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Reliable Multicast Scheme Based on Busy Signal in Wireless LANs

Sunmyeng Kim

For unicast transmissions, the IEEE 802.11 WLAN MAC (Medium Access Control) layer has control packets such as RTS, CTS, and ACK. However, it has no such control packets for multicast transmissions. Therefore, it does not provide reliable multicast transmissions. Most of previous reliable multicast schemes are based on the ARQ (Automatic Repeat reQuest) used for unicast communications. Therefore, it causes the large number of packet transmissions and the excessive control overhead. In this paper, we propose a new reliable multicast scheme. The proposed scheme combines FEC (Forward Error Correction) and ARQ mechanisms to reduce the large number of packet transmissions. Also, it uses busy signals to improve efficiency by reducing the excessive control overhead. The simulation results show that the proposed scheme is more effective in terms of normalized throughput and average delay under a wide range of data packet error rates.

Field of Research: Information Technology

1. Introduction

When a sender transmits data to multiple receivers, multicasting is very useful. It can save the network bandwidth and reduce the data distribution time by transmitting data to all receivers simultaneously. Several applications such as IPTV, multi-party games, video conferencing, and military communications need multicast transmissions to provide better quality of service (QoS).

The IEEE 802.11 wireless LAN (Local Area Network) standard defines a medium access control (MAC) protocol for sharing the channel among stations (IEEE, 1999). The distributed coordination function (DCF) was designed for a contention-based channel access. The DCF has two data transmission methods: the default basic access and optional RTS/CTS (request-to-send/clear-to-send) access. While the RTS-CTS-ACK exchange and the binary exponential backoff algorithm are only used for unicast transmissions, multicast packets are transmitted without these mechanisms. In other words, a multicast sender listens to the channel and then transmits a data packet when the channel is sensed idle for a defined period of time. After receiving the data packet, receivers do not send any feedback such as ACK. Therefore, the sender does not know whether or not the receivers receive the data packet successfully. Because of the lack of feedback, for multicast transmissions, the binary exponential backoff algorithm is useless and the contention window size is fixed. Because of this, multicast transmissions in the IEEE 802.11 DCF do not provide error recovery for data packets, and thus do not guarantee reliability (Chandra *et al*., 2009).

Sunmyeng Kim, Department of Computer Software Engineering, Kumoh National Institute of Technology, Gumi, Korea, Email: sunmyeng@kumoh.ac.kr

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Various protocols have been proposed to enhance the reliability of multicast transmissions for the IEEE 802.11-based wireless networks (Kuri and Kasera, 2001; Srinivas and Ruan, 2009; Wang *et al*., 2008; Li and Herfet, 2008). They can be classified into two categories: one is based on ACK (Srinivas and Ruan, 2009; Wang *et al*., 2008) and the other is based on leader (Kuri and Kasera, 2001; Li and Herfet, 2008). In the ACK-based protocols, a sender retransmits data packets until it receives all the ACK packets from all receivers. In the leader-based protocols, a sender retransmits data packets when there is no ACK from a leader receiver. Previous protocols still have serious problems in reliability and efficiency due to the following three reasons (Wang *et al*., 2008). First, they cause the excessive control overhead by the use of a large number of control packets in the error recovery process. Second, a sender has to retransmit the same data packets several times to satisfy all receivers. Third, in the leader based protocols, receivers do not acquire the information such as frame type, source address, and destination address in the MAC header when receiving an erroneous packet. Therefore, it is difficult for the receivers to decide whether or not to send feedback, and what type of feedback they need to send. This may result in the malfunctioning of the receivers.

Most of previous protocols are based on the ARQ (Automatic Repeat reQuest) scheme used for unicast communications over IEEE 802.11 DCF. Receivers request the retransmission of missing data packets by sending positive acknowledgements (ACKs) and/or negative acknowledgements (NACKs). ARQ-based protocols cannot reduce the impact of independent losses from different receivers. However, when an FEC (Forward Error Correction) is used, only one retransmitted parity packet can satisfy all receivers which lose different packets. FEC is especially effective for multimedia multicast transmissions (Liu *et al*., 2009).

