# End-to-End Quality of Service Scheme for WLAN-Wired Networks

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***Abstract*—Wireless local area network (WLAN) can be used to complement existing last-mile access networks such as ADSL and WiMAX, in the provision of telecommunication services. However, because of the use of IP, it is difficult to provide service guarantees to multimedia traffic such as voice and video. This paper seeks to address the challenge of the provision of quality of service (QoS) to WLAN access network users connected to a telecommunication service network over a wired backbone link. The focus of the paper is the interworking of the WLAN EDCA QoS scheme and the IP layer QoS scheme on the wired network in order to ensure that service guarantees are provided to multimedia traffic. The QoS interworking consists of mapping EDCA access categories (AC) to IP traffic classes in the wired network. The mapping function ensures the consistent application of QoS to the traffic classes on both the wireless and wired networks. The proposed scheme is evaluated and found to perform better than a WLAN-wired network without a QoS integration scheme.**

***Index Terms*—enhanced data channel access, multimedia traffic, quality of service, weighted round robin, wireless LAN.**

## I. INTRODUCTION

ONE of the challenges of provision of telecommunication services to previously under-serviced areas, such as rural communities, is the cost of rollout of last-mile networks. Wireless local area networks (WLANs) which are used as IP data networks in WiFi hotspots, enterprise networks and residential Internet access, can be deployed to augment last-mile networks such as ADSL and WiMAX, and potentially lower the rollout costs in previously under-serviced areas.

Although traditionally used to carry data, WLANs are nowadays used to carry multimedia IP traffic such as voice and video. In this scenario, the delay-sensitive multimedia traffic is carried along the same network as the delay-insensitive data traffic. However WLANs do not provide any QoS and hence it is difficult to guarantee the effective delivery of multimedia traffic. Section 9 in IEEE Std 802.11-2007 provides MAC layer QoS in WLANs through the use of a hybrid coordination function (HCF) [1]. HCF introduced two channel access mechanisms known as the enhanced channel distributed access (EDCA) mechanism and the HCF controlled channel access (HCCA) mechanism. The EDCA enables prioritized QoS and HCCA enables parameterized QoS on the WLAN.

In most cases where WLANs are used as access networks, they interwork with wired backbone networks such as copper and fiber local and wide area network links. It is critical to enable end-to-end QoS in WLANs interworking with wired networks for the effective delivery of multimedia traffic. In order to ensure end-to-end QoS the high priority traffic classes such as multimedia traffic must receive a better grade of service on the WLAN as well as the wired network. This paper introduces a scheme to achieve prioritized end-to-end QoS in a WLAN-wired network by mapping traffic classes across the wireless-wired network boundary.

Section II of this paper presents a background on end-to-end QoS in interworked WLAN-wired networks and related work by other researchers. Section III presents the proposed interworking module and section IV presents results from an experimental evaluation of the proposed scheme. Relevant conclusions are made in section V.

## II. END-TO-END QOS IN WLAN-WIRED NETWORKS

QoS in IP networks is enabled by a combination of channel access and traffic control mechanism. Traffic control mechanisms include packet scheduling, traffic policing, and rate limiting.

QoS is enabled in the MAC layer in WLANs but is enabled at the IP layer in most wired networks. However in the case of TCP traffic over wired networks, QoS is also enabled at the transport layer using flow control. In this paper, QoS at the transport layer will not be considered. Having different QoS mechanisms in the MAC and IP layers presents a challenge in enabling end-to-end QoS.

### *A. Related Work*

Various researchers have proposed schemes that enable the interworking of WLAN MAC layer and wired IP layer QoS mechanism.

