A Novel Multicasting Scheme over Wireless LAN Systems by Using Relay

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Abstract. We propose a novel multicast scheme that can provide quality-of-service (QoS) to multicast service over IEEE 802.11 wireless LANs by utilizing medium access control (MAC) layer relay. It is well known that IEEE 802.11 provides a physical layer multi-rate capability in response to different channel conditions, and hence packets may be delivered at a higher data rate through a relay node than through the direct link if the direct link has low quality and low data rate. We develop the distributed relay node selection algorithm and the relay channel selection algorithm. The effectiveness of proposed scheme is examined by numerical method and simulation. Simulations show that the proposed relayed multicast significantly improves throughput and delay performance.

1 Introduction

As wireless technologies grow rapidly, multimedia contents delivery through multicast scheme over the wireless networks is emerging as an important area in communication networks. We focus on multicast service over the Wireless Local Area Networks (WLANs) technology which is well known that IEEE 802.11 provides a physical layer multi-rate capability in response to different channel conditions. In the WLANs standard, IEEE 802.11b supports transmission rate of 1, 2, 5.5, and 11 Mbps, and IEEE 802.11g supports data rate of 1, 2, 5.5, 6, 9, , 54 Mbps.

However, there is a problem that multicast data rate is limited by the node which has the lowest data rate. It can make more users received multicast data, but causes some nodes which are in good channel condition to lose their data rate. The degradation of multicast data rate can reduce total throughput, and then increase the drop ratio of the multimedia contents, which is due to an increment of the transmission delay. As a result, nodes may suffer poor quality-of-service (QoS).

Therefore, we propose a novel multicast scheme that can provide higher data rate for the QoS guarantee of the multicast service over IEEE 802.11 wireless LANs by utilizing MAC layer relay, called relayed multicast. In our proposed multicast scheme, the nodes which have a good channel relay multicast data to the bad channel nodes. For adopting relay scheme to the multicast, we design the distributed relay node selection algorithm which helps choosing the relay nodes among good channel nodes efficiently. We also develop the relay channel selection algorithm to pick a proper relay channel, which makes transmit simultaneously relayed data.

The rest of this paper is organized as follows. Section 2 gives an overview of the related works, as well as the motivation behind the design of our scheme. The details of relayed multicast including the distributed relay node selection and the relay channel selection algorithm are presented in Section 3. Section 4 describes the analysis of the relayed multicast and shows the simulation results that illustrate the effectiveness of the proposed schemes. We conclude the paper in section 5.

2 Related Works and Motivation

In recent years, many papers proposed various solutions for the QoS guarantee of multimedia contents delivery over IEEE 802.11 [3, 4, 5]. Moreover, some researchers developed many relay schemes to acquire higher data rate and the QoS enhancement for the unicast service [6, 7, 8]. Nevertheless, to the best of our knowledge, there is no work have been studied for the QoS guarantee through the increment of the multicast transmission rate.

Data packets may be delivered at higher data rate through a relay node than through the direct link if the direct link has low quality and low data rate. Therefore the multi-rate capability can be further exploited by MAC layer multihop transmission. In [6], the authors propose the relay schemes to increase the unicast data rate in IEEE 802.11 networks. Similar to [6], by adopting a multihop relay into the multicast, we can acquire multicast data rate gain, which can guarantee better QoS for received nodes.

We consider a wireless network based on IEEE 802.11 WLANs operated as infrastructure mode. The physical layer uses IEEE 802.11b, and, similar to [9], we use multi-channel scheme that contains one general channel to communicate with AP and two relay channel to relay multicast data with single transceiver. To support MAC-level QoS for multicast data, the Enhanced Distributed Coordinate Function (EDCF) is used for the MAC. The EDCF provides the differentiated channel access, which is achieved through varying the amount of time a station would sense the channel to be idle and the length of the contention window.

3 Relayed Multicast

To exploit the multi-rate capability of IEEE 802.11, we organize multicast nodes into two groups based on channel condition between the AP and a multicast node; the multicast group and the relayed multicast group. The nodes in the multicast group have a good channel condition enough to receive data packets at the 5.5 Mbps data rate. The multicast group also includes all nodes which can receive data in 11 Mbps. The remaining nodes which are able to receive data packets at only 2Mbps are put into the relayed multicast group.