In order to improve multicast reliability while minimizing feedback overhead, we propose a simple and effective scheme, called busy signal based reliable multicast (BSRM). The proposed scheme combines FEC and ARQ mechanisms to reduce a large number of packet transmissions and to provide data reliability in the IEEE 802.11 WLAN multicast environment. FEC is the best mechanism to use for real-time multimedia applications since it does not need time to detect errors and request retransmission. The BSRM uses block erasure codes denoted as $C(n, k)$. In these codes, the original data stream is divided into blocks of k packets and then n ($> k$) encoded packets are generated by using k original packets. A receiver can recover all the original k packets as long as it successfully receives k distinct packets. The proposed scheme also uses short duration busy signals (i.e., pulses of energy) to improve efficiency by reducing the excessive control overhead.

The paper is organized as follows. In Section 2, the BSRM scheme is presented in detail. In Section 3, performance studies are carried out through simulation results. Finally, we draw conclusions in Section 4.

2. BSRM Scheme

For reliable multicast transmissions, three important problems described in Section 1 should be solved: (1) how to decrease the excessive control overhead, (2) how to reduce a large number of packet transmissions, and (3) how to avoid the malfunctioning of receivers in the leader-based protocols. In the proposed scheme, these three problems are solved by two ways: FEC and busy signals.

2.1 System Architecture

The sender side of the proposed BSRM scheme is implemented in the AP and includes the FEC generator and the ARQ server. The FEC generator intercepts original multimedia packets and generates FEC parity packets used for error recovery based on block erasure codes denoted as $C(n, k)$. It then sends the parity packets along with the original packets to the ARQ server. In this paper, without distinguishing between original and parity packets, we call them data packets unless otherwise specified.

The ARQ server transmits the data packets to receivers. It first transmits only k original packets to receivers without any feedback from them. After the kth data packet transmission, it requests a feedback signal from the receivers. After receiving the data packets and a packet has an error, each receiver performs error correction. If the received packets are not enough for error recovery, the receivers request an additional data packet transmission by using a busy signal after receiving the feedback request from the ARQ server. When the ARQ server receives the busy signal, it transmits data packets as many as the receivers request, and then also transmits a feedback request. The receivers again perform error correction and, on the reception of the feedback request, transmit a busy signal for requesting another data packet transmission if it is still not enough to recover error. This packet transmission process is repeated until all the receivers recover the original packets and do not request any more data packet transmission.

2.2 Protocol Description

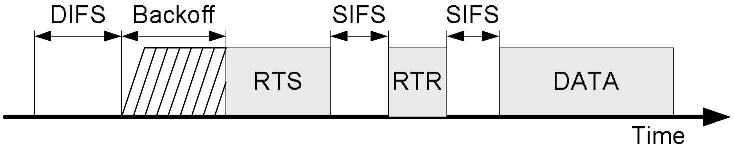
Our protocol needs minor modifications to the unicast DCF. However, the basic operation of the proposed protocol is the same as that in the unicast DCF.

The format of the data packet in the BSRM is modified from the standard data packet in the IEEE 802.11 WLANs. The format eliminates the sequence control and address4 fields, and includes three new fields (block number, block size, and packet index) for identifying block order, block size, and data packet order in a block, respectively.

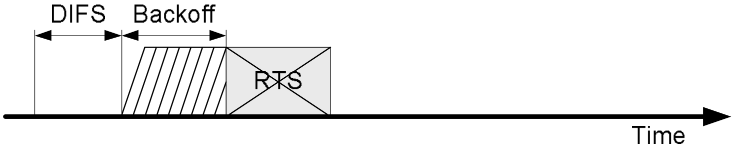
For unicast transmission in the DCF, the RTS/CTS access method uses four-way handshaking (RTS-CTS-DATA-ACK) mechanism. However, the BSRM basically uses three-way handshaking (RTS-RTR-DATA) mechanism (see Fig. 1). The CTS is a packet, but the RTR (ready to receive) is a busy signal. Transmitting data packets involves transmission of short RTS packet and RTR busy signal prior to the transmission of a data packet. When a receiver successfully receives an RTS packet and is ready to receive a data packet, it transmits an RTR busy signal for a slot time (see Fig. 1-(a)). Otherwise, it does not transmit any response (see Fig. 1-(b)). Even if the RTRs from multiple receivers collide, it does not matter since the RTRs are only busy signals and, from the busy signals, a sender knows there is at least one receiver ready to receive a data packet. In the RMBP scheme, all receivers do not acknowledge every data packet regardless of a successful transmission, an error, or a collision. Instead, the AP uses a feedback request busy signal, which will be explained later, for receivers to inform the AP of how many additional data packets are needed to recover data packets.

