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A reliable and scalable groupCast block acknowledgement scheme for video multicast over IEEE 802.11aa

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Abstract. Reliable video delivery is one of the most important requirements to satisfy end user needs. With the proliferation of multimedia technologies there is a growing demand for video multicast, particularly in challenging wireless environments. Effective video multicast services need to meet the conflicting goals of assured data rate and reliability. The most used IEEE standards (802.11a/b/g/n) do not ensure reliable multicasts since throughput remained primary focus of research in recent past. The IEEE 802.11aa remains the only standard that attempts to handle the unreliability issue with multicasting. However, the block acknowledgement scheme of the IEEE 802.11aa standard suffers from scalability issue. As the number of receivers increases, the number of acknowledgement packets increases proportionally. This increasing acknowledgement storm eventually causes a decrease in the average peak signal-to-noise ratio (PSNR) of the video frames. Therefore, in order to overwhelm the scalability limitation of the IEEE 802.11aa block acknowledgment scheme, this paper proposes a modified block acknowledgment scheme for video multicast. Our scheme considers the impact of the loss of different frames on video quality under Moving Picture Expert Group 4 (MPEG-4) and H.264 video coding. We provide a Markov chain model and numerical analysis of our proposed protocol. Simulation results indicate that proposed scheme performs well in terms of PSNR.

Keywords: IEEE 802.11aa, MPEG-4, Multicast, PSNR, Reliability

1. Introduction

Multicasting is the method used to deliver the same data to multiple group members at once. The use of multicast services in various applications over wireless local area networks (WLANs) include video streaming to group of students, streaming of sport events in smart stadium, video gaming, video on demand, and file sharing etc. [1]. Multicast of video streaming services is both promising and growing technology for multimedia services over WLANs [2]. Mobile networks like worldwide interoperability for microwave access (WiMAX) and long term evolution (LTE) also support scalable video multicast. Historically, throughput had been regarded as the primary demand of multimedia applications. However, video streaming has placed new demands upon the underlying WLANs. Video quality relies on the reliable delivery of video traffic. Therefore, video multicast frames need to be reliably delivered to all stations in the multicast group. Legacy IEEE 802.11 standard [3] supports only unreliable multicast

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service since it does not support retransmission of lost packets. Under the IEEE 802.11e standard [4], differentiation and prioritization among four different types of traffic classes is supported through enhanced distributed coordination access (EDCA). However, even EDCA does not consider multicast transmission despite support for multiple traffic classes since it does not provide multiple classes for video. Many codecs, such as Moving Picture Expert Group 2 (MPEG-2), MPEG-4, and MPEG-4 advanced video coding (AVC) do not provide equal frames even though some of them are more significant than others. IEEE 802.11aa standard [5] extended the existing EDCA prioritized mechanism of the IEEE 802.11e to provide differentiation among different video flows. IEEE 802.11aa added two additional queues within the existing EDCA access categories [6] to provide prioritization for both audio and video streaming. The main features of medium access control (MAC) under the IEEE 802.11aa standard are stream classification service (SCS) and groupcast with retries (GCR). In this paper, we focus on GCR service. A detailed overview of the GCR scheme can be found in [7].

Carrier sense multiple access with collision avoidance (CSMA/CA)-based scheme suffers from various kinds of overheads at MAC and physical (PHY) layers hampering the efficiency of schemes [8]. Main sources of overhead are backoff time, distributed inter-frame space (DIFS) time, acknowledgement (ACK) packets, short inter-frame space (SIFS) time, and headers for MAC and the PHY layer. To decrease the overhead, a block ACK (BA) scheme was proposed in the IEEE 802.11e standard [9]. In the GCR-BA scheme, a group of packets destined for the same receivers is allowed to be transmitted (reducing the per packet DIFS to a single DIFS) without being acknowledged (significantly decreasing the SIFS's). After the transmission of a block, the sender initiates a block ACK request (BAR) packet to confirm the number of packets that were successfully received. Receivers then respond with a BA packet. The efficiency of the BA scheme comes from the fact that the overhead is greatly reduced, because DIFS and backoff times only occur before the first packet of the block, and only one ACK packet is used for all the packets in the block.

The main contributions of this paper can be summarized as follows.

– To overcome the scalability limitations of GCR-BA scheme of IEEE 802.11aa, this paper proposes a modified GCR-BA scheme by considering the importance of different frames for multimedia traffic.
– We provide a Markov chain modeling and numerical analysis of the proposed scheme and compare it with that of legacy 802.11, GCR Unsolicited (GCR-UR), GCR-BA and proposed protocol schemes.

The reminder of the paper is structured as follows. Section 2 provides the related work in detail. Section 3 presents the proposed protocol. Section 4 provides a numerical analysis in detail. Section 5 discusses the performance evaluation, and finally, Section 6 concludes the paper.

2. Related work

In IEEE 802.11-based WLANs, most research efforts on multicasting have concentrated on improving transmission reliability by incorporating automatic repeat request (ARQ) into the protocol architecture. In [10], authors presented a leader-based protocol (LBP) for multicast in WLANs. Their proposed protocol chooses one of the multicast receivers for the exchange of control packets (ready-to-send (RTS), clear-to-send (CTS), and ACK) to control the amount of traffic. However, LBP does not consider the numerous parameters associated with video compression techniques, such as frame type and frame size. Lim et al. [11] proposed the reliable and efficient multicast protocol (REMP) for scalable video streaming. Depending on network conditions REMP dynamically adjusts the number of transmissions of control packets. In stable channel conditions, an access point exchanges control packets with selected multicast receivers only. In an unstable channel conditions, control packets are exchanged with all multicast receivers, which may significantly increase overhead as number of multicast receivers grow, hence reduce overall system performance. Choi et al. [12] extended their leader-based multicast service (LBMS) using the new network management messages in the IEEE 802.11v standard. However, their focus was usage of the management message, without considering directed multicast service (DMS). Santos et al. [13] evaluated coexistence of multicast video and unicast data traffic for both DMS and GCR. However, they measured multicast throughput, multicast delay, and unicast throughput. Thus, there was no direct indictor of video quality measurement.

