A Cross-Layer Framework for Wireless LAN QoS Support

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***Abstract*— The IEEE802.11x based wireless LAN technologies are leading the indoor Internet distribution in education, business and home environments. They are usually deployed as wireless extension of a broadband access to the network (i.e. DSL, cable modem, etc). These technologies are based on CSMA/CA media access with a positive MAC layer acknowledgement and a retransmission mechanism that aids noisy channel propagation condition and eventual undetected collisions. While TCP traffic benefits from a layer 2 retransmission policy the multimedia traffic experiences large delays and jitter resulting in a poor user experience. In this paper we satisfy the emerging user need of a MAC layer Quality of Service (QoS) support by taking advantage from layers 4-7 information. We believe the concepts and the architectural design presented are suitable to enhance QoS support in wireless technologies.**

I. Introduction

The massive market success of cheaper, smaller and more powerful notebook and other mobile computing devices has fueled the growth of the WLAN industry in recent years. Within the period of one year, the sales of IEEE802.11 cards have increased dramatically from 5,000 to 70,000 pieces per month [1]. A growing demand for wireless networks at home is driven by the introduction of multi-computer homes, network enabled appliances, and wireless consumer electronics looking to communicate and share resources such as printers, files and broadband Internet connections (Figure 1).

The multi-service wireless network resulting from such a broad variety of network nodes must accommodate several types of traffic, devices and services [2]. Ideally a multi-service LAN supports :

- **(a)** bursty asynchronous data transfer, telemetry, multi-cast video/audio streaming and interactive voice,
- **(b)** multiple devices with different data rate and energy target,
- **(c)** applications with a broad range and increasing band-width requirements,
- **(d)** an efficient spectrum allocation between different devices,
- **(e)** an efficient gateway service to the Internet,
- **(f)** an easy plug and play installation.

Fig. 1. The multi-service wireless network scenario.

Today's leading wireless technologies such as the IEEE802.11x family and Bluetooth meet some, but not all of the multi-service networking requirements. In this paper we describe a novel system architecture for QoS support in WLAN. While the concepts introduced are fairly general and applicable with minor adaptations to several different technologies, such as Bluetooth, UP-5, Hyperlan, etc. For the sake of simplicity, in this work, we focus our discussion on the IEEE802.11 family WLAN.

The paper is organized as follows: in section II the IEEE802.11 MAC algorithm is briefly described, while in section III we introduce the problem statement and the related work on this area. Our QoS architecture is presented in section IV. Section V reports the final remarks and concludes this paper.

II. Background

DCF (Distributed Coordination Function) is the basic access mechanism of IEEE802.11b, and uses a Carrier Sense Multiple

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Access with Collision Avoidance (CSMA/CA) algorithm to mediate the access to the shared medium. In the implementations, a Direct Sequence Spread Spectrum (DSSS) is adopted as radio transmission technology. It uses a complementary code key (CCK) and operates in the Instrumental, Scientific and Medical (ISM) bandwidth 2.4-2.4835 GHz. The ISM bandwidth is a license free spectrum shared between a number of devices (e.g. microwave oven, cordless phones, scientific equipment, Bluetooth, etc. [3]). As with all shared-bandwidth technologies, good network planning is required in order to meet the performance expectations especially when IEEE802.11 is used with delay sensitive applications such as interactive voice or video.
Wireless channels, indeed, may be affected by the distance (i.e. path loss), the environment changes and the obstacles (i.e shadowing and multipath fading) and the presence of other devices operating in the same frequency (e.g. 2.4 GHz cordless phones or a microwave ovens). The IEEE802.11 provides a MAC layer data acknowledgment, used to recover from interference, and an optional in band channel reservation used to reduce the collision probability (4-way handshake mechanism).

With the 4-way handshake mechanism, before a data packet is sent, the station senses the medium. If the medium is idle for at least a DCF interframe space (DIFS) period of time, a source starts its transmission request by sending a RTS (Request To Send) packet to the destination. The destination, after a time called SIFS (Short Inter Frame Space), replies with a CTS (Clear To Send) packet. All terminals hearing RTS and/or CTS (i.e. the nodes in the sender and receiver radio range) set the NAV (Network Allocation Vector) to the time necessary to complete the packet transmission (this information is in both RTS and CTS packets) in order to defer transmissions during this time. When the source receives a CTS, it waits for SIFS and transmits the data packet. After receiving the packet correctly, the destination waits SIFS and sends an ACK (acknowledge) packet.

