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Leader-Based Multicast Service in IEEE 802.11v Networks

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***Abstract*— With the advent of various multimedia streaming applications requiring reliability and high bandwidth, multicasting in wireless LANs has been gaining more attentions as the supported bit rate increases. However, according to the specification of the IEEE 802.11 standard, broadcast/multicast frames are transmitted at a fixed and low bit rate due to the absence of a feedback mechanism such as ACK. This simple broadcasting technique with no feedback signal raises some issues; reliability, efficiency and fairness. In this paper, hence, we propose a framework for multicasting termed Leader-Based Multicast Service (LBMS) to alleviate those limitations. LBMS consists of a leader-based transmission and feedback mechanism for multicasting by extending the IEEE 802.11v standard, which is the next-generation standard for network management. Also, we try to support legacy 802.11 stations can still participate in multicasting. Simulation exhibits that the gain of the proposed multicasting scheme increases as (i) more stations compete for the channel, and (ii) the wireless channel condition becomes poorer.**

I. Introduction

The demand on multimedia multicast/broadcast applications such as video conferencing and news broadcasting over WiFi has been raised rapidly. The best option for these applications is *multicasting* because it can simultaneously distribute multimedia data to multiple users efficiently. However, the IEEE 802.11 standard [1] supports multicast transmissions by simple broadcasting without any feedback (e.g. acknowledgement). The lack of feedback results in three problems: no contention window (CW) adaptation, no retransmission, and no rate adaptation, which in turn causes fairness, reliability and efficiency issues, respectively.

Firstly, the collided multicast frame is just dropped without any retransmission at the MAC layer because there is no way to know the collision of a multicast frame due to the absence of an acknowledgement. Thus, the current IEEE 802.11 standard supports just an unreliable service. As the number of other flows increases, the loss rate of multicast frames also increases. Secondly, no feedback signaling means that an access point (AP) cannot easily collect state information of stations (STAs) which are participating in a multicast group. Hence, most of the commercial APs use a fixed and low transmission rate (typically, one of basic rates) for multicasting in order to guarantee that as many multicast packets as possible can be received successfully. This situation causes an inefficiency problem similar to a performance anomaly problem [4]. Thirdly, a STA transmitting multicast frames neither receives an acknowledgement nor performs binary exponential backoff. Thus, the CW size of a unicast flow is doubled on every collision; however, the CW size of a multicast flow is always fixed at the minimum value. Because of these different operations, in the networks congested by multicast and unicast flows, there will be an unfairness problem between them.

There have been some studies [5-8] for these issues. However, all of them address only the subset of the issues and lack backward-compatibility with the legacy 802.11 protocol. That motivates us to introduce a novel multicasting framework, leader-based multicast service (LBMS), that improves fairness, reliability and efficiency by leveraging new network management messages in the IEEE 802.11v standard [3]. Even though the LBMS relies on IEEE 802.11v messages, legacy 802.11 STAs can still receive multicast frames in the LBMS framework[1].

The remainder of this paper is organized as follows. In Section II, we introduce representative previous works to enhance multicasting in IEEE 802.11 wireless LANs. Then, we propose a novel framework for multicasting called Leader-Based Multicast Service (LBMS) to improve reliability, efficiency, and fairness in Section III. In Section IV, ns-2 simulations are carried out to show that LBMS has better performance compared to legacy 802.11 multicasting. Finally, we conclude our work in Section V.

II. Related Work

Kuri et al. [5] proposed a novel mechanism called a leader-based protocol (LBP) for multicasting to improve the reliability of multicast frames. In LBP, one of multicast receivers serves as a leader that replies with an ACK frame. However, LBP requires non-IEEE802.11-compliant frames and mechanisms, and how to select a leader is missing. Dujovne et al. [6] experimentally test LBP by emulating LBP multicasting. An AP sends unicast frames to a particular node which plays as a role of a leader, and other nodes overhears those frames. All the receptions by the nodes are logged for reliability analysis.

[1]Legacy 802.11 STAs have some limitation, which will be detailed later.

The experimental study confirms that LBP outperforms the legacy IEEE 802.11 standard by lowering the packet loss rate significantly. However, it assumes that a multicast receiver with the worst channel condition is always known.

