PROVIDING ENHANCED FRAMEWORK TO SUPPORT QOS IN OPEN WIRELESS ARCHITECTURE

G. Cecchetti and A. L. Ruscelli
RETIS Lab, Scuola Superiore S. Anna, Pisa, Italy
email: g.cecchetti@sssup.it, a.ruscelli@.sssup.it

***Abstract*— This paper presents a novel approach to support Quality of Service for *Open Wireless Architectures* (OWA), building a suitable framework over the top of the heterogeneous wireless MACs. It lets to enhance the existing QoS support provided by standard MAC protocols and it uses the contract model to guarantee QoS, taking into account the applications requests. It negotiates dynamically *Application Level Contracts* which will be translated seamlessly in *Resource Level Contracts* for the underlying network services. It receives the feedback by underlying network services to adjust the scheduling algorithms and policies to provide hard and soft guarantees. The framework comprises *QoS Manager*, *Admission Control*, *Enhanced Scheduler*, *Predictor* and *Feedback System*. The QoS manager component is able to dynamically manage available resources under different load conditions. A IEEE 802.11e Wireless LAN is simulated to show the benefits of this approach.**

***Index Terms*— QoS Management, OWA, Scheduling Algorithms, WLAN.**

I. INTRODUCTION

The future wireless service provisioning will be characteri-zed by global mobile access in which 4G mobile technologies [1], [2] provide convergence of the wireless mobile and wireless access in an open, common, flexible and expandable platform. This approach to the network convergence finds in *Open Wireless Architecture* (OWA) [3] or *Converged Broadband Wireless Platform*, the medium for realizing global mobile access, high quality of service, simple, seamless, automatic access to media services for voice, data, message, video, world-wide web, etc, utilizing an horizontal communication model. This architecture includes base-band signal processing, RF, Networking, OS and application parts so that the same end equipment can flexibly work in the wireless access domain as well as in the mobile cellular networks, with optimal spectrum efficiency and resource management.

The increasing spreading of mobile communications and the growing attention toward 4G mobile communications [4], [5] necessarily will have to take into account Quality of Service support. It is essential for several multimedia applications like VOIP, video conference call, audio and video streaming, contents distribution, Internet services and real time control services. These kind of applications have strict latency/throughput requirements while the used medium offers time and space varying communication conditions.

QoS support for OWA needs to be functional for integrated wired and wireless access modes using a common methodology and offering a differentiated service according to several applications requirements. Wireless access networks are subject to fast changes in *signal to interference plus noise ratio* (SINR) due to phenomena like *path loss*, *shadowing*, *multipath fading*, signal attenuation and interference. SINR, in turn, affects the *bit error rate* (BER) experienced by the wireless endpoints. In this environment channel capacity varies over time and space, especially when the stations are on the move and when there are networks with variable topology. It turns out that the variability of available radio resources does not allow the network to provide hard QoS guarantees. Instead, the network must provide soft QoS guarantees constrained by a minimum channel quality. Some of these guarantees regards: *delay*, *delay jitter*, *packet loss ratio*, *throughput*, *bandwidth*.

In particular the QoS provision must take into account the support done by each single access mode. For example recently approved IEEE 802.11e standard [6] for WLANs offers a complete set of primitives to provide delay guarantees while the previous IEEE 802.11b [7] was designated only for best effort services. However also IEEE 802.11e does not provide scheduling algorithms for packet transmission nor policies scheme for access control to the medium, leaving space to build blocks for a full Quality architecture.

In this article we present a novel framework to provide a comprehensive Hard and Soft QoS support for multimedia traffic streams with some discussion. We specifically focus on its components: QoS Manager, Admission Controller, Scheduler, Predictor and Feedback mechanism. We apply this framework to 802.11e based WLAN as an example of real case study. We show that such approach handles time-varying network conditions, heterogeneous traffic streams, VBR streams and it manages efficiently link layer resources.