If the transmission fails due to an ACK packet loss or transmission error, a backoff time B (measured in time slots) is chosen randomly in the interval $[0, CW]$, where CW is the Contention Window. After a successful transmission, the contention window is reset to CW_{min}, otherwise, CW is calculated as $CW_i = 2^{k+i-1} - 1$, where i is the number of attempts (including the current one) that have been made to transmit the frame, and k is a constant defining the minimum contention window, CW_{min}. After the medium has been detected idle (also logically idle) for at least a DIFS, the backoff timer is decremented by one for each time slot if the medium remains idle (the count down is stopped if the channel is busy and restart when the channel is idle again after DIFS). When the backoff timer reaches zero, the frame is transmitted. If the transmission frame is broken, a new backoff time is chosen and the backoff procedure starts again. Since the contention window is exponentially increased, the risk of further collisions is reduced.

The IEEE802.11 retransmission mechanism has been designed to avoid excessive transport layer retransmissions due to noisy channels. While TCP traffic has major benefits from MAC layer retransmission, interactive multimedia suffers from high jitter and delay. Moreover interactive multimedia traffic is loss-tolerant and there is not any effective gain even from extremely low loss rate that provided by the layer 2 retransmissions [4].

As the demand of wireless applications increases, to accommodate high quality multimedia transmission, the infrastructure must respond promptly to provide adequate support. The IEEE802.11 working group has recently introduced a new standard to provide more bandwidth and an appropriate QoS support, IEEE802.11e [5].

Today's IEEE802.11 provides a transmission rate up to 54Mbps with IEEE802.11a and g and provides a basic QoS support with IEEE802.11e, similar to the one in the wired Ethernet [6]. In the IEEE802.11e the QoS support is realized by introducing Traffic Categories (TC). The exponential backoff as well as the Contention Window (CW) size are related to the specific traffic category; moreover, a TC queuing system is used for the traffic prioritization purposes. The current standard, in EDCF mode, requires RTS and CTS packets to be retransmitted up to 7 times and data packet up to 4 times although many implementors use higher values [7] [8].

III. Problem Statement

There are several concerns about the QoS support in the currently leading WLAN standard. The IEEE802.11a, b, and g, version do not have any QoS support unless extended with the IEEE802.11e. The QoS support in the IEEE802.11e still presents several open issues:

- **Traffic Categories assignment:** The standard does not define how the Traffic Categories (TC) are assigned. They can be assigned directly by the application or by another entity in the network although an application update,in this case the introduction of a middleware component may be required. If the network is already QoS enabled (i.e. DiffServ) the proper TC can be assigned mapping the upper layer QoS parameter. In general edge-oriented technique is more appropriate since it cannot take into account specific media related constraints.
- **Content Based Policies:** Within the same flow each packet may have a different level of importance with respect to the perceived quality; in the case of MPEG2 video, for example, I-frames are much more important than B and P-frames in terms of perceived quality. Content based differentiation may be the key in a networking scenario with high multimedia content such as home networking.
- **Hybrid Networks:** The deployment of IEEE802.11e will probably require a hardware substitution or a firmware update depending on the manufacturer. During initial phases of deployment, the nodes that use different technologies (802.11b and e) may well be in the same network (being served by an 802.11e enabled Access

Point) and such situations may exacerbate unfairness between 802.11b and 802.11e clients.

In this paper we presents a cross-layer QoS support for IEEE802.11x, (a,b,g,e,n); mainly we introduce a classification policy point that uses layers 4-7 information present in the packets to perform a flow classification and further packet type classification within the same flow. This allows us to apply different layer 2 strategies based on the content of the packet. Similar approaches have been partially described for the Bluetooth environment in [9]. In [10] a content weighted retransmission policy for MPEG4 over IEEE802.11b is also introduced.

IV. System Description

We introduce in the wireless network infrastructure, usually consisting of Access Points (APs) and clients, a number of new functionalities located in the APs and in the wired back-end of the network.

The *Wireless Quality Enhancer (WQE)* is the core of our architecture; it has been designed to be an enterprise/department wide entity in charge of the traffic classification and policy definition. The access point functionality has to be extended in order to support the policy execution. Basically WQEs are *policy makers* while APs are *policy actuators* as depicted in figure 2.