Fig 1: Packet Transmission Operation in BSRM

(a) Neither RTS error nor collision case



(b) RTS error or collision case

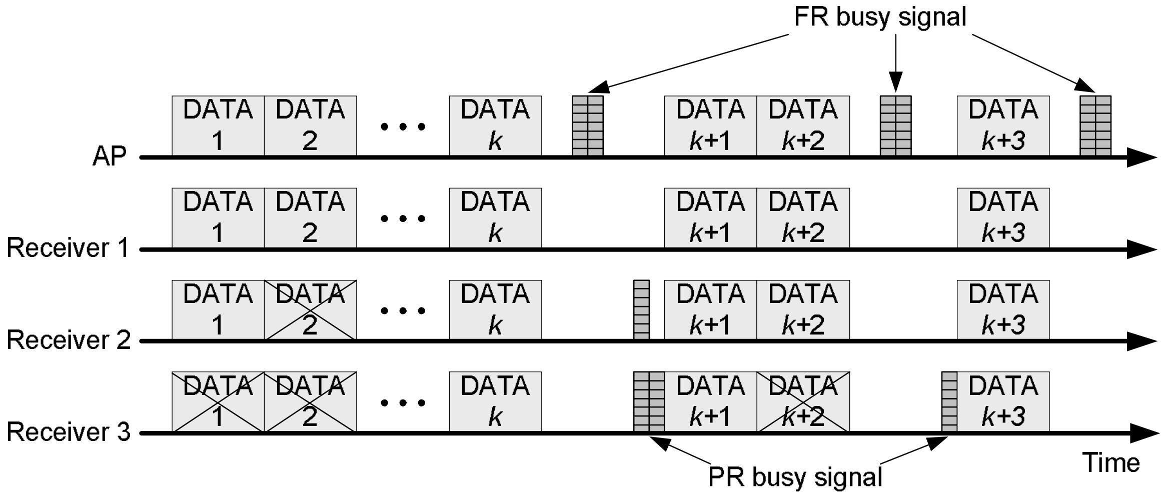


When the AP has a multicast data packet to send, it operates like the unicast DCF. If the channel is free for DIFS period, the AP decreases its backoff counter as long as the channel is idle, does not decrease when a transmission is detected on the channel, and tries to transmit an RTS packet when the backoff counter reaches zero. If the channel is determined to be busy at any time, then the backoff procedure is suspended. After sending an RTS packet, the AP does not expect to receive a CTS packet. Instead, it listens to the channel to see if any receiver transmits an RTR busy signal. If the AP senses the RTR busy signal, it transmits a multicast data packet to receivers (see Fig. 1-(a)). Otherwise, it again initiates its backoff procedure and repeats the process (see Fig. 1-(b)).

The diagram of a block transmission between the AP and receivers is shown in Fig. 2. In the figure, DATA *i* means the transmission of the *i*th data packet in a block, and is made up of five components: 1) DIFS; 2) backoff; 3) RTS; 4) RTR; and 5) DATA (see Fig. 1). The AP first transmits only *k* original packets to receivers. And then it transmits a feedback request (FR) busy signal for two time slots after SIFS interval immediately following the transmission of the *k*th data packet. An FR busy signal needs for a receiver to decide when to transmit a feedback signal. After receiving the FR busy signal, a receiver waits for a SIFS interval and transmits a packet request (PR) busy signal back to the AP if it has received less than *k* correct packets for the current block. Otherwise, it does nothing. The duration of the PR busy signal depends on how many additional packets a receiver needs to recover error. If a receiver has received *i* (< *k*) correct packets, the duration is (*k* - *i*) * *aSlotTime*, where *aSlotTime* is the duration of a slot time. After transmitting an FR busy signal, the AP expects PR busy signals from receivers whose transmissions were unsuccessful. In case the AP does not sense PR busy signals, the transmission of the current block is assumed to be completed. Otherwise, from the duration of the PR busy signals, the AP knows how many additional data packets the receivers need to recover error and then transmits as many data packets as the receivers request. This procedure is repeated until all the receivers recover the original packets and do not request any more packet transmission.