II. THE FRAMEWORK

The framework interfaces the software applications with heterogeneous networks MAC layer. It implements a contract based scheduling that is suitable to integrate QoS support provided by standards as IEEE 802.11e, IEEE 802.15 and IEEE 802.16. With some extension it can operate also with mobile access networks. It represents high level abstraction that lets practitioners to concentrate on the specification of the application requirements. The contract model is the mechanism that we have chosen for the application to dynamically specify its own set of complex and flexible execution requirements. From the application perspective, the requirements of an application component are written as a set of a service contracts for different resources, which are negotiated with the underlying implementation. To accept a set of contracts the proposed system has to check, as part of the negotiation, if it has enough resources to guarantee all the specified minimum requirements while keeping guarantees on all the previously accepted contracts negotiated by other application components. If a result of this negotiation is accepted, the system will reserve enough capacity to guarantee the minimum requested resources and it will adapt any spare capacity available to share it among the different contracts that have specified their desire or ability for using additional capacity. The contract also contains Quality of Service tuning parameters that may be used by *QoS manager*.

Its architecture is composed by QoS manager and the scheduling subsystem. (See Fig.1).

A. QoS manager

QoS manager [8] is a middleware layer that *mediates* between application and underlying components of this framework. Different applications specify different sets of high level parameters (e.g., Multimedia Streaming, VOIP, signaling protocol and file transfer have different parameters and performance indicators). The set of high level QoS requirements of the application will be specified through an *Application Level Contract* (ALC). The QoS manager acts as a proxy: it translates the high level QoS requirements of the application into the resource allocations, it computes transmission para-meters values and it negotiates them with admission control. The set of low level resource requirements produced by QoS manager will be called *Resource Level Contract* (RLC). Actually the underlying network may be heterogeneous, it may vary in topology and standards offering a completely variable scenario. For this reason, QoS manager has to interact with different scheduling subsystems, one for each different standard. Each subsystem has an admission control, a scheduler, a predictor and a feedback control. Note that each subsystem has its own admission control which checks the resource usage for the corresponding standard. We can assume without lack of generality that each protocol does not interfere with other ones. When QoS manager interacts with a subsystem it provides the appropriate parameters and it takes into account the specific protocol used.

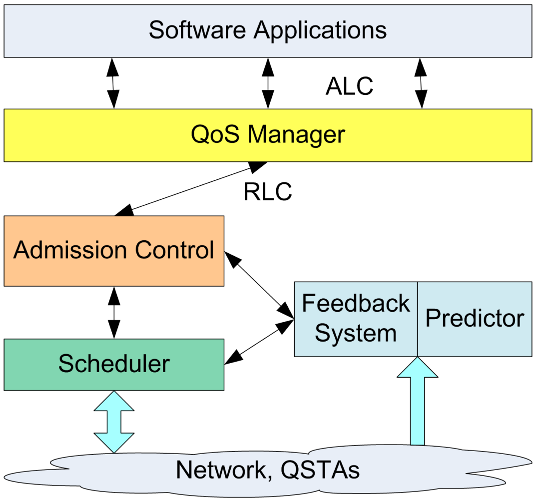

Fig. 1. The Proposed Framework

Moreover QoS manager:

- adapts automatically the resource allocation to dynamic changes in the requirements of the application (e.g., when an application wants to change the contract profile, the QoS manager contacts again the corresponding admission control service and negotiates a new RLC);
- adapts dynamically the resource allocation in order to optimize the resource utilization without sacrificing on QoS requirements;
- maintains as much as possible the resource allocation for each application as close the minimum that is needed to fulfill the ALC.

Finally, in the case an overload occurs (e.g. due to varying network conditions or if a more important QoS request is received), it can decide to change one or more ALCs to degrade the QoS level of one or more applications by a call-back notification so that the application itself can adapt its QoS requirements.

B. The Admission control

When QoS manager requires admission to the admission control the latter computes the theoretical new bandwidth utilization and checks if it is admissible without degradation of preexistent transmissions. The response is sent back to the QoS manager. If the instance request is successful a RLC is established and the QoS manager can communicate transmission parameters to the corresponding scheduler.