J. Peng et al. [7] proposed a new Automatic Repeat reQuest scheme for reliable Broadcasting (BARQ). It incurs control overhead by introducing a virtual ACK bitmap. In BARQ, a sender needs to specify the following elements in this bitmap: the starting time, the timeslot length, and the assignment of the timeslots to broadcasting receivers. When a receiver needs to confirm its reception of a frame with the sender, it transmits an ACK pulse for a specified period of time in the assigned timeslot announced in the bitmap. Basically, a sender constructs a virtual ACK bitmap after sending a frame and the receivers fill in the bitmap to indicate their reception status of the frame. The sender then checks the filled-in bitmap to determine if retransmission is needed. However, BARQ does not comply with the IEEE 802.11 standard.

Villalon et al. [8] proposed Auto Rate Selection for Multicasting (ARSM). ARSM adopts LBP for reliability and improves network throughput by allowing an AP to dynamically select the bit rate for multicasting based on the feedbacks on multicast receivers' channel conditions. If the AP detects the losses of consecutive multicast frames, it sends a Multicast Prove (MP) frame to the receivers to reduce the transmission bit rate for multicasting. The MP frame contains the Signal-to-Noise Ratio (SNR) of the current leader. Upon receiving the MP frame, each multicast receiver estimates its own SNR and replies to the AP by issuing a Multicast Response (MR) frame containing its estimated SNR. Depending on the estimated SNR value, each receiver sets its backoff timer to reduce the collision probability among MR frames. After receiving MR frames, the AP chooses its transmission bit rate to adapt to the lowest SNR value. However, the ARSM requires new MAC control frames and modifies the PHY layer header as well.

III. LBMS: Leader-Based Multicast Service

In this section, we propose a Leader-Based Multicast Service (LBMS) which provides not fully-reliable but *semi-reliable* multicasting due to limitation of feedback from a leader only. However, we believe this semi-reliability can fit into loss-tolerant multimedia streaming services. To achieve this semi-reliability, an AP will retransmit a lost multicast frame up to a predetermined number of times. In detail, the LBMS consists of a leader election protocol and a leader-based multicast transmission protocol, which will be explained in the following subsections.

A. LBMS Request/Report Action Frames

For the LBMS, we first define two new network management frames in an IEEE 802.11v compatible manner, as shown in Fig. 1.

The LBMS Request and Report frames use the Action frame body format in [3]. In both LBMS Request and Report frames, the Category and Action fields indicate the Wireless Network Management category and whether this frame is an

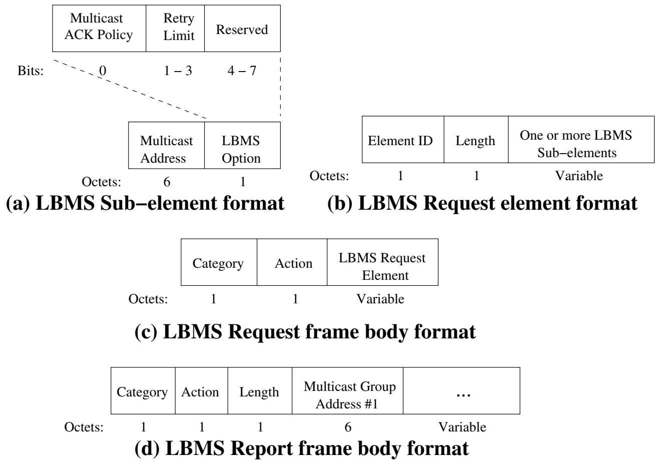

Fig. 1. LBMS Request/Report frame body formats

LBMS Request/Report frame, respectively. When a STA joins a multicast flow, it sends the AP an LBMS Request frame including an LBMS Request element, which contains one or more LBMS Sub-elements. In each LBMS Sub-element, the Multicast Address field is set to the MAC address corresponding to the multicast group for the LBMS, and the LBMS Option field consists of Multicast ACK Policy and Retry Limit. The ACK Policy and the Retry Limit fields represent the acknowledgement policy (0 for No ACK and 1 for Normal ACK) and the maximum retransmission number of multicast frames, respectively. Depending on a STA's channel condition, it can suggest the AP the values of the ACK policy and the Retry Limit. The AP can send an LBMS Report frame to a leader STA; the STA may serve as a leader of multiple multicast flows.