Fig. 2 gives an example of the procedure described above. The AP transmits *k* data packets. Receivers 1, 2 and 3 receive no erroneous data packets, one erroneous data packet (DATA 2) and two erroneous data packets (DATA 1 and DATA 2), respectively. Therefore, after receiving an FR busy signal from the AP, they transmit PR busy signals, of which durations are one time slot for receiver 2 and two time slots for receiver 3. From the PR busy signals, the AP knows that the receivers need two additional data packets to recover error and then transmit two packets. The receivers receive the data packets and perform error correction again. After receiving an FR busy signal, receiver 3 transmits a PR busy signal for a time slot since one data packet is still not enough to recover error. However, receivers 1 and 2 do not transmit a PR busy signal because it has enough packets (>= *k*) to recover. The AP transmits a data packet for receiver 3 and an FR busy signal. At this point, none of the receivers transmit any PR busy signals which results in the AP not sensing any busy signals. Therefore, the transmission of the current block is completed.

Fig 2: Block Transmission between the AP and Receivers



In the proposed protocol, we use an RTR busy signal and a FR busy signal. We assume they have different durations to avoid the malfunctioning of the receivers. If the durations were the same, receivers would not know exactly when to transmit their PR busy signals and would transmit them after receiving RTR busy signals from other receivers. Distinguishing an RTR busy signal and an FR busy signal from a packet transmission is very important to guarantee the proper operation. To do this, the duration of a transmission is used. The transmission time for a packet has the duration of at least three time slots, because it includes the physical preamble and header of 20 *us*. The durations of an RTR busy signal and an FR busy signal are one time slot and two time slots, respectively. Estimating the duration is simple without any additional overhead or cost, because every receiver performs carrier sensing. Each receiver, by using carrier sensing, observes the channel status and measures the duration of the busy period. Therefore, the proposed scheme can discriminate between busy signals and a packet transmission when receiving a signal.

3. Simulation Results

In this section, we discuss the simulation results of the proposed BSRM scheme. To validate the proposed scheme, we compare them to the results of the mLBP, in which we apply FEC to the LBP (Leader Based Protocol) proposed in (Kuri and Kasera, 2001). The mLBP generates FEC parity packets used for error recovery based on block erasure codes. If receivers receive an erroneous packet in the mLBP, then they are programmed not to send any response; otherwise, they send feedback signals accordingly as follows: After receiving each data packet, the leader transmits an ACK if at least *k* data packets are correctly received, or otherwise transmits a NACK. When receiving less than *k* correct data packets, non-leader receivers transmits NACKs to collide with the ACK from the leader, or do not transmit any response otherwise. The AP assumes that the transmission of a block is completed when receiving an ACK from the leader.

In the IEEE 802.11 WLANs, multicast data packets are transmitted at the lowest transmission rate in order to provide a multicast service to all receivers. However, we simulated an IEEE 802.11a network with transmission rates of 54Mbps for data packets and of 6Mbps for control packets. In the simulation, there are no unicast transmissions, and only the AP transmits multicast packets. We assume that the data packet error rate is independent among receivers and the error rate for control packets is 20% of the error rate given for data packets. The number of receivers is set to 10.