Skyrianoglou *et. al.* proposed the introduction of a wireless adaptation layer (WAL) between the MAC and IP layer in the wireless stations (STAs) [2]. The WAL intercepts an outgoing

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wireless IP packet, extracts the QoS classification from the header, and then places the packet in an outgoing queue based on the QoS classification. A QoS module in the WAL is used to provide service differentiation for different traffic classes. For packets received from the wired network, the WAL in the access point (AP) performs the same process as that of an ordinary wired station. The disadvantage with Skyrianoglou *et. al.*'s scheme is that an additional layer is introduced between the MAC and IP layer in a wireless STA. This is not in agreement with the widely accepted IEEE 802.11-2007 standard.

Park *et. al.* proposed an architecture to map IP layer differentiated services (diffserv) code point (*DSCP*) QoS values to MAC layer EDCA traffic categories (*TC*s) [3]. The scheme reads the *DSCP* of the IP packets and uses it to place the packets into the appropriate EDCA AC. The disadvantage of Park *et. al.*'s architecture is that all STAs have to be modified to support diffserv functionality which is an inconvenient task that adds more complexity to the management of WLANs.

A scheme by Haffajee *et. al.* to interwork WLAN access networks with a WiMAX backbone network provides useful design ideas for enabling end-to-end QoS in a WLAN-wired integrated network [4]. The scheme uses IP layer *DSCP* values as a guide for the implementation of QoS using EDCA in the WLAN and WiMAX MAC layer QoS classes.

### B. *QoS in the Wired Network*

QoS in a wired IP network is commonly implemented at the network layer, due to the very low error-rate of the wired physical media. This paper focuses on the use of packet scheduling as one of the means of achieving QoS on the IP layer. Packet queue scheduling determines the allocation of bandwidth and buffer space, and influences the drop probability [5], [6]. The commonly used packet scheduling mechanisms are first-in-first-out (FIFO), round robin (RR) queuing, weighted round robin (WRR) queuing, and priority queuing (PQ).

This research focuses on the use of weighted round robin (WRR) queuing to provide prioritized QoS on the wired network. This is because FIFO does not provide any QoS, while PQ provides premium service to the priority queue traffic at the expense of the lower priority traffic [5]. Although RR queuing provides an equal amount of service to all traffic queues, it does not provide QoS.

Weighted round robin (WRR) queuing is a variation of RR that assigns servicing weights to each queue [6]. The queues are then serviced according to the weights assigned to them with the value of each weight denoting the number of packets that will be transmitted from the queue. Weighted fair queuing (WFQ) is a more complex and less common implementation of WRR [6].

To derive an expression for the sending throughput of packets in queue *i*, a router with *n* queues each assigned weight $w_i$ will be considered. At a link transmission rate *R*, class *i* packets in queue *i*, will receive throughput given by [6]:

$$\frac{w_i}{\sum_{i=1}^{n} w_i} \mathrm{R} \qquad (1)$$

### C. *QoS in the WLAN*

The IEEE Std 802.11-2007 WLAN supports the legacy distributed coordination function (DCF) channel access method [7]. DCF uses carrier sense multiple access with collision avoidance (CSMA/CA) to schedule access to the wireless medium. CSMA/CA is used with a variety of timers which include:

- A random backoff time (*BT*) that is activated by an STA right after a busy channel becomes free and available.
- DCF interframe space (*DIFS*) which is used for DCF channel access.
- Short interframe space (*SIFS*) which is the shortest duration timer and is used for high priority medium access control frames such as acknowledgements.

*BT* is given by [7]:

$$BT = randomSlotNumber() \times slotTime \qquad (2)$$

Where *randomSlotNumber()* is a pseudorandom integer selected from the uniform distribution given by [0, contention window (*CW*)]. The range [*0, CW*] is divided into integer slots denoted by *slotTime*. *CW* is an integer that is determined by the particular IEEE 802.11 physical layer characteristics and can take on a value within the range [*CWmin, CWmax*].

Another QoS function introduced by the IEEE Std 802.11-2007 is the traffic specification (TSPEC) management [1]. The TSPEC function defines a traffic flow in terms of its QoS characteristics such as transmission rate, packet size, and delay bound, and they are used in both EDCA and HCCA mode. TSPECs aid in admission control decisions, transmission opportunity (*TXOP*) scheduling, and the setup and teardown of traffic flows.

