B. *Admission Control in IEEE802.11e*

The Hybrid Coordinator (HC) is responsible for admission control decisions at the QAP. The IEEE standard specifies the use of Traffic Specification (TSPEC) messages for negotiating admission control for IEEE 802.11e WLANs. QoS Stations (QSTAs) use TSPEC messages to specify their traffic flow requirements such as, packet size, service interval, data rate and delay. The HC may accept or reject a new TSPEC request based on the network conditions.

Fig 4 shows a typical TSPEC negotiation between a QSTA and the HC. TSPEC negotiation for a new Traffic Stream (TS) request is always initiated by the Station Management Entity (SME) of a QSTA and accepted or rejected by the HC. The SME allows higher layer protocols and applications, such as RSVP, to allocate resources within the MAC layer. The SME of the QSTA indicates its TSPEC to its MAC layer, via a MLME-ADDTS (MAC Layer Management Entity-ADDTS) request. The QSTA MAC interface will then forward the ADDTS request to the HC, while starting the ADDTS respond timer. The MAC layer of the HC will then generate the MLME_ADDTS indication for its SME. The Admission Control Unit (ACU) in the SME will decide whether to accept or reject the TS. Once decided, the HC will notify the QSTA with an appropriate response. If the response times out, the request message will be resent.

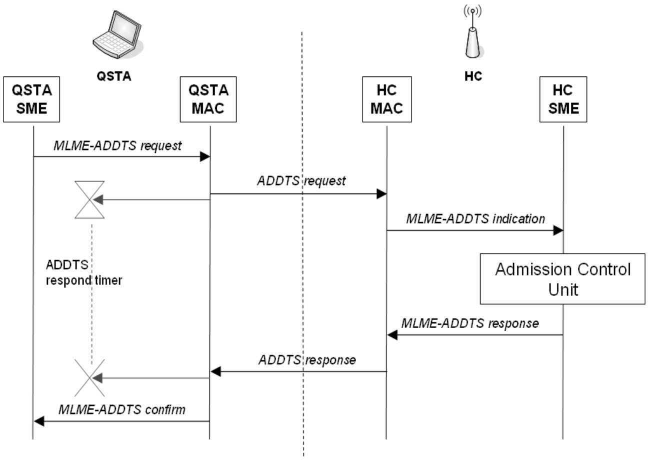

Fig 4: TSPEC Negotiation.

III. RELATED WORK

A Distributed Admission Control (DAC) scheme was proposed by the 802.11e working group, to protect the QoS for active flows [4]. In the DAC, the QAP attempts to limit the transmission duration of each AC. The QAP announces a transmission budget for each AC, every beacon interval. The transmission budget is the additional amount of transmission time available for an AC during the next beacon interval. It is calculated by subtracting the measured occupied time during the previous beacon interval from the transmission limit of the AC. During every beacon interval, each station determines an internal transmission limit per AC based on successfully used transmission time, from the previous beacon interval, and the transmission budget. When the transmission budget for an AC is depleted, a new flow will not be able to obtain any more transmission time, and existing flows will not be allowed to increase their transmission time. It was shown that the DAC scheme is able to protect the flows in the EDCA so that they can achieve their desired throughput, while the total throughput is improved due to less contention. However the DAC scheme can only protect the existing EDCA flows when the traffic load is not very heavy. Another shortcoming of the DAC scheme is that it is difficult to avoid network performance fluctuations, because of stations continuously adjusting their transmission parameters every beacon interval.

Daquing Gu and Jinyun Zhang [5] proposed a Threshold Based Admission Control scheme. In this scheme, each station needs to measure the traffic conditions on the wireless link. The network defines suitable upper and lower bound threshold values that indicate the current network load. The network load can be indicated using either average collision ratios, or relative occupied bandwidth indications. The admission control scheme takes no action when the network load is between the defined upper and lower threshold values. When the chosen metric indicates that the network load is above the higher threshold, the network will stop the transmission of the lowest active AC for the next sampling period. When the network load is below the lower bound threshold value, the inactive AC with highest priority will be admitted during the next sampling period. The advantage of this scheme is that it can easily be implemented for both ad-hoc and infrastructure mode. However, the threshold values are difficult to set. In addition, since the transmission of data flows are stopped and resumed depending on the network availability, there is no way to guarantee the instantaneous QoS metrics.