Before admitting the new flow the admission control uses the following admission test:

$$\sum_{i=1}^{N} \frac{Q_i}{P_i} \leq U_{lub} \ ,$$

where:

- $Q_i \triangleq C_i/r_i$ is the average time budget of the medium which is reserved to the i^{th} network station (QSTA$_i$) transmitting within each period P_i,
- r_i is the physical bit rate assumed for admission control computations of the i^{th} traffic stream (TS$_i$),
- C_i are the bytes transmitted during the P_i, and
- U_{lub} is least upper bound utilization factor computed for the worst-case available bandwidth.

In all cases if the sum of the bandwidth utilization of the existing reservations, plus the utilization of the new reservation does not exceed U_{lub}, the request is forwarded to the scheduler. If there is not enough bandwidth to serve the new request three different admission control policies exist which act as follows:

- *saturation policy*, the highest possible budget is assigned to the task so that the total resource utilization does not exceed U_{lub},
- *compression policy*, in respect of the established ALCs, all the reservation (RLCs) are recomputed ("compres-sed") so that we can make new space for the new request,
- *reject policy*, the transmission is rejected.

C. The scheduler

The scheduler manages each TS transmission for each admitted QSTA and it assigns dynamically both the period P_i and transmission duration TX_i to follow the channel variability and streams characteristics. We propose a scheduler which can handle TS with Hard and Soft Real Time guarantees [9] with special regard to VBR flows. VBR flows are supported by assigning transmission duration in agreement to the effective temporal demands of QSTA and the length of its queues. The assignment of P_i is dynamic, so it lets to increase the transmission frequency of the stations having in queue traffic with tightening requirements of QoS. The scheduler is also able to reclaim the unused time of QSTAs which have exhausted their transmission before the end of their transmission duration and then it assigns that time to the stations which have still useful data to transmit. Delay or advance of the transmission with respect to the pre-agreed rate (in terms of bytes which have been anticipatively used or have not been transmitted by mobile station) are formalized as the scheduling error $\varepsilon_i^{(k)}$, defined, at the k^{th} time instant, as the difference between the cumulated bytes to transmit $z_i^{(k)} \triangleq kC_i^{(k)}$ and the bytes actually transmitted $\overline{z}_i^{(k)}$:

$$\varepsilon_i^{(k)} \triangleq z_i^{(k)} - \overline{z}_i^{(k)}$$

The dynamic equation for the evolution of the scheduling error for the i^{th} real-time data flow is:

$$\varepsilon_i^{(k+1)} = \varepsilon_i^{(k)} + C_i^{(k)} - \gamma_i^{(k)} Q_i^{(k)}$$

where $\gamma_i^{(k)}$ is the actual channel speed.

D. The predictor

The Predictor estimates the future available bandwidth and the QSTA queue length, sensing the channel medium and listening to the messages sent by QSTAs. It uses the recent history of these values to correct its estimation. The predictor can be both deterministic and stochastic depending on TS. This information is used by the Feedback System.

E. The feedback subsystem

The feedback subsystem senses the effective information acknowledged by stations. It also uses the information provided by the predictor to vary transmission parameters of the scheduler in order to respect hard and soft deadlines. It is responsible to minimize the scheduling error. The rapidity of this action can be improved turning on special weights w_i for each TS$_i$. The feedback system can compensate little variations of network conditions without the intervention of admission control to establish new RLCs.

During *normal condition*, if:

$$\sum_{i=1}^{N} \frac{Q_i^{(k)}}{P_i} \leq U_{lub}$$

feedback system controls the scheduling error assigning:

$$\forall i, \ Q_i^{(k)} \triangleq \widetilde{Q}_i^{(k)} = \frac{C_i^{(k)} + \alpha_i \varepsilon_i^{(k)}}{\rho_i^{(k)}}$$

where $\widetilde{Q}_i^{(k)}$ is the required assigned budget to compensate the scheduling error, $\alpha_i \in]0,1]$ and $\alpha_i \varepsilon_i^{(k)}$ is a fraction of the current scheduling error for each TS$_i$ and $\rho_i^{(k)}$ is the predicted channel speed at the physical layer.