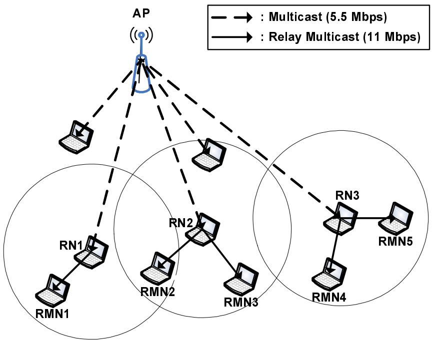

Fig. 1. An example of the relayed multicast.

Fig. 1 illustrates an example of the relayed multicast. The Multicast group nodes (MNs) are connected with the AP by dotted lines, and the relayed multicast group members are connected with their relay nodes (RNs) by solid lines. First of all, the RMNs select their relay nodes out of the multicast group using the distributed relay node selection algorithm, and then choose relay channels to communicate with their relay nodes using the relay channel selection algorithm. Through these two methods, relayed multicast nodes (RMNs) can find the relay nodes appropriate for the relayed multicast that are able to relay data to the relayed multicast group in 11 Mbps.

3.1 Distributed Relay Node Selection Algorithm

In the wireless environments, because of the wireless multicast advantage [10], all MNs need not to relay multicast data. To relay efficiently, only a few nodes are needed. Moreover, the wireless multicast is the same mechanism as the broadcast in the physical layer. For reasons of that, it is not important for the RNs to know to transmit which RMNs. Instead of that, it is reasonable that RMNs decide to select their RNs. Our proposed selection algorithm, the distributed relay node selection, is designed in the relayed nodes side.

We assume receiver-initiated channel condition measurement and let the receiver notify the sender's transmission rate via control packets. Each node can overhear all ongoing control packets, and know the channel condition between the sender and itself by sensing the signal strength and extracting the piggybacked transmission rate in control packets.

At first, AP sends the multicast service advertisement (MSA) to whole nodes in its transmission range. The MNs respond to AP with the service request message (SRM). They put in their maximum data rate between AP and themselves in the SRM. The RMNs can overhear this message. By extracting the piggybacked transmission rate in the SRM, they find the nodes that are able to communicate with AP in 5.5 Mbps. Among those nodes, they select some nodes that have the signal strength of the SRM is high enough to communicate with themselves in 11 Mbps. Each RMN_i has the individual the candidate set of the relay nodes, X_i.

After constructing X_i, RMN_i sends the request to relay (RTR) message to the MN which was sensed the SRM in the strongest signal strength. The node that receives the RTR will perform the relay nodes (RN_i). At the same time, RMN_j $(i \neq j)$, other nodes among the rest of the RMNs that are in the transmission rage of RMN_i extract the RTR, and then check the destination address. If the address is the entry of their candidate set X_j, they also set that node as their RN. They do not have to send RTR to the other MNs. The algorithm continues until all RMNs have their RNs.

3.2 Relay Channel Selection Algorithm

In conventional IEEE 802.11 WLANs that operate under single channel PHY, all nodes in the transmission range of transmitting node should wait until the end of transmission because it protects collisions. However, it leads to transmission delay when the RNs relay data. In that case, the relayed multicast may show lower performance than conventional multicast.

To solve this problem, we utilize the multi-channel approach. As we mentioned section 2, there are 3 non-overlap channels in the IEEE 802.11. Unfortunately, with one receiver constraint, the standard only defines the MAC operations for single channel mode. We design a simple multi-channel MAC algorithm for relayed multicast. We use 3 channels (C_1, C_2, and C_3) for relay, and the algorithm operates as below.

At first, RN_i broadcasts the channel assignment message (CAM) for C_1. After receiving CAM from RN_i, RMN_{ij} which is in the overlap zone checks the relay channel list (RCH). If C_1 is not in the list, C_1 is entered into the RCH $= C_1$, and RMN_{ij} send the channel assignment success message (CAS) to RN_i.

Then, RN_j broadcasts the CAM for C_1. At this time, because C_1 is the entry of RCH, RMNij send the channel assignment failure message (CAF) to RN_j. In the CAF, the available relay channel is piggybacked. In this case C_2 is available, so RN_j broadcasts the CAM for C_2. After receiving CAM for C_2 from RN_j, RMN_{ij} enters C_2 into the RCH $= C_1$, C_2, and then sends the CAS to RN_j.