Dennis Pong and Tim Moors [6] proposed an admission control scheme based on two-state Markov chain model for IEEE 802.11 Wireless LANs. The scheme estimates the throughput that flows would achieve if a new flow with certain parameters were admitted. The new flow is admitted only if it can achieve its required throughput, while preserving the throughput guarantees for all other existing flows. The model deals with the EDCA parameters of minimum contention window size and TXOP duration, as well as monitored collision statistics. The analytical model is derived under saturation conditions, as admission control usually becomes assertive when the network load is saturated [7]. Their work also tries to adjust the contention window parameters so that the goals of admission control can be achieved. The advantage of using this model-based admission control algorithm is that it is able to provide

TABLE II
VARIABLES USED IN THE ANALYTICAL MODEL

τ_i	Transmission probability of a VS i
pi	The measured collision probability of VS i
W_i	The value of CW$_{\min}$ for VS i
b_i	Maximum backoff stage for the contending VS i
S_i	Estimated achievable throughput for VS i (Bytes per second)
$E\{P_i\}$	The expected size of the data payloads transmitted during a TXOP for VS i (Bytes)
$P(S \mid VS = i)$	Probability of a successful transmission for a VS i
$P(C)$	Probability of a collision in a slot
$P(S)$	Probability that a slot is idle
$P(I)$	Probability that there is a successful transmission in a slot
$T_{col,i}$	Cycle duration of a collision experienced by VS i (seconds)
$T_{suc,i}$	Cycle duration of a successful transmission of VS i (seconds)
σ	slot time (seconds)

quantitative bandwidth guarantees for the EDCA. However, accurate estimations can only be obtained if there are no more than one flow admitted per AC for each station. Their work also does not take virtual collisions into consideration. The continuous adjustments of the contention windows, may also lead to severe fluctuations of the network, and estimates of the achievable throughput for flows. However, this work still remains a very promising prospect, as a model based admission control may well lead to the best solution for providing quantitative bandwidth guarantees.

IV. PROPOSED ADMISSION CONTROL FOR IEEE 802.11E

This Section presents a measurement aided model-based EDCA admission control scheme that is similar to the solution presented in [6]. However the proposed analytical model is modified to provide more accurate bandwidth estimations, especially when the AC queues contain multiple flows.

Admission control is implemented in the ACU of the QAP. When stations initiate sessions, they state their bandwidth requirements using TSPEC as defined in [2]. The corresponding AC queue will then attempt to increase its required throughput, as it would have to accommodate an additional flow. Using a modified version of the IEEE 802.11 MAC analytical model presented in [7], the QAP is able to calculate the achievable throughput for each AC queue. The admission control scheme should accept a new flow only if the required throughput for all AC queues can be guaranteed (i.e. achievable throughput is more than or equal to the required throughput, for each AC queue). If Any AC queue cannot achieve their required throughput, then the new flow should be rejected. Once the process is completed, the ACU will send a MLME-ADDTS response message, containing the decision of whether the new flow is accepted or rejected.

A. Estimating the achievable throughput for Virtual Stations

This section presents a technique for throughput estimations based on a legacy IEEE 802.11 MAC analytical model presented in [7]. The analytical model is extended so that it can be used for estimating the achievable throughput for EDCA virtual stations. Each AC queue is modeled as a virtual station, because they contend for the channel access medium independently. The model assumes that the packet collision probability is constant and independent of the transmission state. It also assumes that all virtual stations constantly have non-empty queues, which is acceptable since we are primarily concerned with estimating available bandwidth under saturated conditions. The model utilizes collision statistics of each VS in order to predict their achievable throughput. Table II lists the variables that are used in the modified analytical model.