During *overload condition*, if

$$\sum_{i=1}^{N} \frac{Q_i^{(k)}}{P_i} > U_{lub}$$

depending the feedback scheme adopted, the allocated budget to each station i is decreased. For example, if the feedback scheme uses a weighted distribution, for each TS$_i$, $\widetilde{Q}_i^{(k)}$ is decreased of an amount proportional to the weight w_i assigning:

$$\forall i,\, Q_i^{(k)} \triangleq \widetilde{Q}_i^{(k)} - \frac{w_i \widetilde{Q}_i^{(k)}}{\sum_{j=1}^{N} w_j \widetilde{Q}_j^{(k)}} \left(\sum_{j=1}^{N} \widetilde{Q}_j^{(k)} - U_{lub} P_i \right)$$

where

$$\frac{w_i \widetilde{Q}_i^{(k)}}{\sum_{j=1}^{N} w_j \widetilde{Q}_j^{(k)}}$$

is the percentage of decreasing.

This system can use different feedback schemes according the profile of each TS. By this way the Framework can react to network variations using different compensation models on the basis of the application served.

III. FRAMEWORK APPLIED TO IEEE 802.11E WLANS

We have integrated [10] the recently approved standard IEEE802.11e for WLANs with the proposed framework. For which concerns QoS support, the previous standard IEEE 802.11 can only provide best effort services and so it is poorly for multimedia applications, while this new standard introduces a so-called Hybrid Coordination Function which multiplexes between two medium access mechanism: a distributed end contention-based scheme, *Enhanced Distributed Channel Access* (EDCA), and a centralized scheme, *HCF Controlled Channel Access* (HCCA).

A. Enhanced Distributed Channel Access (EDCA)

EDCA is a channel access mode which provides prioritized QoS and enhances the original *Distributed Coordination Function* (DCF), which works as a “listen-before-talk” scheme based on *Carrier Sense Multiple Access with Collision Avoidance* (CSMA/CA). It classifies traffic through the introduction of Access Categories (ACs). Each AC has its own transmission queue and its own set of channel access parameters, in particu-lar *Transmission Opportunity* (TXOP) limit is the maximum duration for which a node can transmit after obtaining access to the channel. Using these parameters, when data arrives from higher layers it is classified and placed in the appropriate AC queue. Then an internal contention algorithm is used to calculate the total backoff time for each AC. The AC with the smallest backoff wins the internal contention and uses this backoff value to contend externally for the wireless medium. Nodes with higher priority can access the channel earlier than other nodes and prioritized flows have the advantage of longer channel access with their TXOP.

B. HCF Controlled Channel Access (HCCA)

HCCA provides a centralized polling scheme to allocate guaranteed channel access to traffic flows based on their QoS requirements. It uses a QoS-aware *Hybrid Coordinator* (HC) which is usually located at the *QoS Access Point* (QAP) in infrastructured WLANs and it provides polled access to the wireless medium. In order to be included in the polling list of the HC, a *QoS Station* (QSTA) must send a QoS reservation request using the special QoS management frame which contains flow information. Each individual flow needs one particular reservation request and it is classified and assigned to one of eight Traffic Streams of that QSTA. TS parameters are collected by using a *Traffic Specification* (TSPEC). HC aggregates every TSPEC of QSTA TSs and determines the values of parameters needed by the transmission itself: *Service Interval* (SI) and TXOP. SI is the time duration between successive polls for the node, while TXOP is the duration of each node based on the mean application data rates of its requested flows. When HC gains control of the channel and within *Controlled Access Phase* (CAP) it polls the QSTAs according to its polling list, generated by a scheduler. The 802.11e does not specifies this scheduler but just offers some guidelines to design it. Moreover it provides a reference scheduler that is compatible with the use of link adaptation and it respects the minimum performance requirements.