3.3 Temporal Operation of The Relayed Multicast

We now consider the temporal operation of the relayed multicast. Transmission/reception activity between AP and nodes is used a general channel (G-channel). In addition, each RN has a relay channel (R-channel) it uses to relay multicast data from AP to RMNs. Because we assume a single transceiver case, each node has only a single channel at a time. Thus, we use a new frame for changing channel before relay operation, the relay channel change message (RCH). If RMNs receive the RCH from their RNs, they jump to their R-channels that were determined by using the relay channel selection algorithm. After receiving relayed data, RMNs return to the G-channel. For a reliable MAC-layer

Table 1. Simulation Parameters

Paylod	8000 bits	SIFS	10 μs
MAC header	224 bits	AIFS(3)	SIFS + 1 * Slot time
PHY header	192 bits	AIFS(2)	SIFS + 1 * Slot time
ACK, CTS	112 bits + PHY header	AIFS(1)	SIFS + 1 * Slot time
RTS, CCM	160 bits + PHY header	AIFS(0)	SIFS + 1 * Slot time
Slot time	20 μs	CWmin(0...3)	[31, 31, 15, 7]
Simulation time	100 s	CWmax(0...3)	[1023, 1023, 31, 15]

multicast, we adopt leader-based-ack mechanism. A leader of each group is selected by the first node to send the SRM and RTR.

Our proposed scheme operates in the following order.

1. The AP multicasts data to the multicast group in the 5.5 Mbps after waiting AIFS(1) and backoff when the channel is sensed idle.
2. A leader of the multicast group sends an ACK to the AP after SIFS.
3. RNs send the RCH to the RMNs, and then relay the data after SIFS.
4. Leaders of RMNs respond to RNs with the ACK, while other RMNs return to the RMNS by overhearing the ACK.

4 Performance Evaluation

In this section, the performances of our design is examined by the numerical method and our event-driven simulation program, written in the MATLAB. In order to select a suitable data rate, we assume the distance thresholds for 11Mbps, 5.5 Mbps, and 2 Mbps are 100m, 200m, and 250m respectively, similar to [12]. The payload size for best effort is set to be 1000 bytes and all nodes are always backlogged. The best effort data uses AC(0), and RTS/CTS mechanism. To support QoS for multicast data and relay data, AC(1) and AC(2) are adopted respectively. Nodes are uniformly distributed centering around AP, and the service area is within 250m radius of the AP. Other simulation and IEEE 802.11e MAC parameters are set as in Table 1. We investigate the overall throughput and transmission delay compared with conventional multicast service which uses only 2Mbps. With this setup, we investigate the overall throughput, transmission delay performances.

4.1 Numerical Result

In [7], Hao Zhu and Guohong Cao show an analysis of their proposed relay scheme for unicast traffic by using Bianchi's Markov Chain model [11]. In this section, similar to [7], we analyze the saturation throughput gain of the relayed multicast as compared with conventional multicast operating 2 Mbps.

For simplicity, we assume the channel condition is ideal, and do not apply IEEE 802.11e in this analysis. Assume that each node applies the binary exponential backoff algorithm with the maximum backoff stage m, the number of flows is represented n, and the initial backoff window size W. Then, the probability τ that a flow transmits in a slot time is obtained from the following functions:

$$\tau = \frac{2(1-2p)}{(1-2p)(W+1)+pW(1-(2p)^m)} \tag{1}$$

$$p = 1-(1-\tau)^{n-1} \tag{2}$$

p denotes the conditional collision probability that a transmitted packet encounters a collision because at least one of the n-1 remaining nodes transmit in the same time slot.

If there are no hidden terminals, multicast is exactly same as unicast operation because we can treat the set of receiver as one node. In the relayed multicast case, if it is possible for RNs to transmit concurrently to their RMNs, the relayed multicast can be analyzed similar to multicast. There exists only one difference that relayed multicast uses DCF scheme twice; for the multicast, and the relay.