Using derivations presented in [7], it is possable to calculate the transmission probability of a VS i, as follows:

$$\tau_i = \frac{2(1-2pi)}{(1-2p_i)(W_i+1)+p_iW_i(1-(2p_i)^{b_i})} \tag{1}$$

The collision probabilities of each VS are measured at each station, while the minimum window sizes and the maximum backoff stages are static variables. Once the transmission probabilities of each VS are known, the estimated achievable throughput can be calculated for each VS:

$$S_i = \frac{P(S \mid VS = i)E\{P_i\}}{P(C)T_{col,i} + P(I)\sigma + P(S)T_{suc,i}} \tag{2}$$

The denominator in (2) is the average cycle duration for a transmission. The numerator is the average amount of successful data for a VS i, Transmitted during the cycle.

TABLE III:
CYCLE DURATION TIMES OF DIFFERENT ACCESS SCHEMES

Access Scheme	Cycle	Frame sequence in cycle duration
Basic	$T_{suc,i}$	Data frame + SIFS + ACK + AIFS[AC = i]
	$T_{col,i}$	Data frame + AIFS[AC = i]
RTS/CTS	$T_{suc,i}$	RTS + SIFS + CTS + SIFS + Data frame + SIFS + ACK + AIFS[AC = i]
	$T_{col,i}$	RTS + AIFS[AC = i]
TXOP	$T_{suc,i}$	TXOP[AC = i] + AIFS[AC = i]
	$T_{col,i}$	Data frame + AIFS[AC = i]

The probabilities, $P(S \mid VS = i)$, $P(C)$, $P(S)$ and $P(I)$ can be calculated as follows:

$$P(S \mid VS = i) = \tau_i \prod_{j=1}^{m} (1 - \tau_j);\ j \neq i \ \textit{\& lower internal VS} \tag{3}$$

$$P(S) = \sum_{i=1}^{m} P(S \mid VS = i) \tag{4}$$

$$P(\textit{1 or more Tx in slot}) = 1 - \prod_{j=1}^{m} (1 - \tau_j) \tag{5}$$

$$P(C) = P(\textit{1 or more Tx in slot}) - P(S) \tag{6}$$

$$P(I) = 1 - P(\textit{1 or more Tx in slot}) \tag{7}$$

The cycle duration times, $T_{col,i}$ and $T_{suc,i}$, are the times required to transmit the associated frame sequences, including preambles and the physical layer headers. The frame sequences depend on the access scheme used and is shown in Table III.

B. Measuring the collision probabilities of each Virtual Station

As seen in (1), the measured collision probably, pi, is required from each VS. Each VS keeps a counter to monitor the number of collisions as well as the number of successful transmissions. Assuming a reliable (approximately error free) wireless channel, the number of retransmissions should be the same as the number of collisions. The collision probability is calculated every update period using an exponentially weighted average to smooth out short term fluctuations due to interference:

$$p_{i,new} = (1 - \alpha) p_{i,current} + \alpha p_{i,prev} \tag{8}$$

The update period is chosen to be the beacon period and α is chosen to be 0.8. The values chosen for these two parameters are considered to be effective for removing short term fluctuations and maintaining a good long term trend. The collision probability can be calculated from (9).

TABLE IV:
DEFAULT VALUES FOR THE EDCA PARAMETERS
AS USED IN SIMULATIONS

	AC_VI	AC_VO	AC_BE
AIFS	2	2	3
CW_{min}	3	7	15
CW_{max}	7	15	1023

$$p_{i,current} = \frac{\#\textit{Collisions}}{\#\textit{Collisions} + \#\textit{Successful Transmissions}} \tag{9}$$

The counters are reset at the end of each update period. The collision statistics is forwarded to the QAP using the highest priority AC.

V. THE ACCURACY OF THE EDCA ANALYTICAL MODEL

The admission control scheme presented in this paper can only be effective if the bandwidth estimations are reasonability accurate. For this reason, a simulation study was conducted to analyze the accuracy of the EDCA analytical model at a saturation level. Simulations were conducted using the Network Simulator 2 (NS-2) [8]. The ns-2 802.11e contributed model [9] was used to provide necessary IEEE 802.11e support as well as IEEE 802.11a support [10].

During simulations, there were no hidden stations present and the wireless channels were assumed to be error free. The simulation consisted of six wireless stations and one access point. Each station contained three active AC's (AC_VO, AC_VI and AC_BE) with unlimited data to send. Default values for the EDCA parameters were used as indicated in Table IV. Only one MAC Service Data Unit (MSDU) was allowed to transmit during a TXOP.