Authors in [1] presented an analytical model for delay estimation directed multicast service (DMS), GCR-UR and GCR-BA of IEEE 802.11aa standard. The delay of the Block ACK protocol is inversely proportional to the transmission opportunity (TXOP) limit. In [14], authors proposed a protocol which is capable of block negative acknowledgment (BNACK) in wireless networks based on IEEE 802.11. The proposed protocol addresses reliable multicast and address retransmission of missing packets. The protocol is able to outperform the ideas of IEEE 802.11v and IEEE 802.11aa. The receiving nodes are assumed to be in the coverage area of the sender nodes and that transmission takes place at a specific rate with no collision. Using the BNACK policy, packets are transmitted in blocks followed by a block NAK request (BNR) and only member with lost packets provide the feedback. In this way, if all packets are transmitted correctly no BNAK is transmitted which saves the bandwidth. However, the reliability of the proposed protocol depends on the reception of BNR.

High bandwidth application like video streaming requires high bandwidth and reliability. In 802.11p, the link is degraded due to mobile and static link in vehicular network. This paper [15] proposed hybrid architecture based on fourth generation long term evolution (4G/LTE) and IEEE802.11p to support vehicle-to-everything (V2X) video streaming. The proposed protocol works on the principle of always best in best possible way. In the proposed network architecture, vehicles can communicate using ad hoc link or using cellular network infrastructure such as 4G/LTE. The proposed protocol focusses on packet loss rate and tries to keep it minimum which is not addressed before. The results show feasibility of the proposed approach and significant improvements on link reliability.

A detailed analysis and evaluation of a novel multicast scheme under the IEEE 802.11aa standard was evaluated by Banchs et at. [16]. They shed light on throughput and reliability. They used the legacy definition of reliability (the total number of successfully received frames over all frames). However, this definition may not be true for multimedia applications in particular, where different types of frames impact video quality differently. Xiao et al. [17] have shown in this context that higher throughput does not al-ways mean better video quality. Moreover, the authors confirmed that the new mechanism of the IEEE 802.11aa standard is able to substantially improve performance, and can provide different trade-offs considering complexity, efficiency and reliability.

Ivanov et al. [18] studied the amendment provided in IEEE 802.11aa and provided an analytical model of GCR retransmission method. Daldoul et al. [19] evaluated the throughput and reliability of DMS, GCR-BA and GCR-UR with different group sizes. They stem the analytical with simulation results and conclude that GCR-UR is the most appropriate scheme for bigger group sizes. However, DMS does not scale very well. GCR-BACK is also not found suitable for large number of receivers. For providing service differentiation between real-time and non-real-time video queues Lai and Liou [20] presented an efficient scheduler between the primary and alter-native queues of SCS in IEEE 802.11aa. Their proposed scheme maintains priority and fairness between primary and alternative queue of SCS. Tang and McKinley [21] showed that as the number of receivers sending feedback packets increase, packet loss is exacerbated. Moreover, multicast feedback causes more data packet loss than unicast. The results highlighted the significant impact of loss density on performance of multicast reliability in WLANs.

The work in [22] proposed a quality of experience (QoE) based link adaptation (QLA) mechanism for H.264 AVC streaming through IEEE 802.11a/g LANs. QoE is becoming very important in IEEE 802.11 LANs. It used the metrics such as resolution buffering time and smoothness to assess the user experience. The legacy IEEE 802.11a/g broadcast mechanism lacks link adaptation and retransmission mechanisms. This work also discussed a link adaption mechanism to optimize video streaming for users QoE. Previous MAC layer link adaptation work didn′t optimize it for video transmission. On the contrary, this work has focus on link adaption for H264/AVC video streaming through IEEE 802.11. The proposed scheme used regression method to define utility function. A higher average playback video stream indicates a higher video stream thus a user is more. The purpose of QLA is to select a set of multiple coding schemes and retries limits which maximize the utility. The legacy IEEE 802.11 lacks ACK for multicasting. This work also proposed a scheme to use block ACK for multicast to achieve reliability. QLA is evaluated for different channel conditions. The results showed that utility of proposed scheme is higher than other schemes.

Shin et al. [2] presented various reliable multicast schemes, including application layer forward error correction (FEC), and a reliable multicast protocol under the IEEE 802.11v [23] and 802.11aa [5] standards. Evaluation of these protocols was done via simulations. Results reveal similar behavior as concluded in [24] that GCR with BA achieve high reliability when there is a small number of a multicast receiver. However, increasing number of receivers causes increase in feedback ACKâŁ™s, and eventually, the average peak signal-to-noise ratio (PSNR) decreases. Therefore, in this paper, we propose a modified GCR-BA scheme under the 802.11aa standard for multimedia traffic to address the scalability limitations discussed so far by limiting the control overhead. Considering the significance of different frames [17, 24], there is no control packet for predicted frames (P-frames) and bidirectional frames (B-frames) in our proposed BA scheme.

3. Proposed groupcast block acknowledgment scheme

With growing multimedia traffic video compression is of utmost importance. MPEG4 and H.264 are among the most popular standards for this purpose and include three types of frames: intra-coded (I-frames), P-frames and B-frames [25]. Reconstruction of a video frames is exclusive to I-frames. Since, I-frames are self-contained, they prevent inter-frame error propagation. Being self-contained in nature, I-frames result in best quality video, however, are not compression friendly. I-frames are inevitable for interactive video playback since a new group of pictures (GOP) cannot start without these. A typical GOP order is $IBBPBBPBBPBB$. If an I-frame is lost, all P- and B-frames up to the next I-frame are of no use. Therefore, the reliability of the I-frame is very important. Because the size of the frame is bigger than the maximum service unit (MSU), the number of packets, n_k, comprising frame k is a random variable. The total number of fragmented packets of N_f frames is therefore obtained by

$$M = \sum_{k=1}^{N_f} n_k. \tag{1}$$

Figure 1 highlights a system model. The system consists of N nodes, including a multicast source and $N - 1$ multicast members. We assume that each node always has a packet available for transmission. GCR Block ACK and Proposed GCR Block ACK algorithms are presented in Algorithms 1 and 2, respectively. The proposed solution does not use BA or BAR or any other control packets for both P and B-frames. BA is transmitted by each receiver if they correctly received the packet belonging to an I-frame. This reduction in control overhead leads to increasing scalability of GCR-BA protocol.