C. Framework integration

The framework implementation requires to build an interface between the 802.11e MAC and the QoS manager. This interface implements RLCs through the admission control for each TS$_i$ managed by QoS manager as follows:

$$\sum_{i=1}^{N} \frac{TXOP_i}{SI_i} \le U_{lub}$$

We have adapted the formulas introduced in our work to WLAN parameters. Now, the dynamic equation for the evolution of the scheduling error for the TS$_i$ is:

$$\varepsilon_i^{(k+1)} = \varepsilon_i^{(k)} + C_i^{(k)} - PHYrate^{(k)} TXOP_i^{(k)}$$

where $PHYrate^{(k)}$ is the physical channel speed and $C_i^{(k)}$ are the bytes transmitted during SI_i.

The TXOP$_i$ are computed as follows:

$$\forall i,\, TXOP_i^{(k)} \triangleq \widetilde{TXOP}_i^{(k)} = \frac{C_i^{(k)} + \alpha_i \varepsilon_i^{(k)}}{\rho_i^{(k)}}$$

D. *Experimental results*

Applying our framework to IEEE 802.11e WLANs we have focused on CBR and VBR streams, typical in multimedia transmissions like *Voice Over IP* and *Vide Conference* applications.

We implemented the proposed framework in the ns-2 network simulator [11], using the HCCA implementation framework described in [12]. Then we compared the results with respect of reference IEEE 802.11e standard scheduler. The physical layer parameters are those specified by the High Rate Direct Sequence Spread Spectrum (HR-DSSS) [13], also known as 802.11b, and are reported in Table I.

TABLE I

MAC/PHY SIMULATION PARAMETERS

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

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

We simulate a VoIP traffic stream as an ON/OFF source: during ON (talkspurt) periods the traffic is CBR with parameters that depend on the encoding scheme. The encoding scheme that we employ is the G.711 [14], which produces 50 packets of 160 bytes (including IP/UDP/RTP headers) per second. Talkspurt and silence periods are distributed according to Weibull distributions [15] with mean of 0.87 s and 1.58 s respectively.

We simulate Video Conference traffic according to a pre-encoded MPEG trace file (LectureHQ) from the Internet archive of traces [16]. MPEG4 encoders produce streams of frames of variable size at fixed intervals [17]. In our simulation analisys, the frame rate is 30 fps which corresponds to a frame interarrival time of about 33.3 ms, the average rate is about 158 Kb/s and the peak rate is about 2.7 Mb/s. In both VoIP and Video Conference (VC) traffic models the downlink and uplink traffic flows of a bi-directional TS are not correlated.

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

We evaluate a scenario with four stations with mixed CBR and VBR traffic. To do so, we set up an increasing number of QSTAs, from 0 to 4, each having a bi-directional VoIP TS and bi-directional Video Conference TS. The delay bound of VoIP is set to 20 ms and that of VC TSs to 33 ms.

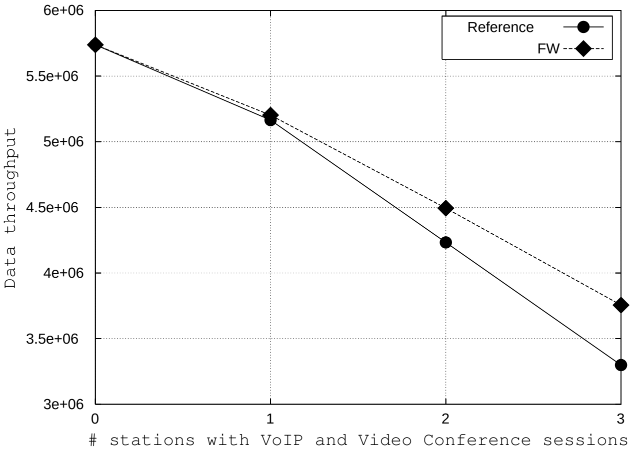

Fig. 2. Throughput of stations.

The Fig. 2 shows the throughput achieved by stations with data traffic against the number of stations with bi-directional VoIP and VC sessions. If there are not any stations with CBR and VBR TSs, the data throughput is maximum and the framework behave in a very similar way to the standard protocol. Otherwise, if there are TSs with significantly different delay bound requirements, such as the VoIP and VC TSs, the MAC overhead of the reference scheduler is higher than that with framework scheduler and, therefore, the throughput achievable by data traffic is much lower.

