An Adaptive ARQ Enhancement to support Multimedia Traffic using 802.11 Wireless LANs

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Abstract – As the demand for broadband multimedia wireless services increases, the need to provide QoS and higher data rate enhancements to the widely deployed IEEE 802.11 wireless LAN standard has become apparent. In this paper we propose a class-based adaptive ARQ scheme with QoS support for multimedia traffic, to facilitate higher throughputs through the reduction of MAC overhead. This scheme operates on top of the EDCA mechanism proposed in the IEEE 802.11e draft standard, which provides QoS support in the MAC layer through the use of service differentiation and traffic class prioritization. An OPNET simulation model is used to show that the proposed ARQ enhancement increases system performance.

Keywords - 802.11, WLAN, EDCA, QoS, Adaptive ARQ

I. INTRODUCTION

The Wireless LAN (WLAN) industry is experiencing rapid growth, which is being driven by current trends including increased use of laptops and Personal Digital Assistants (PDA), rapid advances in WLAN data rates (from 2Mb/s to 108Mb/s in the past four years), and precipitous drops in WLAN prices [1]. Furthermore, the increase in data rate intensive multimedia applications, and the flexibility of high-speed WLANs as an alternative to wired enterprise network infrastructure, has provided motivation for developing advanced service differentiating architectures to provide Quality of Service (QoS) support and higher throughputs.

Although the 802.11 Medium Access Control (MAC) sublayer provides limited QoS support for multimedia traffic through an optional centralized access mechanism called the Point Coordination Function (PCF), further QoS enhancements are needed in order for 802.11 WLANs to facilitate service differentiation. The PCF possesses several problems in providing guaranteed QoS policies, including unknown transmission durations of polled stations, and unpredictable beacon delays. This may severely affect QoS-sensitive applications, as variable time delays can be introduced. As the predominant WLANs in use today and those expected to be in use in the future employ some form of decentralized or distributed medium access mechanisms based on carrier sensing [2], further enhancements to the 802.11 distributed access mechanism, called the Distributed Coordination Function (DCF), are required in order to

provide QoS provisions for multimedia applications. The DCF is a mandatory part of the IEEE 802.11 MAC standard, and offers best effort packet transmission services [3]. A new coordination function known as Enhanced Distributed Channel Access (EDCA) is being developed to provide QoS enhancements in the MAC layer. The EDCA mechanism is incorporated in the upcoming 802.11e standard [4,5], which provides service differentiation through transmission prioritization, as well as parameterized reservation using centralized control. Fig. 1 shows the architecture of 802.11e and its coexistence with legacy 802.11.

In recent years, there have been many proposals for QoS support and throughput enhancement in 802.11 WLANs. A thorough survey of 802.11 QoS schemes is presented by Zhu et al. in [6], which includes MAC layer service differentiation, admission control and bandwidth reservation, and link adaptation in the physical layer (PHY). Adaptive cross-layer QoS schemes are presented in [7,8], which include real-time retransmission limit adaptation at the MAC layer for the robust streaming of video over 802.11 WLANs. Hybrid Automatic Repeat Request (ARQ) and Forward Error Correction (FEC) schemes at both the MAC and PHY layers are presented in [9,10,11] to reduce overhead and enhance MAC layer performance. Throughput enhancement schemes are also described in [12,13], which include many of the proposals currently being considered by the 802.11n Task Group for a future higher throughput standard.

Figure 1. 802.11e Architecture

In this paper we propose a class-based adaptive ARQ scheme to further improve the QoS and MAC efficiency. The current 802.11 standard employs a simple *stop and wait* ARQ protocol for error control, where a positive acknowledgment (ACK) is transmitted by the destination station (STA) upon successful reception of a data packet (MPDU). If the originating STA does not receive a positive ACK, the MPDU is retransmitted. This process continues until either the MPDU is successfully transmitted, or a retransmission attempt limit is reached upon which the MPDU is discarded. Although this approach is well suited to distributed WLAN architecture, MAC overhead is increased through the transmission of ACKs, and can introduce unnecessary waiting periods for delay sensitive traffic. To further improve MAC efficiency and facilitate higher data rates, a class-based adaptive ARQ scheme is proposed for real-time services, where additional ARQ modes (currently being defined in the 802.11e standard) are dynamically employed based on class-specific QoS parameters. In addition to the legacy *stop and wait* (ACK) ARQ mode, 802.11e defines a No Acknowledgment (*No ACK*) mode where no MAC-level recovery is employed, and a Block Acknowledgment (*Block ACK*) mode where a group of MPDUs are transmitted in succession and acknowledged by a single ACK. The proposed Adaptive ARQ scheme also incorporates the discarding of MSDUs¹ from the transmitter queue if they have not been sent successfully before a class-specific delay threshold is exceeded. This mechanism is also currently being defined in the upcoming 802.11e standard.