Algorithm 1 Proposed GCR Block ACK Scheme

```
Procedure:
type ← TypeofFrame();
Mm ← getMulticastMembers();
loop:
if (node == sender) then
    transmitframe(Mm);
end if
if (node == receiver) then
    if (type == I) then
        transmitBlockAckRequest();
        transmitBlockAck;
    end if
    if (type == P || type == B) then
        break;
    end if
end if
end loop:
end Procedure:
```

Algorithm 2 GCR Block ACK Scheme

```
Procedure:
type ← TypeofFrame();
Mm ← getMulticastMembers();
loop:
if (node == sender) then
    transmitframe(Mm);
end if
if (type == I||type == P||type == B) and
(!BlockACKReceived()) then
    retransmitI − frame();
    retransmitP − frame();
    retransmitB − frame();
end if
if (node == receiver) then
    if (type == I) ||type == P || type == B
    then
        transmitBlockAckRequest();
        transmitBlockAck;
    end if
end if
end loop:
end Procedure:
```

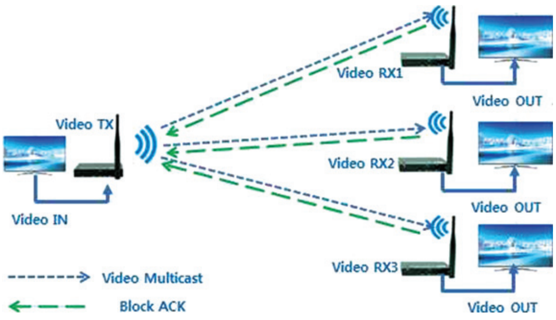

Fig. 1. Proposed System Model.

4. Performance analysis

4.1. Failure probability

In our performance analysis, the slotted time model introduced by Bianchi [26] is used. Channel is accessed at discrete times only (i.e., after an integer multiple of backoff slots from the last channel activity). This paper considers N stations in multicast networks; all of them generate traffic, keeping payload size intact. Furthermore, a saturated condition is considered, during performance analysis. This paper assume that stations experience identical channel conditions, and they suffer from the same channel error probability, p_e. Let p_c be the probability that a transmitted packet sees a collision on the channel. A block of video packets is sent using the GCR-BA scheme. (For clarity, hereinafter, we use the term packet for a MAC layer frame, and frame for an application layer video frame).

This paper compares the performance of GCR-UR, No-ACK No-retry, GCR-BA and our proposed protocol. (Hereinafter, we refer to No-ACK No-retry as legacy 802.11 multicast). Under the legacy 802.11 multicast protocol, the multicast receivers will not transmit an ACK packet, and therefore, there is no retransmission from the sender station, i.e., a multicast packet is transmitted only once. However, in GCR-UR, there are multiple transmission attempts for the same packet. The multicast packet is correctly received by each multicast member when it does not collide with another packet and does not suffer from channel error. Thus, the failure probabilities for the GCR-UR, legacy 802.11, GCR-BA scheme, and proposed protocols can be written as

$$p_f = p_c + (1 - p_c)p_e. \quad (2)$$

Let τ be the transmission probability that a station transmits in a randomly chosen slot time. In a steady state, each $N - 1$ remaining node transmits a packet with probability τ for each protocol, and p_c is equal to

$$p_c = 1 - (1 - \tau)^{N-1}. \quad (3)$$

4.2. Packet transmission probability

This paper considers a fixed number of stations in a saturation condition. A discrete integer time scale is adopted: t and $t + 1$ correspond to the beginning of two consecutive slot times, and the backoff counter of each station decrements at the beginning of each slot time. Let $s(t)$ and $b(t)$ denote the stochastic process representing the backoff stage and the backoff counter value for the given station at slot time t respectively [27]. Let $b_k = \lim_{t\to\infty} P\{b(t) = k\}$ be the stationary distribution of the Markov chain, where the backoff counter $k \in [0, W - 1]$ in Fig. 2.

Let $b_{i,k} = \lim_{t\to\infty} P\{s(t) = i, b(t) = k\}$ be the stationary distribution of the Markov chains in Figs. 3 to 5, where backoff stage $i \in [0, m]$, $k \in [0, W_{i-1}]$. At each packet transmission, a backoff timer is used and is randomly selected in the range $[0, W - 1]$, where W is called the contention window starting with the minimum value CW_{min}, which will be doubled at each failure of transmission/retransmission until it reaches the maximum value, CW_{max}. The relation between CW_{max} and CW_{min} is $CW_{max} = 2^m CW_{min}$, where m is the maximum backoff stage or retransmission count.

Letting $CW_{min} = W$, we can summarize the contention window as

$$W_i = \begin{cases} 2^i W, & 0 \le i \le m \\ 2^i m, & i > m. \end{cases} \quad (4)$$

4.2.1. Legacy 802.11 Multicast

In order to compute the transmission probability that a station transmits in a randomly chosen time slot, we consider a discrete-time Markov chain. The state transition diagram describing the backoff counter decrement under the legacy 802.11 multicast

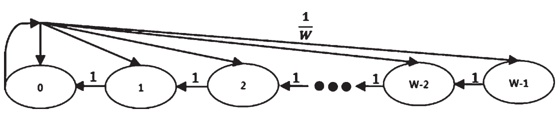

Fig. 2. Markov chain model for the legacy 802.11 multicast protocol.

protocol is shown in Fig. 2. The one-step transition probabilities are

$$\begin{cases} Pr\{k|k+1\} = 1, & k \epsilon (0, W-2) \\ Pr\{k|0\} = \frac{1}{W}, & k \epsilon (0, W-1). \end{cases} \quad (5)$$