The IEEE 802.11-2007 has a priority parameter value that can be any integer from 0 to 15 [1]. The first eight integers in the priority parameter field define the individual higher layer (application) user priority (*UP*) values of the WLAN MAC service data unit (MSDU). The *UP* value, which is similar to the IEEE 802.1D user priority values, defines the traffic category (*TC*) the MSDU belongs. The remaining priority parameter values (8 to 15), define QSTA traffic classes known as traffic streams (*TS*) that can be associated to a specific TSPEC.

EDCA enables different priority access to the medium using *TC*s, which are grouped into a maximum of four access category (*AC*) queues. A typical *UP/TC* to *AC* mapping scheme was issued by the wireless fidelity (Wi-Fi) Alliance's Wi-Fi Multimedia (WMM) [8], [9].

In EDCA, preferential channel access is determined by the individual *AC* arbitrary interframe space values (*AIFS*) instead of *DIFS*. The *AIFS* of individual *AC*s is given by [1], [9]:

$$AIFS(AC) = SIFS + AIFSN(AC) \times slotTime \qquad (3)$$

*AIFSN(AC)* is an integer that determines the number of equal duration time slots that will be used to determine the value of *AIFS(AC)*. The higher the *AC* priority the lower the *AIFSN* value and hence the *AC* will have a higher chance of accessing the channel. The values for *AIFSN(AC)* and *slotTime* are obtained from the beacon frames transmitted by the QoS-enabled AP (QAP).

The differentiated channel access mechanism of EDCA is illustrated in Figure 1 [9].

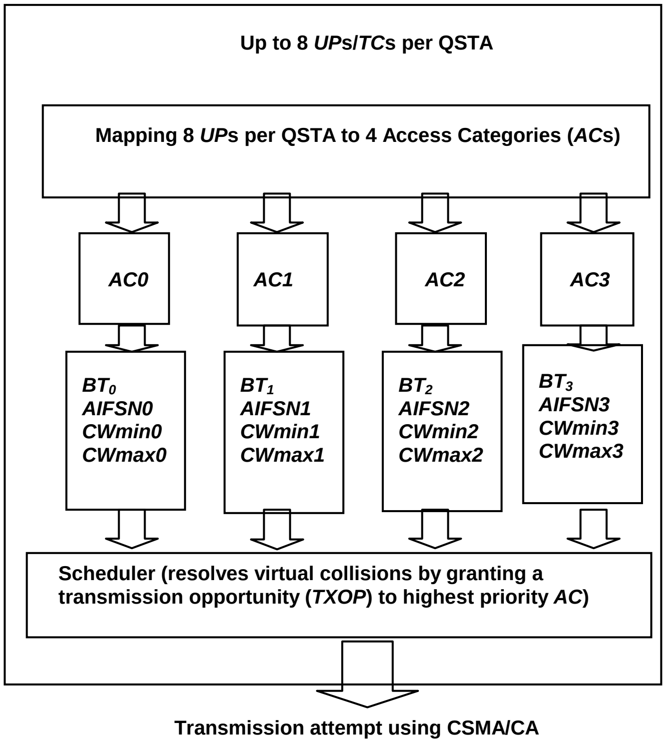

**Figure 1: EDCA Channel Access Mechanism [9].**

Upon expiry of *AIFS(AC)*, the individual contending *AC*s start counting down their backoff counters, *BTx* (where *x* can be 0, 1, 2 or 3) before any winning *AC* can be granted a *TXOP*. The backoff time, *BTx*, can take on any value in the range [*CWminx*, *CWmaxx*] (where *x* can be 0, 1, 2 or 3).

In the event of unsuccessful transmission the *CWmin* value is increased by a multiplicative factor known as the persistence factor (*PF*) [9].