Five simulations were conducted with varied MSDU sizes. The achievable throughput obtained from the analytical model was compared to the actual saturation throughput from simulations. Fig 5 shows the throughput comparisons of one of the wireless stations. In the figure, 'sim' refers to the simulated results and 'mod' refers the throughput estimations obtained from the EDCA analytical model.

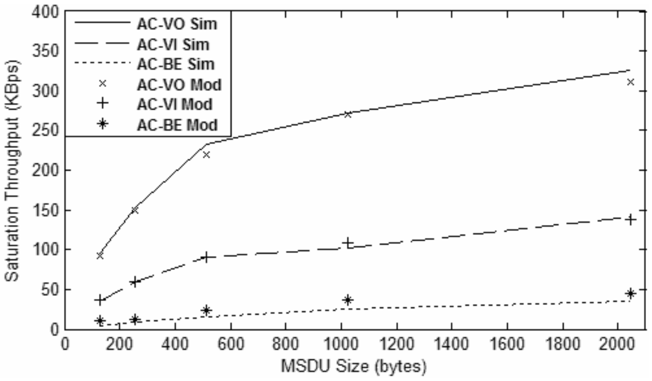

Fig 5: Comparison of the estimated throughput and the actual simulated throughput.

As seen from these results, the measurement aided EDCA analytical model provides a good estimation for the achievable throughput of AC queues. It can also be seen that higher priority AC's can achieve a higher throughput when the channel is fully utilized.

VI. CONCLUSIONS AND FUTURE WORK

The EDCA access mode in IEEE 802.11e is able to provide relatively good QoS support for wireless users. However, QoS for real-time flows are heavily degraded in the presence of saturated network conditions. This paper proposes an admission control scheme that protects the QoS of existing flows by rejecting admission requests that may degrade the network. The admission control scheme aims to protect flows at a saturated network level rather than at low network load. This is to ensure the optimal use of the network resources. Admission control decisions are based on throughput estimations that are obtained by using an EDCA analytical model. The analytical model is further aided by the measurement of collision statistics. Simulation results show that the analytical model is fairly accurate, setting a platform for an effective Admission Control Unit. Future work aims to obtain simulation results that will validate the improved performance of the admission control scheme. The performance of optional transmission modes, such as TXOP bursting, will also be investigated.

REFERENCES

[1] ANSI/IEEE Std 802.11 "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications", 1999.

[2] IEEE Std 802.11e. "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications; Amendment: Medium Access Control (MAC) Quality of Service Enhancements", 2005.

[3] S Mangold, S Choi and G.R Hiertz, "Analysis of IEEE 802.11e for QoS support in Wireless LANs", IEEE Wireless Communications, pp 40-50, December 2003.

[4] Y. Xiao and H. Li, "Evaluation of Distributed Admission Control for the IEEE 802.11e EDCA", IEEE Communications Magazine, vol. 42, no. 9, pp. S20–S24 2004

[5] D. Gu and J. Zhang, "A New Measurement-based Admission Control Method for IEEE 802.11 Wireless Local Area Networks," Mitsubishi Elec. Research Lab, Tech. rep. TR-2003-122, Oct. 2003.

[6] D. Pong and T. Moors, "Call Admission Control for IEEE 802.11 Contention Access Mechanism," Proc. IEEE GLOBECOM'03, vol. 1, San Francisco, CA, Dec. 2003, pp. 174–78.

[7] G. Bianchi, "Performance Analysis of the IEEE 802.11 Distributed Coordination Function", IEEE JSAC, 18(3): 535-47, Mar. 2000.

[8] http://www.isi.edu/nsnam/ns/

[9] http://yans.inria.fr/ns-2-80211/

[10] IEEE Std 802.11a (Supplement to ANSI/IEEE Std 802.11 1999 Edition) "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Higher Speed Physical Layer (PHY) in the 5 GHz band", 1999.

Conroy A. Smith obtained his Bsc(Eng) degree in Electrical and Computer Engineering from the University of Cape Town in 2005. He joined the Communications Research Group at the University of Cape Town where he is currently working towards his MSc (Eng) degree.