From Fig. 2, we can derive the following relations through chain regularities.

$$b_k = \frac{W-K}{W} b_0, \quad 0 < k \leq W-1. \quad (6)$$

$$\sum_{k=0}^{W-1} b_k = 1. \quad (7)$$

As any transmission may occur when the backoff time counter is equal to zero, solving Equations 6 and 7, we have

$$\tau^{legacy} = b_0 = \frac{2}{W}. \quad (8)$$

4.2.2. GCR unsolicited retries

In the GCR-UR scheme, multicast data packets are transmitted several times without waiting for an ACK packet after each transmission. In the GCR-UR scheme, the transmitter always chooses the minimum contention window for each retry, because the transmitter has no idea whether the transmission was a success or failure due to the absence of the ACK packet from multicast receivers. The bi-dimensional process $\{s(t), b(t)\}$ with the discrete-time Markov chain of GCR-UR is shown in Fig. 3. The one-step transition probabilities are

$$\begin{cases} Pr\{i,k|i,k+1\} = 1, & k \epsilon (0, W_0-2) \quad i \epsilon (0, m) \\ Pr\{i,k|i-1,0\} = \frac{1}{W_0}, & k \epsilon (0, W_0-1) \quad i \epsilon (1, m) \\ Pr\{0,k|m,0\} = \frac{1}{W_0}. \end{cases} \quad (9)$$

In a steady state, the following relations can be derived through chain regularities.

$$b_{i,k} = \frac{W_i - K}{W_i} b_{i,0}, \quad 0 < k \leq W_0 - 1, 0 \leq i \leq m. \quad (10)$$

$$\sum_{k=0}^{W_0-1} b_{i,k} = 1. \quad (11)$$

From Equations 10 and 11, we can write

$$b_{i,0} = \frac{2}{W_0}. \quad (12)$$

Since any transmission may occur when the backoff counter value reaches zero regardless of the retransmission, we have

$$\tau^{GCR-UR} = \sum_{i=0}^{m} b_{i,0}. \quad (13)$$

4.2.3. GCR block ACK

The unit of transmission in the BA scheme is a block. There is a single ACK packet for multiple data packets in the GCR-BA scheme. The units of transmission under legacy 802.11 multicast and GCR-UR protocols are data packet and ACK packet. Therefore, the GCR-BA scheme is expected to be more effective [8]. The GCR-BA scheme operates in a way similar to the legacy distributed coordination function (DCF). In particular, we may treat a block in the GCR-BA scheme as a packet in the DCF because both of them are considered as a unit of operation. Therefore, it is possible to extend the previous analysis, which was designed for legacy DCF, to find the transmission probability. A similar technique has been used elsewhere [9, 29]. However, in case of collision, a whole block needs to be retransmitted in the GCR-BA scheme. Bianchi [26] used a Markov chain model with the assumption that packet retransmissions are unlimited until its successful reception. Wu et al. [28] extended the analysis of Bianchi [26] to include finite packet retry limits as defined in the IEEE standard. The bi-dimensional process $s(t)$, $b(t)$ with the discrete-time Markov chain for GCR-BA is shown in Fig. 4. The one-step transition probabilities of the backoff stage are given as

$$\begin{cases} Pr\{i,k|i,k+1\} = 1, & k \epsilon (0, W_i-2) \quad i \epsilon (0, m) \\ Pr\{0,k|i,0\} = \frac{1-p_f}{W_0}, & k \epsilon (0, W_0-1) \quad i \epsilon (0, m-1) \\ Pr\{i,k|i-1,0\} = \frac{p_f}{W_i}, & k \epsilon (0, W_i-1) \quad i \epsilon (1, m) \\ Pr\{0,k|m,0\} = \frac{1}{W_0}. & k \epsilon (0, W_0-1) \end{cases} \quad (14)$$

Because of the stationary distribution of the Markov chain we have the following relations.

$$b_{i-1,0} p_f = b_{i,0} \quad 0 < i \leq m. \quad (15)$$

$$b_{i-1} p_f^i = b_{0,0} \quad 0 \leq i \leq m. \quad (16)$$

Owing to the chain regularities, and using Equation 15, we have

$$b_{i,k} = \frac{W_i - K}{W_i} \begin{cases} (1-p_f) \sum_{j=0}^{m} b_{j,0} & i = 0 \\ p_f b_{i-1,0} & 0 < i \leq m. \end{cases} \quad (17)$$

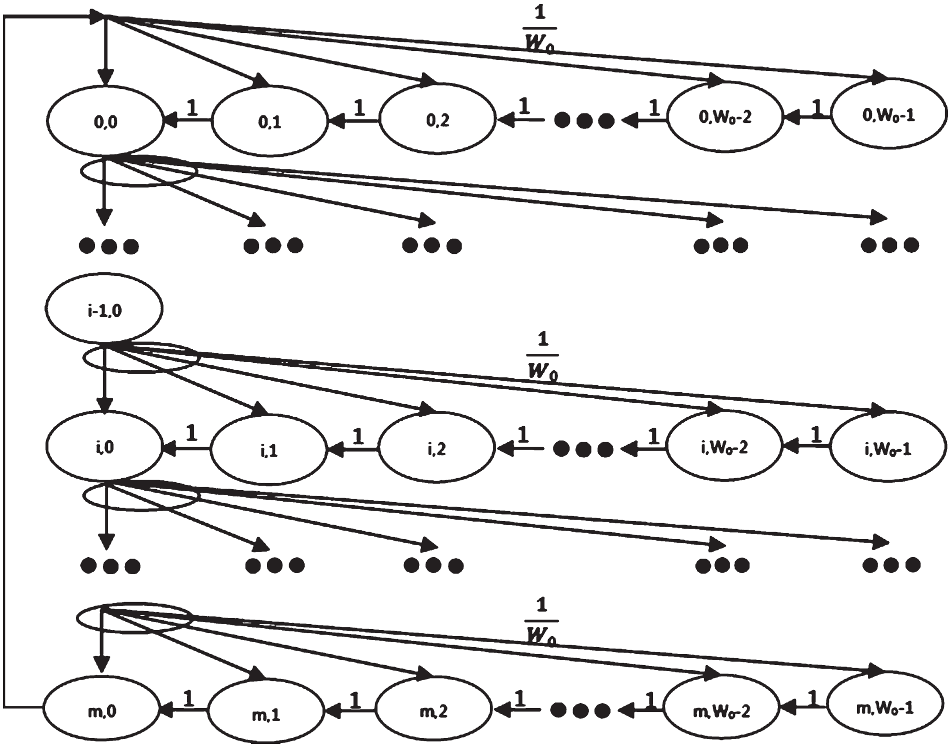

Fig. 3. Markov chain model for the GCR-UR scheme.