## III. PROPOSED ARCHITECTURE

End-to-end prioritized QoS in a WLAN-wired network can be achieved by ensuring that the classification and prioritization of traffic is consistent on both the WLAN and wired networks. In the proposed architecture, consistency is achieved by mapping the traffic classes across the WLAN-wired interface in both directions of traffic flow. The bi-directional traffic flows can be identified by source IP, source port, destination IP, destination port, or transport layer protocol.

The mapping of the traffic classes between the two networks is as shown in Table II [1], [3]. The mapping is carried out in a module located in the QAP. The flow label field in the IPv6 header is also used to indicate the QoS due to different traffic classes [10], [11].

TABLE II
PROPOSED MAPPING SCHEME

| **Traffic class** | **Type of traffic** | **IEEE 802.11e *AC* (*AC* Index)** | ***DSCP*** | **Flow Label** |
|---|---|---|---|---|
| Class 1 | Voice | *AC_VO* (11) | 101110 (*EF*) | 0 |
| Class 2 | Video | *AC_VI* (10) | 100xxx (*AF*4x) | 1 |
| Class 3 | Signaling traffic | *AC_BK* (01) | 010xxx (*AF*2x) | 2 |
| Class 4 | Normal data traffic (web, email) | *AC_BE* (00) | 000000 (default best effort) | 3 |

The mapping module is a software program and its logical operation is illustrated in Figure 2.

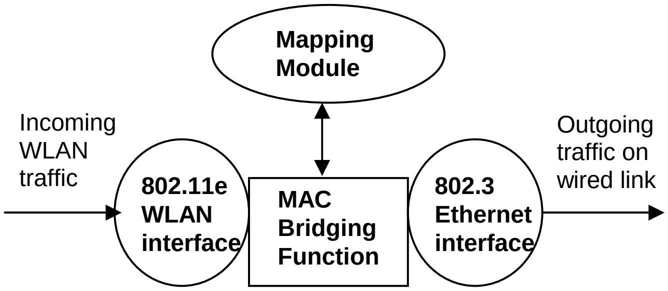

**Figure 2: Logical Layout of Mapping Module in AP.**

With the introduction of the mapping module in the QAP the normal bridging function will alter slightly, with incoming wireless and Ethernet packets passing through the module which performs the mapping lookup. The mapping module also writes the *DSCP* value for the case of a packet from the WLAN to the wired network. For the case of a packet from the wired network to the WLAN, the packet will just be placed in the appropriate *AC* queue in the WLAN interface.

## IV. EXPERIMENTAL EVALUATION AND RESULTS

The proposed design was evaluated using the NS2 network simulator and the network topology used is illustrated in Figure 3. There were bottlenecks in the network that were used to demonstrate the presence of QoS among contending traffic.

### A. *Network Model*

The WLAN is based on the IEEE 802.11b standard and implements EDCA QoS only. The WLAN has a bandwidth of 2Mbps.

The effective bandwidth of a WLAN is dependant on the number of transmitting STAs present [9], [12]. A WLAN with two transmitting QSTAs and a QAP that does not originate traffic has an effective bandwidth of approximately 1Mbps. It is expected that the WLAN link will become congested with traffic at an offered load of 1 Mbps and begin operating in its saturation region.

Assuming an almost fair distribution bandwidth, each QSTA will obtain 0.5Mbps of bandwidth and the QAP will send and receive 1Mbps of traffic. The wired link has 2Mbps bandwidth at all segments except the bottleneck link, which has 1Mbps.

In the experiment, the performance of a WLAN-wired network with the proposed QoS mapping scheme integrated will be compared to that without. An EDCA WLAN and wired link routers that implement single FIFO queues will represent the network without the proposed mapping scheme. The WLAN-wired network's router links have single FIFO queues, apart from the bottleneck link which implements three WRR serviced queues at either end of the link.