Ts^M, Ts_M^{RM}, and Ts_R^{RM} are denoted the average time for the channel being sensed busy because of successful transmission under conventional multicast, multicast from AP to MNs, relay from RNs to RMNs. Tc^M, Tc_M^{RM}, and Tc_R^{RM} are the average time for the channel being sensed busy because of during a collision conventional multicast, multicast from AP to MNs, relay from RNs to RMNs respectively:

$$\begin{aligned}
Ts^M &= DIFS + data(2Mbps) + SIFS + ACK + 2\times\delta \\
Tc^M &= DIFS + data(2Mbps) + \delta \\
Ts_M^{RM} &= DIFS + data(5.5Mbps) + SIFS + ACK + 2\times\delta \\
Tc_M^{RM} &= DIFS + data(5.5Mbps) + \delta \\
Ts_R^{RM} &= DIFS + RCH + SIFS + data(11Mbps) + SIFS \\
&\quad + ACK + 3\times\delta \\
Tc_R^{RM} &= DIFS + RCH + SIFS + data(11Mbps) + 2\times\delta
\end{aligned} \tag{3}$$

The data includes the overhead of PHY and MAC header and payload, and δ means propagation delay. From the result of [11], the average time to transmit one packet is calculated as follows. T_M and T_{RM} correspond the average packet transmission time under conventional multicast and relayed multicast:

$$\begin{aligned}
T_M &= (1-P_{tr})\sigma + P_{tr}P_sTs^M + P_{tr}(1-P_s)Tc^M \\
T_{RM} &= (1-P_{tr})\sigma + P_{tr}P_sTs_M^{RM} + P_{tr}(1-P_s)Tc_M^{RM} \\
&\quad +(1-P_{tr})\sigma + P_{tr}P_sTs_R^{RM} + P_{tr}(1-P_s)Tc_R^{RM}
\end{aligned} \tag{4}$$

σ is the duration of an empty slot time. P_{tr} is the probability that there is at least one transmission in the considered slot time, and P_s means the probability that a transmission occurring on the channel is successful.

$$P_{tr} = 1 - (1-\tau)^n \tag{5}$$

$$P_s = \frac{n\tau(1-\tau)^{n-1}}{P_{tr}} = \frac{n\tau(1-\tau)^{n-1}}{1-(1-\tau)^n} \tag{6}$$

Then, the ratio between the saturation throughput of conventional multicast and relayed multicast is represented in the proportion of T_M to T_M, denoted by T_M.

$$\begin{aligned}\gamma &= \tfrac{T_M}{T_{RM}} \\ &= \tfrac{(1-P_{tr})\sigma + P_{tr}P_s T{s^M} + P_{tr}(1-P_s)T{c^M}}{2(1-P_{tr})\sigma + P_{tr}P_s(Ts_M^{RM} + Ts_R^{RM}) + P_{tr}(1-P_s)(Tc_M^{RM} + Ts_R^{RM})}\end{aligned} \tag{7}$$

We show the numerical analysis of the saturation throughput gain as the function of payload size, and also validate our analysis through simulation. We assume $m = 5$, $n = 5$, and $W = 31$. As shown in Fig. 2, the gap between numerical result and simulation is slightly small. This gap is due to transmit an RCH before relaying. We assumed every RN can transmit simultaneously, but they have different start times since each RN contends to get a transmission opportunity of RCH in the G-channel. We can see that throughput gain increases as payload size increases. There are additional overheads in relayed multicast because of transmitting RCH and relaying data packet. However, since overheads are much smaller than the reduced transmission time by relaying, relayed multicast always shows better performance than conventional multicast regardless of payload size.

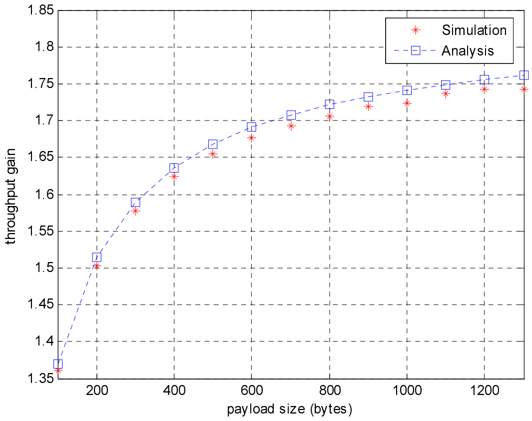

Fig. 2. Throughput gain of relayed multicast.