With Equation 16 and a transition in the chain, Equation 17 can be rewritten as

$$b_{i,k} = \frac{W_i - K}{W_i} b_{i,0} \quad 0 \le i \le m. \tag{18}$$

Thus, by using the normalization condition for stationary distribution, we have

$$\begin{aligned} 1 &= \sum_{i=0}^{m} \sum_{k=0}^{W_i-1} b_{i,k} = \sum_{i=0}^{m} b_{i,0} \sum_{k=0}^{W_i-1} \frac{W_i - K}{W_i}, \\ &= \sum_{i=0}^{m} b_{i,0} \frac{W_i + 1}{2}. \end{aligned} \tag{19}$$

Using Equations 4, 18 and 19, we have

$$b_{0,0} = \frac{2(1-2p_f)(1-p_f)}{W(1-(2p_f)^{m+1}(1-p_f) + (1-2p_f)(1-p_f^{m+1})}. \tag{20}$$

As any transmission may occur when the backoff time counter reaches zero, regardless of the backoff stage, we have

$$\tau^{BA} = \sum_{i=0}^{m} b_{i,0} = \frac{(1-p_f^{m+1})}{(1-p_f)} b_{0,0},$$

$$= \frac{2(1-2p_f)(1-p_f^{m+1})}{W(1-(2p_f)^{m+1}(1-p_f) + (1-2p_f)(1-p_f^{m+1})}. \tag{21}$$

4.2.4. Proposed protocol

There is no retransmission of lost packets for P- and B-frames in our proposed protocol. However, the sender is allowed to retransmit a lost packet of an I-frame. Let P_I be the probability that a packet belongs to an I-frame. Let $P_{P,B}$ be the probability that a packet belongs to a P- or B-frame. Note that $P_{P,B} = 1 - P_I$. A Markov chain model for the backoff stage of the proposed protocol is depicted in Fig. 5. The transition probabilities of the backoff stage in the proposed protocol are given as

$$\begin{cases} Pr\{i,k|i,k+1\} = 1, & k \epsilon (0, W_i - 2) \quad i \epsilon (0, m) \\ Pr\{0,k|i,0\} = \frac{(1-p_f)P_I + P_{P,B}}{W_0}, & k \epsilon (0, W_0 - 1) \quad i = 0 \\ Pr\{0,k|i,0\} = \frac{(1-p_f)}{W_0}, & k \epsilon (0, W_0 - 1) \quad i \epsilon (1, m) \\ Pr\{i,k|i-1,0\} = \frac{P_f}{W_i}, & k \epsilon (0, W_i - 1) \quad i \epsilon (1, m) \\ Pr\{0,k|m,0\} = \frac{1}{W_0}. & k \epsilon (0, W_0 - 1) \end{cases} \tag{22}$$

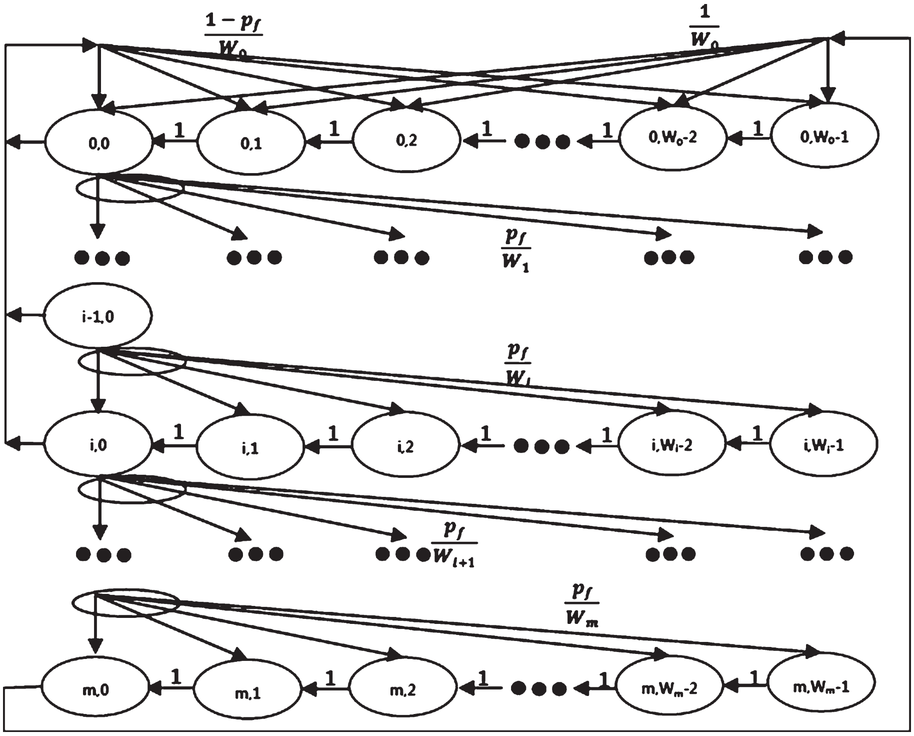

Fig. 4. Markov chain model for the backoff stage in the GCR block ACK scheme.