The paper is structured as follows: Section II describes the 802.11e EDCA. Section III presents the proposed enhanced ARQ scheme. An OPNET based simulation model is described in section IV with simulation results presented in section V. A brief discussion is presented in section VI.

II. 802.11e EDCA

The 802.11 Task Group E (TGe) is currently defining Quality of Service (QoS) enhancements to the 802.11 MAC, with a distributed access mechanism called Enhanced Distributed Channel Access (EDCA). In order to provide service differentiation, faster access to the channel must be given to an Access Category (AC) with a higher priority. Proposals presented by TGe bind the priority of an AC to channel access by assigning different CSMA/CA access parameters for each AC, as shown in Fig. 2. These include the inter-frame space called an Arbitration Inter-Frame Space (AIFS), and the parameters that regulate the CW size, being CW_{min} and CW_{max} . Each AC has its own queue, and contends for the medium using a separate CSMA/CA instance. Collisions between ACs within the same STA are

Figure 2. 802.11e EDCA timing operation

resolved by granting access to the AC with the highest priority, with the lower priority AC behaving as if there was an external collision on the wireless medium. Fig. 3 shows the implementation model architecture of the mapping from higher layers into AC queues, each with their own channel access functions and virtual internal collision resolution. Once a STA has gained access to the medium, it can initiate a Transmission Opportunity (TXOP), which is a bounded duration time interval in which the STA may perform packet bursting where a sequence of short inter-frame space (SIFS) separated data and ACK packets are exchanged.

The *Block ACK* mechanism [14] proposed in 802.11e, allows a group of MPDUs to be transmitted consecutively, separated by intervals as short as a SIFS period, while bundling all corresponding acknowledgements into a single collective block ACK. *Block ACK* mode is initialized by an exchange of setup frames, which negotiate various parameters including buffer size and Block ACK type, with the latter being either immediate or delayed. After the *Block ACK* connection has been setup, the originator may transmit a number of MPDUs separated by SIFS periods, with the total number of MPDUs not exceeding the buffer size negotiated at setup. The originator requests acknowledgement of outstanding MPDUs by sending a Block ACK Request frame. If Immediate *Block ACK* mode is used, the recipient responds immediately after the Block

Figure 3. EDCA implementation architecture

¹ A MAC Service Data Unit (MSDU) is a unit of data arriving at the MAC layer from higher layers. Fragmentation is the process of partitioning a MSDU into smaller MAC level frames called MAC Protocol Data Units (MPDU).

ACK Request frame with a Block ACK Response frame, which contains a record of the acknowledgement state for fragments of up to 64 data packets (MSDUs). If Delayed *Block ACK* mode is used, the recipient responds to the Block ACK Request frame with an ACK. The Block ACK Response frame is then prepared and sent in a subsequently obtained TXOP, with the originator responding with an ACK. This Delayed *Block ACK* mechanism is primarily intended to facilitate inexpensive implementations that use the processing power of a host, and also to allow existing implementations to use this feature with minimal hardware changes. The *Block ACK* mechanism improves channel efficiency by aggregating multiple acknowledgements into one frame. The 802.11e standard also defines a *No ACK* ARQ policy, where the recipient STA does not transmit a positive ACK after the successful reception of a MPDU. Therefore, *No ACK* mode does not employ any MAC-level recovery, and each MPDU is only transmitted once.

III. CLASS-BASED ADAPTIVE ARQ

In this section we present a class-based adaptive ARQ scheme developed to improve MAC efficiency and throughput. As real-time services are often sensitive to delay and delay variation (jitter), the use of the simple *stop and wait* ARQ protocol as defined in the DCF may not provide adequate QoS, and can be inefficient due to the additional signaling overhead and delay introduced by ACK transmission and retransmit procedures.