Finally we have showed that the capacity available for contention-based access with our framework is greater than that offered by IEEE 802.11e standard when there are TSs with different delay bound values.

IV. CONCLUSION

In this paper we have presented a general framework to integrate QoS support in Open Wireless Architecture under time-varying network conditions and different traffic specifications. It provides an interface to QoS support mechanisms for any applications with tightening guarantees and temporal boundaries. This framework lets applications establish contracts with QoS manager that administers the available resources from underlying subsystems. The resulting QoS service is an improvement for applications running over wireless networks. The QoS manager acts as a proxy towards different network subsystems which manage different wireless network protocols. We propose subsystem scheduler that supports real-time applications, variable packet size and variable bit rate traffic streams. Feedback and prediction mechanisms tune the scheduler behavior during transmissions. We apply this framework to recent IEEE 802.11e WLANs and we show some results through simulations. We have discussed features of this framework showing that it is suitable to be used by software requesting application level contracts and it is able to manage available resources dynamically under different load conditions.

V. ACKNOWLEDGEMENTS

This work has been supported by FRESCOR European project (Contract n. 034026).

REFERENCES

[1] J. Shelper, “1g, 2g, 3g, 4g,” *TechColumn*, April 2005.

[2] “Fourth-generation mobile iniatives and technologies,” *IEEE Communication Magazine*, vol. 40, no. 3, Mar 2002.

[3] W. Lu and J. Hu, “Open wireless architecture - the core to 4g mobile communications,” *CIC Journal on China Communications*, Apr 2006.

[4] W. Lu and R. Berezdivin, “Technologies on fourth-generation mobile communications,” *IEEE Wireless Communications*, vol. 9, no. 2, Apr 2002.

[5] W. Lu, “Technologies on broadband wireless mobile: 3gwireless and beyond,” *IEEE Communication Magazine*, vol. 38, no. 10, Oct 2000.

[6] *802.11E-2005 IEEE Standard for Information technology Telecommunications and information exchange between systems Local and metropolitan area networks Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Amendment 8: Medium Access Control (MAC) Quality of Service Enhancements*, IEEE Std. 802.11e, 2005.

[7] *Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specification*, IEEE Std. 802.11, 1997.

[8] T. Cucinotta, L. Abeni, G. Lipari, L. Marzario, and L. Palopoli, “QoS management through adaptive reservations,” *Real-Time Systems Journal*, vol. 29, no. 2-3, Mar 2005.

[9] J. Stankovic, K. Ramamritham, M. Spuri, and G. Buttazzo, “Deadline scheduling for real-time systems,” K. A. Publishers, Ed., Boston, 1998.

[10] G. Cecchetti and A. L. Ruscelli, “A framework for enhanced qos support in ieee 802.11e networks,” in *MobiMedia 2006*, Alghero, Italy, Sep 2006.

[11] *Network Simulator 2*, http://www.isi.edu/nsnam/ns/.

[12] C. Cicconetti, L. Lenzini, E. Mingozzi, and G. Stea, “A software architecture for simulating ieee 802.11e hcca,” in *3rd IPS MoMe*, Warsaw (Poland), Mar 2005.

[13] *Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specification: Higher-Speed Physical Layer Extension in the 2.4 GHz Band*, IEEE Std. 802.11b, 1999.

[14] *Traffic Analysis for Voice over IP*. Cisco Press, November 2001.

[15] P. T. Brady, “A model for generating on-off speech pattern in two way conversation,” *Bell System Technical Journal*, vol. 48, pp. 2445–2472, 1969.

[16] “http://traces.eas.asu.edu/,” continuosly updated.

[17] F. H. P. Fitzek and M. Reisslein, “Mpeg4 and h.263 video traces for network performance,” *IEEE Network*, vol. 15, no. 6, pp. 40–54, November 2001.