Because of the stationary distribution of the Markov chain we have the following relation.

$$\begin{cases} b_{i,0} = (p_f P_I)^i b_{0,0} & i = 0 \\ b_{i,0} = p^i_f b_{0,0} & 0 < i \le m \end{cases} \tag{23}$$

Owing to the chain regularities, we have

$$b_{i,k} = \frac{W_i - K}{W_i} \begin{cases} (1 - p_f)P_I + P_{P,B} \sum_{j=0}^{m} b_{j,0} & i = 0 \\ (1 - p_f)b_{i-1,0} & 0 < i < m. \\ p_f b_{i-1,0} & i = m \end{cases} \tag{24}$$

By imposing the normalization condition and considering Equation 23, we can obtain $b_{0,0}$ as a function of failure probability.

$$\begin{aligned} 1 &= \sum_{i=0}^{m} \sum_{k=0}^{W_i - 1} b_{i,k} = \sum_{i=0}^{m} b_{i,0} \sum_{k=0}^{W_i - 1} \frac{W_i - K}{W_i}, \\ &= \sum_{i=0}^{m} b_{i,0} \frac{W_i + 1}{2}. \end{aligned} \tag{25}$$

$$1 = b_{0,0} \frac{W + 1}{2} + \sum_{i=1}^{m} p^i_f b_{0,0} \frac{2^i W + 1}{2}. \tag{26}$$

$$1 = \frac{b_{0,0}}{2} \left[(W + 1) + W \sum_{i=1}^{m} 2{p_f}^i + \sum_{i=1}^{m} p^i_f \right]. \tag{27}$$

$$1 = \frac{b_{0,0}}{2} \left[(W + 1) + W \frac{(1-(2p_f)^{m+1}}{1-2p_f} + \frac{(1-(p_f)^{m+1}}{1-p_f} \right]. \tag{28}$$

$$b_{0,0} = \frac{2(1 - 2p_f)(1 - p_f)}{(W + 1)(1 - 2p_f)(1 - p_f) + W(1 - p_f)(1 - (2p_f)^{m+1}) + (1 - 2p_f)(1 - p^{m+1}_f)}. \tag{29}$$

As any transmission may occur when the backoff time counter reaches zero, regardless of the backoff stage, we have

$$\tau^{BA} = \sum_{i=0}^{m} b_{i,0} = \frac{(1 - p^{m+1}_f)}{(1 - p_f)} b_{0,0},$$

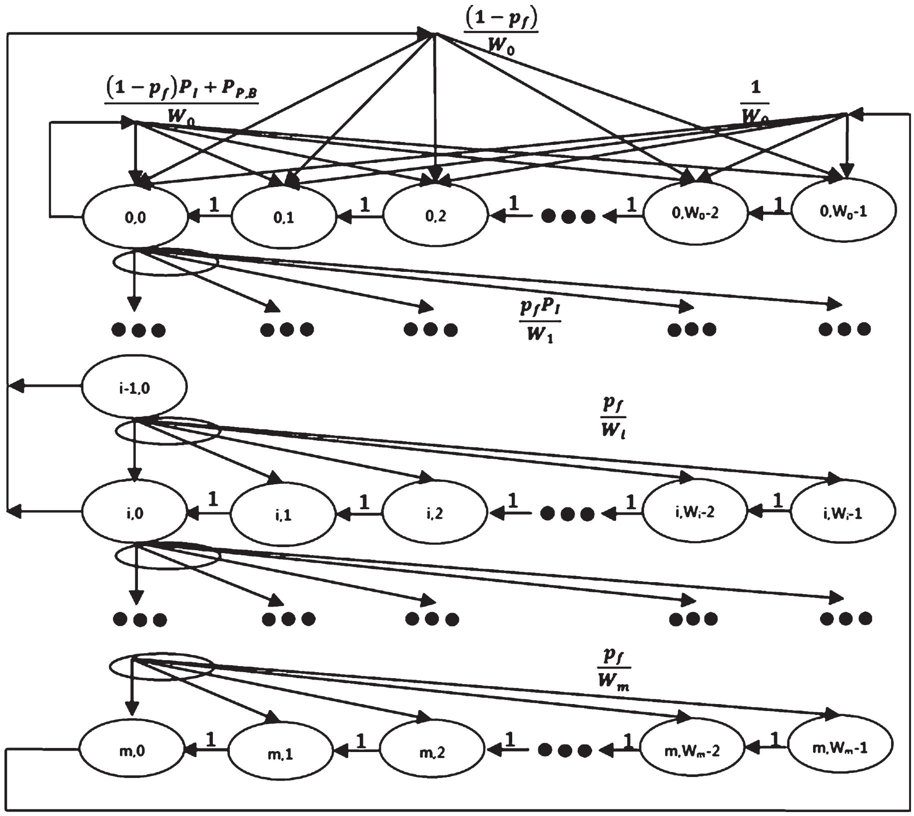

Fig. 5. Markov chain model for the backoff stage in proposed scheme.

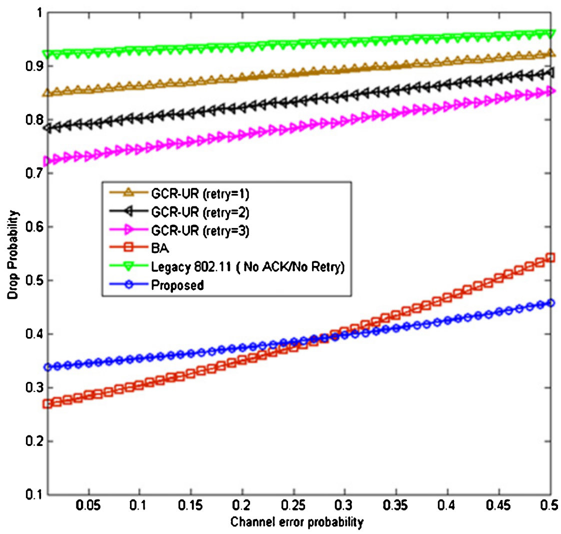

Fig. 6. Average drop probability when number of nodes is 20.