Fig 3: Normalized Throughput According to the Data Packet Error Rate

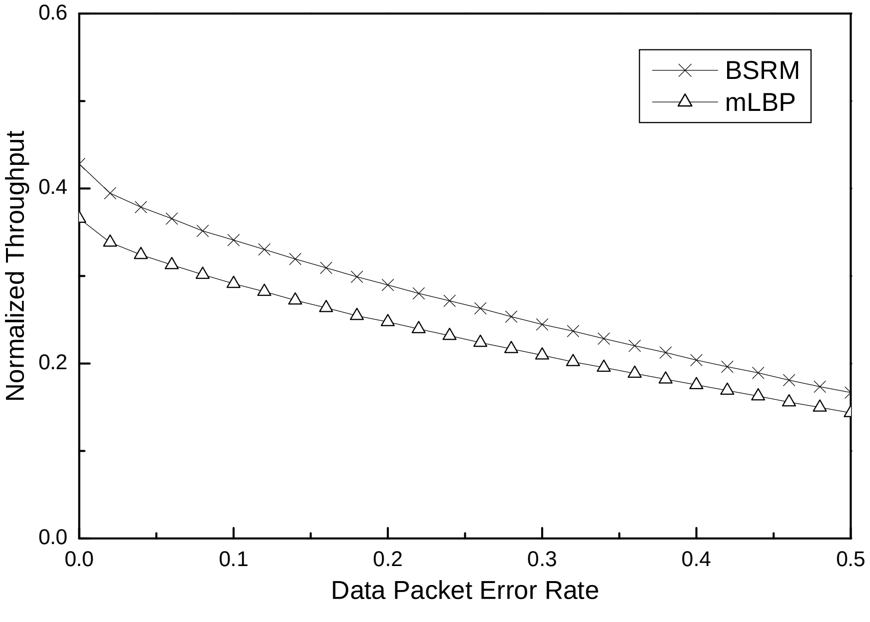
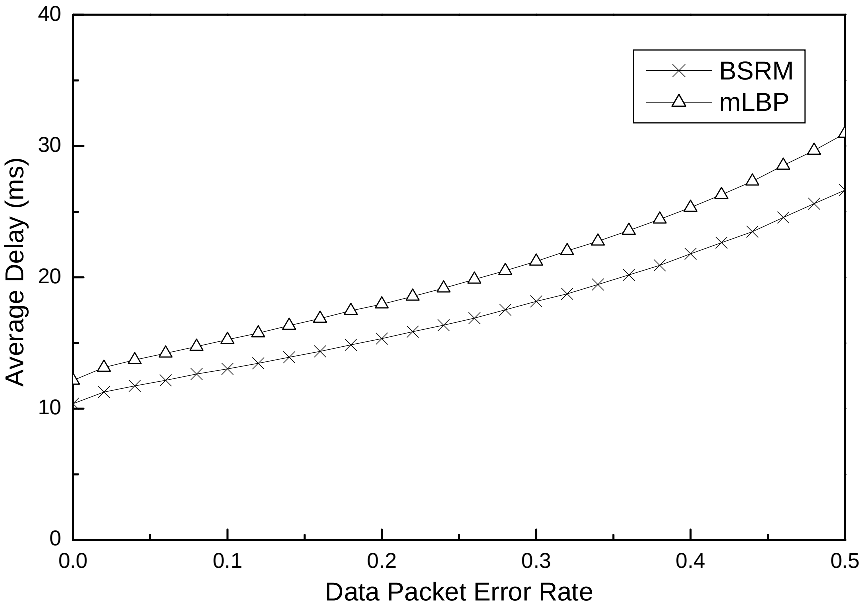


Fig. 3 shows the normalized throughput. The throughput of both schemes decreases as the data packet error rate increases. However, the BSRM has about 4% higher throughput compared to the mLBP regardless of the data packet error rate. The mLBP always needs a feedback signal from receivers for each data packet, and CTS packets from the leader may be erroneous. However, the BSRM needs only one feedback signal for several data packets (see Fig. 2), and RTR busy signals are never lost. Therefore, the BSRM has low control overhead. This is what causes the performance difference between them.

Fig. 4 is the results for the average delay. Delay is the time elapsed from the moment a block arrives at the MAC layer queue until the block is successfully transmitted to all the intended receivers. With the increasing data packet error rate, the average delay gets worse since more packets are necessary to complete the transmission of a block. The delay difference between the BSRM and mLBP comes from the reason explained in Fig. 3.

Fig 4: Average Delay According to the Data Packet Error Rate



4. Conclusion

For multicast transmissions, IEEE 802.11 MAC layer has no control packets such as RTS/CTS/ACK. Therefore, it does not support reliable multicast. In this paper, we proposed a scheme to support the reliable multicast. The proposed scheme combines FEC and ARQ mechanisms, and uses busy signals to avoid the malfunctioning of receivers, and to improve efficiency by reducing the excessive control overhead. The simulation results show that the BSRM is very efficient and has higher normalized throughput and lower delay regardless of the data packet error rate.

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