A. Adaptive ARQ Protocol

The proposed class-based adaptive ARQ scheme dynamically switches between *No ACK* mode and the legacy *stop and wait (ACK)* mode, for both real-time and interactive data services; with large data burst and file transfer services employing the *Block ACK* mode. As *No ACK* mode does not require the additional time to transmit an ACK separated by a SIFS for each MPDU, the channel can be utilized for transmitting other packets during this period. MPDUs generated by real-time sources are usually required to be transmitted within a delay bound. Therefore, providing that channel conditions are good enough to support a desired QoS, the sending of an ACK for each real-time MPDU may not be an optimal solution.

The class-based adaptive ARQ enhancement uses a receiver-initiated scheme where the different ARQ modes (i.e. *stop and wait* and *No ACK*) are dynamically employed based on a traffic class-specific Packet Error Rate (PER) threshold. Upon reception of a MPDU, the recipient STA adds the error status of the packet to a table for later use in the PER calculation. The length of the historical time window from which received MPDU error status is drawn for use in calculating the PER, is regulated by either by a time duration or a packet count since the last PER calculation, depending on the traffic class being serviced. If a time duration parameter is used, the PER is calculated

periodically, with only those MPDUs that were received within the time window being used in the calculation. If a packet count threshold is used, a counter is incremented upon reception of each MPDU. When the counter reaches the threshold, a PER calculation is triggered and the counter is reset. This mechanism is useful for services that have a variable packet inter-arrival time. If both time window regulation parameters are used, a PER calculation is triggered by whichever mechanism occurs first. Video and voice services initially start in *No ACK* mode due to the nature of real-time traffic, and dynamically switch between this mode and the legacy *stop and wait* mode depending on the PER. Fig. 4 shows the signaling protocol used to switch between ARQ modes for a real-time service connection. If the PER at the receiver traverses a traffic class-specific threshold, an ARQ Mode Request frame is sent to the originator, requesting the desired ARQ mode change. ARQ Mode Request frames are not acknowledged due to their periodical nature. Upon successful reception of an ARQ Mode Request frame, the originator changes its ARQ mode accordingly.

The proposed scheme also incorporates the 802.11e mechanism of discarding MSDUs from the transmitter queue based on an AC-specific delay threshold called a MSDU lifetime. A timer is started when a MSDU is first passed to the MAC layer, and if it exceeds its associated MSDU lifetime before successful transmission, all remaining fragments of the MSDU are discarded by the source STA without any further attempt to complete its delivery.

B. Implementation

The Adaptive ARQ scheme can be implemented by having the recipient maintain, for a certain originator MAC address, a PER record table containing a tuple entry for each MPDU received; consisting of the MPDU reception time, and error

Figure 4. Adaptive ARQ scheme signalling sequence: (a) Initially in No ACK mode, (b) ACK mode switch, (c) No ACK mode switch

flag determined by the Frame Check Sequence (FCS) value. A new tuple entry is made into the table upon the reception of all MPDUs addressed to the recipient, providing the address field information in the MAC header is not corrupt. A circular array can be used for the PER record table in order to bound buffer size requirements. The ARQ Mode Request frames used in the signaling of the Adaptive ARQ scheme can be implemented using 802.11 control frames with unique subtype fields within the Frame Control field of the MAC header.

IV. SIMULATION

A. OPNET model

A comprehensive discrete event simulation model using OPNET is used to analyze the performance of the proposed adaptive ARQ scheme operating on top of the 802.11e EDCA mechanism. The model simulates the DCF and EDCA mechanism over the 802.11a PHY layer [15], which supports raw data rates of up to 54Mb/s. Data bursting, defined as TXOPs in 802.11e, has been omitted for simplicity. The 5GHz wireless channel is simulated in OPNET using an empirical model to represent a public *hot spot* propagation environment. All STAs transmit at 54Mb/s with a power equal to 50mW. The propagation path loss is calculated for each packet transmission using a log-distance equation, where the exponent is drawn from a uniform distribution between the bounds of 2 and 3.8, based on empirical values derived from experiments in indoor environments [16,17]. The Signal-to-Noise Ratio (SNR) for each frame is mapped to a BER value through the use of empirical OPNET modulation curves. To further increase the accuracy of the channel model, separate modulation curves are used for each of the 4 modulation schemes used in 802.11a, namely BPSK, QPSK, 16-QAM and 64-QAM.