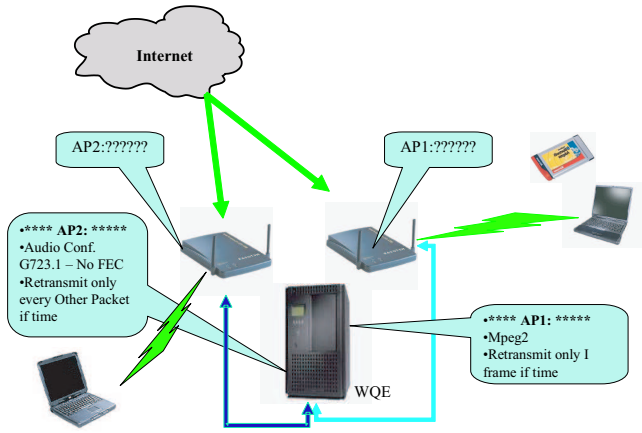

Fig. 2. Content-Based architecture for QoS Support.

A signaling protocol for the APs-WQE communications has been designed as a COPS extension [11][12].

A. Task Description for WQEs and APs

a. Access Point:

(i) *Data:*

- For each flow: when a packet is received, it is forwarded using the appropriate policy if there is any policy for the specific flow type of the received packet.
- If **no** policy is associated with the flow type, the proper *WQE Query*, including a copy of the current packet, is sent to the WQE.

(ii) *Management:*

- Whenever a *Query Reply* for a particular flow F_i is received, the received policy will be applied to all the packets belonging to F_i until the flow ends or is silent for longer than a specific timeout.
- The flow F_i will be deleted from the list of known flows if silent for more than a timeout period. This reduces the misclassification probability for new flows.
- When a RTCP packet arrives, a copy is forwarded to the WQE.

b. WQE:

(i) *WQE Query is Received:*

- Adds the packet, included in the query, to the current flow F_i sample.
- Runs the classification algorithms on the F_i sample.
- Once the flow F_j is classified, the appropriate policy set is retrieved from the policy database and forwarded to the proper AP using a *Query Reply*.
- Anytime an RTCP is received, a receiver buffer size estimation is started for all the receivers.

(ii) *Exceptions:* A flow F_i is classified as *Best Effort* if:

- not yet classified after a specific timeout is expired;
- or if the flow sample is larger than the maximum size.

Considering an MPEG2 flow, for example, the policy can define different behaviors for the different types of packets belonging to the flow: e.g. the I packets are retransmitted more than once while the b and p packets only once or none. The concept of content differentiation can be used to improve the user perceived quality.

B. Flow Classification and Policy Definition

The WQE classification algorithms are the key point for a successful QoS support; the decision is based on the information present in the packet headers. Each flow is identified using the traditional <source IP,destination IP, source port, destination port> socket tuple. The classification follows two main directions at the same time:

(i) *Protocol analysis:* the packet headers are analyzed to check if a specific QoS has already been requested. Others particularly important factors are:

- DSCP: if the network is DiffServ a proper value may be already set.
- Use of Real Time Protocol (RTP): a clear indication of delay-jitter sensitive traffic.
- RTP and packet payload analysis to identify the media codec.

(ii) *Statistical analysis:* Due to codec and application constraints, delay-jitter sensitive traffic usually presents

well known statistics in terms of flow rate and packet size. If the approach based on the traffic type analysis fails this strategy can be used.

A successful classification leads to the definition of the policy set. The WQE defines how the MAC layer parameters can be used to improve the QoS experienced by the user. In the IEEE802.11, for example, the policy set can impact on MAC queuing strategy, MAC retransmission strategy in the event of a packet loss, explicit drop of packets which belong to incomplete video frames, changes in the backoff strategy, etc.

V. Final Remarks

In this paper we introduced a new framework to support QoS in wireless LAN. The proposed architecture uses a Wireless Quality Enhancer located at the wired backend to classify the different traffic and define an appropriate MAC layer policy set at the base station. The basic idea behind is to use the layer 2 customizable parameters to improve the QoS perceived by the user. While the architectural design is fairly general, the simulation and implementation will be oriented to the IEEE802.11 family using the OpenAP [13] technology and an US Robotics 2450 AP [14]. An hybrid simulation approach will be also used to verify the architecture scalability.

The proposed scheme stands in the concept of a MAC layer that adapts its behavior to the transport and application layer requirements. This requires a per flow MAC policy that should accommodate network, transport, application and media requirements for an optimal user experience. The work presented here is an on-going work and still contains a lot of challenges that spawn from the performance modeling to a compact policy definition suitable for relatively small devices such as off the shelf access points.

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