The high priority traffic is low-bandwidth and delay-sensitive VoIP calls composed of 160-byte constant bit rate (CBR) user datagram protocol (UDP) packets. Medium priority traffic represents video traffic made up of 500-byte CBR UDP packets. 500-byte CBR UDP packets are used to simulate low-priority high bandwidth traffic. Although the medium-priority and low-priority traffic-flow both have the same packet size in the experiment, in some instances the low-priority traffic has a higher packet flow rate, hence higher bandwidth, than the medium priority flow. The experiments were conducted with uplink traffic due to software limitations.

### B. *Network QoS Settings*

Three priority levels represented by three *AC*s will be used in the WLAN EDCA and they are shown in Table III.

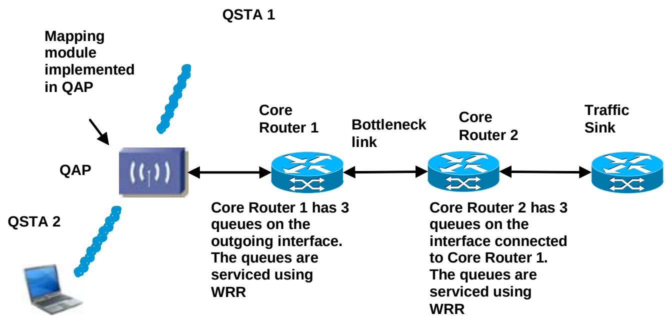

**Figure 3: Network Topology used in Experiments.**

TABLE III
EDCA TIMER PARAMETER VALUES

| Parameter | High Priority | Medium Priority | Low Priority |
|---|---|---|---|
| PF | 2 | 2 | 2 |
| AIFSN | 2 | 4 | 7 |
| CWmax | 7 | 10 | 15 |
| CWmin | 7 | 31 | 255 |

The wired network QoS is implemented using WRR and the queue weights are queues shown in Table IV.

TABLE IV
WRR WEIGHT COMBINATIONS

| WRR Weights | Flow 0/ High Priority | Flow 1/ Medium Priority | Flow 2/ Low Priority |
|---|---|---|---|
| 3, 2, 1 | 3 | 2 | 1 |

### C. *Simulation Results*

The experimental results are presented in the graphs below. In the presented graphs the high priority traffic is labeled flow 0, the medium priority flow 1 and the low priority flow 2.