B. Simulation Scenario

The simulation scenario consists of two STAs in the cell, where at any given time there is only one active station that always has a packet to send, with the other station performing reception and acknowledgment tasks. Table I shows the CSMA/CA access parameters used by the transmitting STA, where Voice AC (AC_VO) parameters are used when transmitting under EDCA. MSDUs are generated using a constant inter-arrival time and 1500 byte packet size. The Adaptive ARQ scheme is simulated using a PER threshold of 2%, with the PER calculated from a historical time window of 1 second duration. A receiver error correction threshold of 10^{-3} is assumed.

TABLE I CSMA/CA ACCESS PARAMETERS

AC	AIFS	CWmin	CWmax
Legacy DCF	2	15	1023
AC_VO	1	7	15

V. SIMULATION RESULTS

The performance of the proposed Adaptive ARQ scheme is analyzed by comparing it with the same traffic generation parameters operating under DCF, EDCA in *stop and wait* (ACK) mode, and EDCA in *No ACK* mode. From Fig. 5 it can be seen that the total throughput using EDCA in *No ACK* mode is superior, providing a throughput increase of up to 9Mb/s compared to the legacy DCF. This is due to the bandwidth normally required for the transmission of the ACK frame and its associated SIFS separation interval being redundant, thus allowing other transmissions to utilize the channel during this period. The *Adaptive ARQ* scheme also exhibits this superior throughput increase by dynamically switching to *No ACK* mode when high SNR conditions are experienced. The tradeoff in increased throughput performance when employing *No ACK* mode is an increased PER. Fig. 6 shows the PER as a percentage of the total packets received within a 1 second historical time window, using both the Adaptive ARQ PER calculation described previously, as well as with the retransmission process invoked (i.e. erroneous MPDUs are only added to the PER calculation table when the retransmission limit is exceeded). It can be seen that as the propagation distance increases, the PER exceeds associated Receiver minimum input level sensitivity limits, and therefore more robust PHY layer modes (i.e. different modulation and coding) should be employed e.g. through the use of Link Adaptation (LA) techniques. Fig. 7 shows that the end-to-end delay for EDCA operating in *No ACK* mode is superior to both EDCA and the DCF. The Adaptive ARQ scheme also experiences this delay reduction, as it dynamically switches from *ACK* mode to *No ACK* mode under facilitating channel conditions. The throughput and delay performance increases gained by the Adaptive ARQ scheme in the 54Mb/s PHY layer mode extend to all of the additional PHY layer modes as defined in 802.11a, providing that channel conditions facilitate a PER less than a service-specific threshold.

VI. DISCUSSION

In this paper we propose a class-based adaptive ARQ scheme to further improve the QoS and MAC efficiency of the 802.11 MAC protocol. From the results, the conclusion can be drawn that the explicit acknowledgment of real-time MSDUs is not always the best approach for real-time services, providing that the PER is below a threshold that source coding or error concealment techniques can combat. The adaptive ARQ scheme reduces the end-to-end delay and significantly increases system throughput under good channel conditions, as the bandwidth normally required for the transmission of an ACK and its associated SIFS separation interval when a station has dynamically switched to *No ACK* mode, can be utilized for other transmissions. The tradeoff in increased throughput and delay performance when employing *No ACK* mode is an increased PER, which may lower the “satisfaction” of a service from an end user

Figure 5. Throughput

Figure 6. PER

Figure 7. End-to-end Delay

perspective, or even render it useless. As some real-time services can cope with a small lose rate, the penalty for eliminating ACK frames is to manage the balance between increased efficiency and decreased reliability. The proposed class-based adaptive ARQ scheme is able to dynamically adapt the ARQ mode under changing channel conditions to

meet the required QoS, so as to retain all the advantages that *No ACK* mode offers, whilst keeping the PER to a level that a service can tolerate. This adaptive ARQ scheme can be further enhanced if coupled with MAC layer Forward Error Correction (FEC) coding, or Link Adaptation (LA) mechanisms at the PHY layer, as different modulation and coding rates can be used to reduce the PER, thus enabling *No ACK* mode to be utilized for longer durations. The inclusion of *Block ACK* mode will further improve performance and bandwidth efficiency.

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