4.2 Simulation Results

Throughput Enhancement Fig. 3 shows the system throughput of relayed multicast and conventional multicast. Throughput is calculated by the total amount of payload (in bits) delivered divided by the simulation time. The maximum throughput gain, 28%, can be achieved in the case that user density is 0.3. Throughput curve decrease exponentially according to increase user density, and when the user density is over 7, the throughput of relayed multicast is less than that of conventional multicast. The reason of throughput decrease is MAC protocol of IEEE 802.11 which use contention based CSMA/CA. Relayed multicast needs 2 contention period, one is for multicast to MNs and the other is for relay to RMNs. Thus, the collision and waiting time will increase as the user density increase. In relayed multicast, since RCH message is transmitted in G-channel, it causes the additional transmission delay at the RNs, and then the efficiency of relayed multicast decrease rapidly.

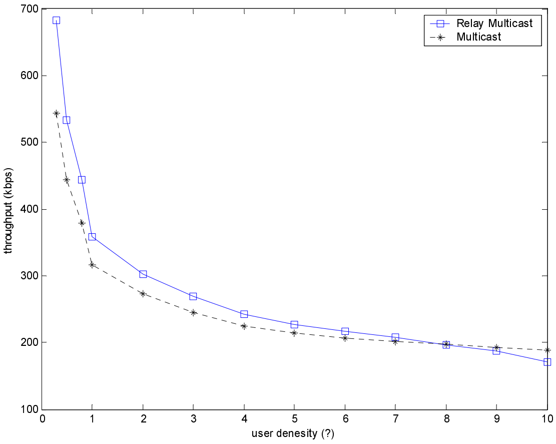

Fig. 3. The throughput comparison.

Transmission Delay Performances Fig. 4 and 5 show the transmission delay performances according to user density and data rate. Each case use data rate = 256Kbps and user density = 1. Both cases, relayed multicast shows much better performance. Especially, when user density is fixed, relayed multicast keeps transmission delay under 1 second. Through these results, despite additional transmission for relay packets, relayed multicast can reduce transmission delay compared with conventional multicast. Considering that almost multicast are video services, relayed multicast needs less buffering time than that of conventional multicast to maintain the video quality.

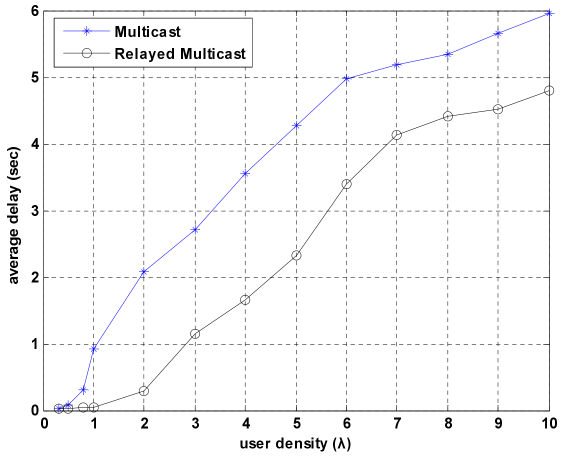

Fig. 4. The transmission delay according to user density.

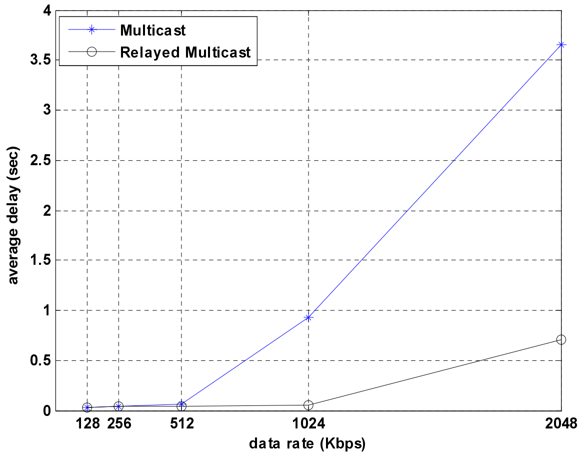

Fig. 5. The transmission delay according to data rate.

5 Conclusions

In this paper, we design a new multicast scheme for IEEE 802.11 wireless LANs by utilizing MAC layer relay, called relayed multicast. For effective relayed multicast, we develop the distributed relay node selection and relay channel selection algorithm. Numerical results and Simulation show that the proposed scheme can increase the throughput, and significantly reduce the transmission delay. Therefore, multicast nodes can be served higher data rate multicast service and guaranteed the QoS of the multimedia service.

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