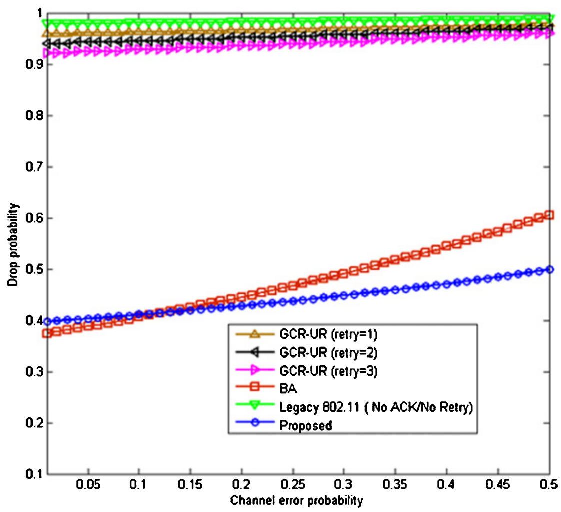

Fig. 7. Average drop probability when number of nodes is 30.

$$= \frac{2(1-2p_f)(1-p_f^{m+1})}{(W+1)(1-2p_f)(1-p_f) + W(1-(2p_f)^{m+1}(1-p_f) + (1-2p_f)(1-p_f^{m+1})}. \tag{30}$$

4.3. Packet drop probability

Under the legacy 802.11 protocol, each multicast packet is sent once. Therefore, a failure under legacy 802.11 is considered as a drop. The drop probability in legacy 802.11 multicast can be written as

$$p_{d,legacy} = p_f, \tag{31}$$

where p_f is the failure probability under the legacy 802.11 multicast protocol.

In GCR-UR, the same packet is transmitted multiple times, and the packet is considered as a drop when a multicast packet is not received successfully in any of the transmission attempts. In the GCR-BA scheme, the packet is considered as a drop because of retry limit exhaustion. In the proposed protocol, the packets belonging to I-frames are considered as drops because of retry limit exhaustion.

Therefore, the drop probability for GCR-UR, GCR-BA, and packets belonging to I-frames can be written as

$$p_{d,GCR-UR} = p_{d,GCR-BA} = p_{d,I} = p_f^{m+1} \tag{32}$$

Failures of P- and B-frames are considered as drops, and are represented as $p_{d,P}$ and $p_{d,B}$, respectively.

5. Performance evaluation

A simulation study is performed to compare the performance of reliable multicast schemes using NS-2 (Network Simulator 2.35) [30], and Evalvid (a video evaluation framework) [31]. Protocols evaluated include the proposed modified GCR-BA scheme and a comparison is drawn with legacy 802.11 multicast, GCR-UR, and GCR-BA. GCR-UR is evaluated using different retries (1, 2, and 3). Packets are transmitted at 6 Mbps. PSNR is calculated as a primary source of video quality measurement on receivers. PSNR is among the most used objective metrics to assess application-level quality of service (QoS) for video communications. International Telecommunications Union (ITU) describes this metric [31] as

$$PSNR(n)_{db} = 20log_{10}\left\{\frac{V_{peak}}{\sqrt{MSE_n}}\right\}, \tag{33}$$

where $V_{peak} = 2^k - 1$ indicates the maximum pixel value of image and k represents bits per pixel. For 8 bits pixel representation V_{peak} is 255. Mean square error (MSE) is an estimate of error variance, and the value of MSE is given as

$$MSE_n = \frac{\sum_{i=1}^{N_{col}}\sum_{i=1}^{N_{row}}\left[Y_{S(n,i,j)} - Y_{D(n,i,j)}\right]^2}{N_{col}N_{row}}, \tag{34}$$

where N_{col} and N_{row} represent total number of columns and rows respectively, in the input images; i and j are columns and rows positions under consideration; n indicates current frame number; Y_S and Y_D are the luminous component of the source and destination images, respectively, as defined in [31].

The average drop probabilities of the different protocols are shown in Fig. 8. Under the legacy 802.11 multicast protocol, packet drop probability is higher than other protocols because there is no ACK packet and no retransmission. The failed packet is considered as a drop, and packet drop is due to packet collisions and channel errors. The failure probability in the GCR-UR scheme is the same as legacy 802.11 multicast protocol. However, the drop probability of the GCR-UR scheme decreases when we increase the number of retries. However, overhead is introduced by the retransmission of the same packet. The drop probability of the GCR-BA scheme is higher than the proposed protocol when there are more nodes in multicast groups. This is because the GCR-BA scheme requires feedback from all multicast members for all types of packets, which increases network overhead, and as a consequence, increases the drop probability. In contrast to the GCR-BA scheme, in our proposed protocol, multicast members need to transmit an ACK packet only for packets belonging to I-frames, so that minimizes the feedback traffic and drop probability. However, when the number of nodes is small, the drop probability is higher in our proposed protocol, because there is no retransmission of packets belonging to P- and B-frames.

Figures 6 and 7 show the packet drop probability with different channel error probabilities when the number of nodes is 20 and 30, respectively. It is clear that our proposed protocol is more effective when there is a higher channel error probability. This is because there are more retransmissions with a higher channel error probability and the proposed method reduces the overhead of retransmissions.

In Fig. 9, PSNR is plotted against the number of nodes in multicast group. Average PNSR decreases with increasing number of nodes for all the protocols evaluated. However, the legacy 802.11 multicast suffers severe performance degradation due to lack of support for retransmissions. The proposed protocol shows higher average PSNR compared to existing standards due to its lower drop probability. How-

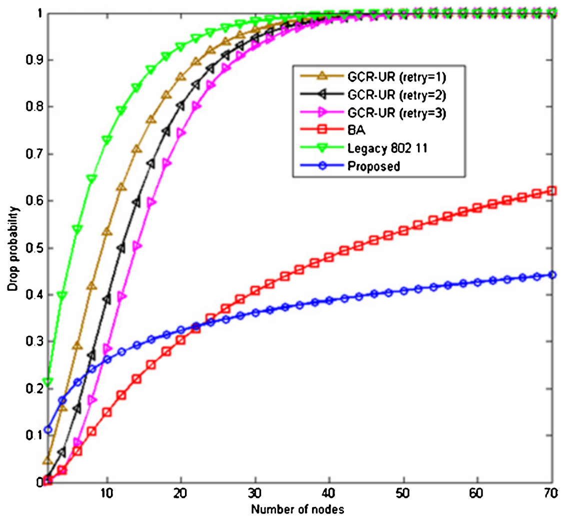

Fig. 8. Average drop probability as a function of the number of nodes.