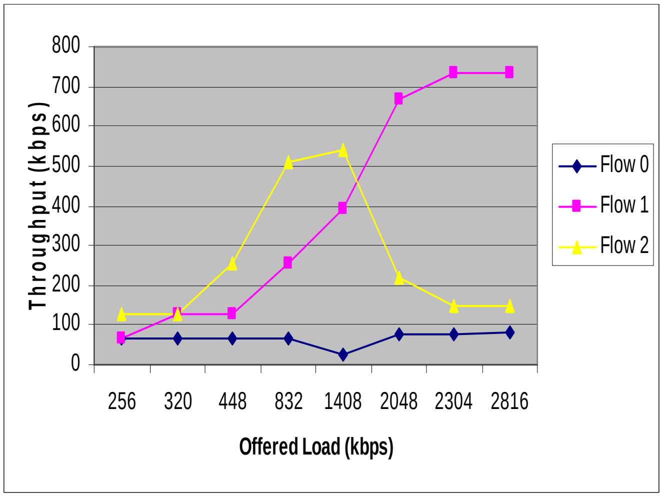

**Figure 4: Throughput performance of WLAN-wired network without QoS integration scheme.**

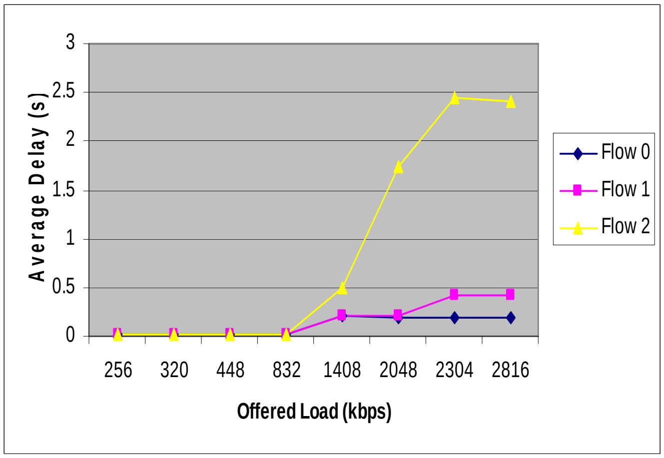

**Figure 5: Average Delay performance of WLAN-wired network without QoS integration scheme.**

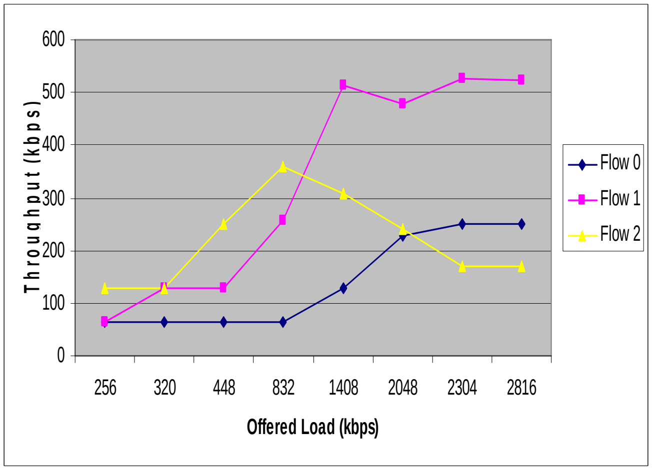

**Figure 6: Throughput performance of WLAN-wired network with QoS integration scheme.**

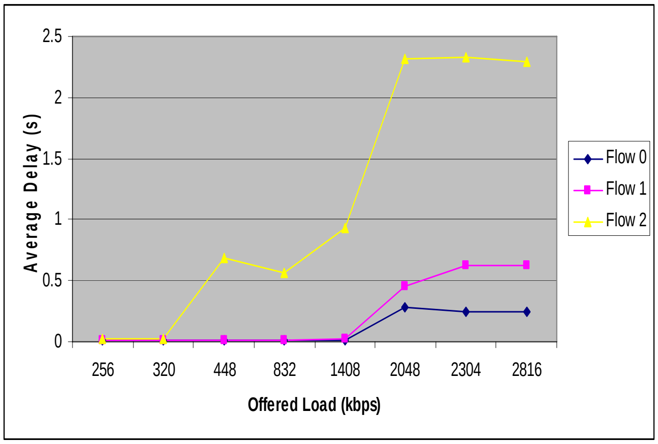

**Figure 7: Average Delay performance of WLAN-wired network with QoS integration scheme.**

Before the WLAN mode of saturation, which occurs at an offered load of approximately 832kbps, the high and medium priority flows, in both WLAN-wired networks have similar throughput performance. Beyond an offered load of 832 kbps the high priority traffic performs much better in the network with the QoS integration scheme. This is in contrast to the medium and low priority traffic. The medium and high priority traffic are affected by receiving proportionally less service from WRR.

The high and medium priority flows, in the network with a QoS integration scheme, have a better average delay performance beyond an offered load of 832 kbps. However above an offered load of 1408 kbps, flow 0 of both networks have an equivalent level of performance. The average delay of the medium priority traffic, of the network with a QoS integration scheme, increases significantly beyond an offered load of 1408 kbps. The low priority traffic experiences a higher average delay in the network with a QoS integration scheme than in that without. Both the medium and low priority traffic experience more delay because of receiving proportionally less service from WRR.

The packet loss performance of the networks is presented in the graphs below.