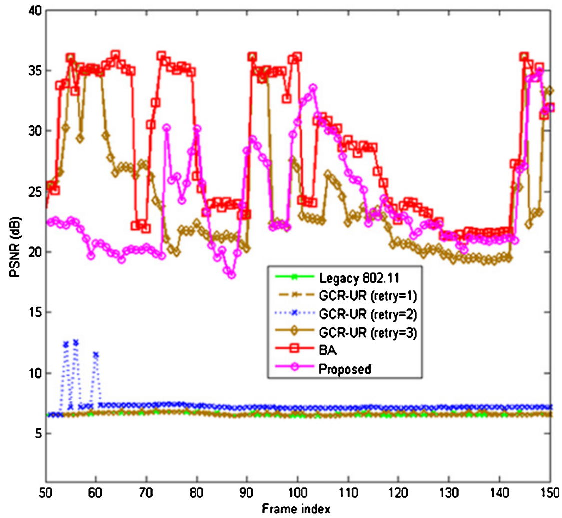

Fig. 10. PSNR of the video sequence (when the number of nodes is 10).

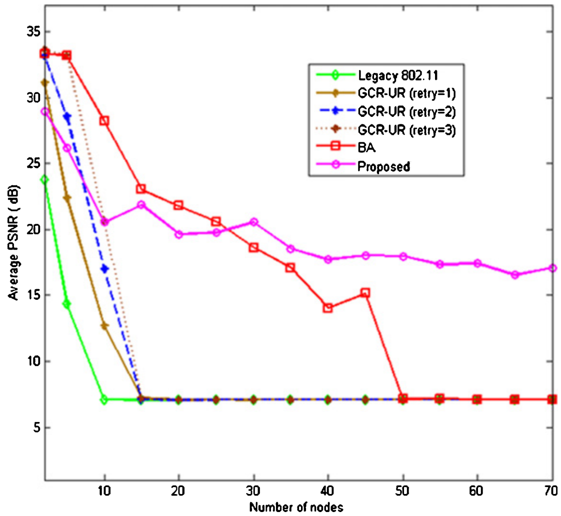

Fig. 9. Average PSNR as a function of the number of nodes (channel error probability = 0.1).

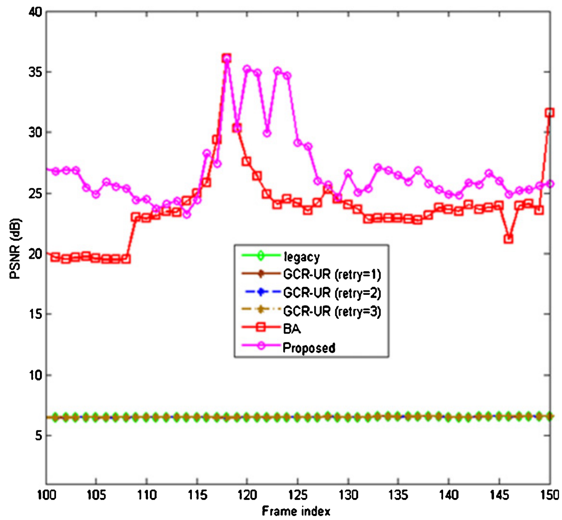

Fig. 11. PSNR of the video sequence (when the number of nodes is 30).

ever, it is evident from Fig. 9 that the proposed scheme achieves lesser PSNR with lesser number of nodes since P- and B-frames are not retransmitted in our proposed protocol, causing higher drop rate and hence effecting PSNR. Higher PSNR for large number of nodes is also achieved for the same reason of no retransmission of P- and B-frame packets. Also there is no BA request and response for packets belonging to P- and B-frames. Hence, we reduce feedback traffic and increase PSNR. Average PSNR of the GCR-UR scheme increases with increase in retry limit as shown in Fig. 9. However, fractional airtime and overhead increase as we increase retries [2]. Furthermore, when the channel condition between the transmitter and receiver is good, retransmission may not be necessary in the GCR-UR scheme.

Figures 10 and 11 show the time-varying PSNR of considered protocols when the number of nodes is 10 and 30, respectively. Results confirm that legacy 802.11 multicast protocol is least reliable compared to others. In case of GCR-UR, number of retires define reliability. Therefore, in the GCR-UR scheme, there is a trade-off between reliability and overhead. Furthermore, multiple transmissions of the same packet can be unnecessary if the channel condition is good. The GCR-BA scheme suffers from scalability problems as its reliability decreases with increasing number of nodes. These observations are also confirmed in [2]. Our proposed protocol does well in terms of reliability as the number of nodes in the multicast network increase, thus solving the scalability problem of the GCR-BA scheme.

6. Conclusion

Reliable delivery of video multicast is important. Therefore, the 802.11aa standard specifies a different scheme for reliable multicast transmission. In this paper, we propose a modified groupcast with retries block acknowledgement (GCR-BA) scheme for multimedia applications to address the scalability problem with the GCR-BA scheme. We consider the impact of the loss of different frames on video quality, and retransmit the important intra-coded frames (I-frames). To reduce the overhead, we remove block acknowledgement (ACK) request, block ACK, and retransmission of predicted frames (P-frames) and bidirectional frames (B-frames). Results show that legacy 802.11 standard is less reliable than other protocols. GCR Unsolicited (GCR-UR) reliability depends on the number of retransmissions of the same frame. The proposed protocol performs well in terms of peak signal-to-noise ratio when there is large number of nodes, as compared to the GCR-BA scheme.

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