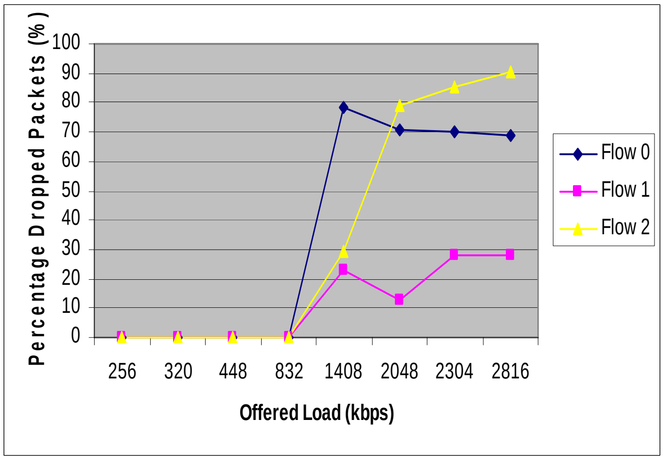

**Figure 8: Packet Loss performance of WLAN-wired network without QoS integration scheme.**

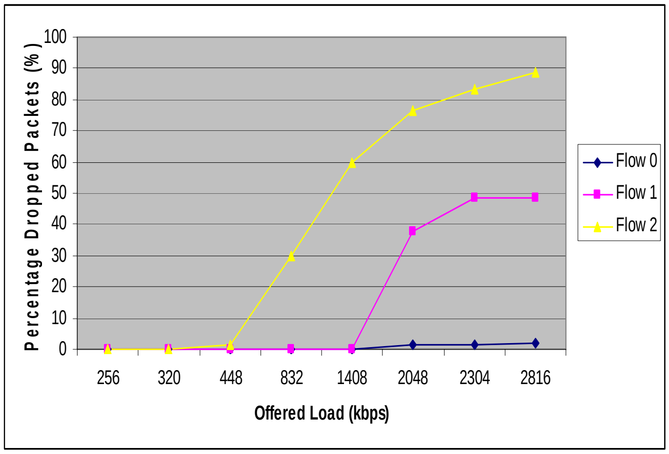

**Figure 9: Packet Loss performance of WLAN-wired network with QoS integration scheme.**

Considering the dropped packets graph for the network with a QoS integration scheme, the high priority traffic does not drop packets up to an offered load of 1408 kbps, after which it drop less than 2% of its packets. This is in contrast to the network without a QoS integrated scheme where all flows start dropping packets after an offered load of 832 kbps. However the lowest priority flow in the integrated QoS network starts dropping packets at a load of 320 kbps and this is due to its getting the least allocation of resources. However the lowest priority traffic is not completely starved of service.

## V. CONCLUSION

A scheme has been presented that maps IEEE 802.11e MAC layer QoS classes to IP layer QoS classes at the boundary of the WLAN-wired network in a QAP. The experimental results show that the proposed scheme achieves a uniform and consistent QoS when integrated in a WLAN-wired network. The WLAN-wired network with the QoS integration scheme performs better than that without by ensuring the higher priority traffic receives much better treatment than lower priority traffic. Although the WLAN-wired network with the QoS integration scheme dropped many packets for flows other than the highest-priority flow, due to link congestion link and QoS prioritization, there was no complete starvation of service for the lowest-priority flow. The solution to excessive packet drops would be to implement admission control and proper network dimensioning, which are outside the scope of this research.

The proposed scheme enabled the implementation of end-to-end prioritized QoS in a heterogeneous WLAN-wired network. The proposed scheme is simple to implement since it is located in the QAP and designed to work with any available prioritization or differentiated services QoS scheme in a wired IP network. The proposed scheme will enable WLAN networks to effectively deliver multimedia services, and boosts the case for the deployment of WLAN as a complement to existing last-mile networks. WLANs would eventually increase the penetration of telecommunication networks in new under-serviced markets such as rural areas, at a lower cost.

Further work is needed in the evaluation of the proposed scheme using downlink traffic. The performance of the scheme in the presence of admission control should also be examined.

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