B. Leader Election Protocol

We do not specify how to select a leader; instead, we provide a mechanism by which various leader selection algorithms can be embodied. A leader may be dynamically changed depending on varying channel conditions or group membership changes. For example, the leader can be intelligently selected based on frame error rate (FER) statistics; the FERs of multicast receivers can be obtained through multicast diagnostic report messages defined in [3]. If an STA wishes to join a particular multicast flow, it transmits an LBMS Request frame or (re-)association request frame containing the LBMS request element. After the AP selects a leader for a multicast flow (by an arbitrary criterion), the AP sends an LBMS Report frame containing the corresponding multicast address to the chosen leader. On the reception of the LBMS Report frame, the chosen leader should generate an ACK frame for each successfully received multicast frame from then on.

Fig. 2 shows how to change a current leader to new one. If the AP wishes to replace the leader (Fig. 2(b)), the AP should send the current leader (to be replaced) an LBMS Report frame without the multicast address of the corresponding multicast flow (Fig. 2(c)). Or if the current leader wishes to stop serving

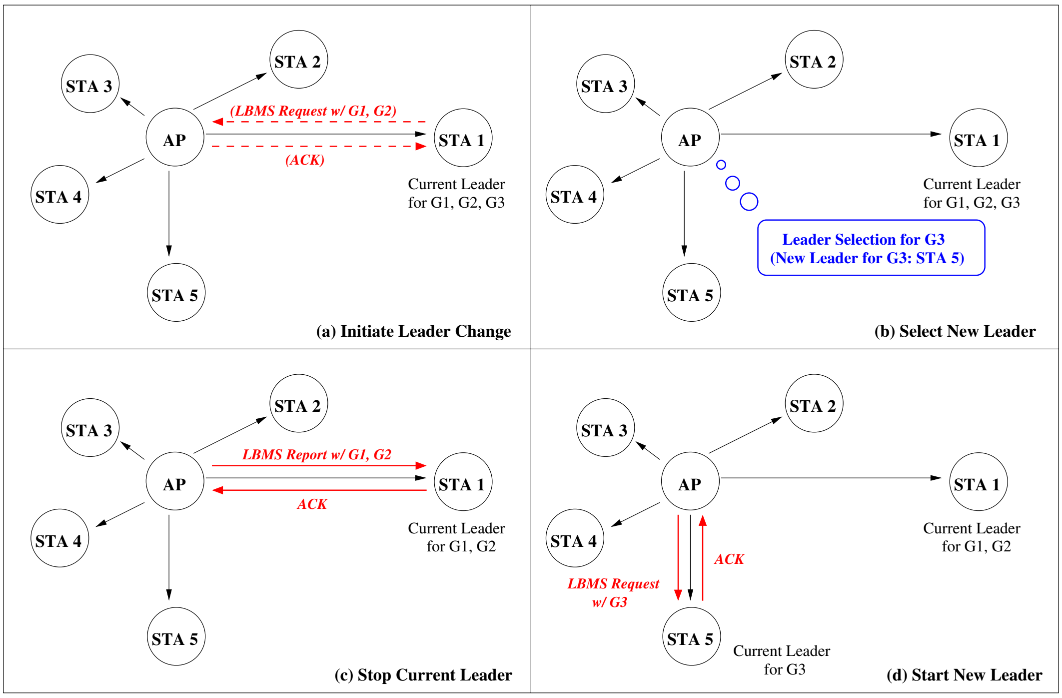

Fig. 2. Leader change procedure in LBMS

as a leader, it may send an LBMS Request frame without the LBMS sub-element of the corresponding multicast flow to the AP to initiate the above procedure (Fig. 2(a)). Then, the AP sends an LBMS Report frame containing the corresponding multicast address to a new leader (Fig. 2(d)). For robust operations, the AP should consider the case that the current leader may leave without any notification. To this end, if the pre-defined number of consecutive ACK frames are missing, the AP should select a new leader.

C. Leader-Based Multicasting

In the LBMS, a leader should send an ACK frame after SIFS on every successful reception of a multicast frame. If the AP does not receive any ACK frame, it should double its CW for fairness with other unicast flows. The acknowledgement history can be used by the AP to adapt the PHY transmission rate of multicast frames to improve the efficiency.

When the LBMS is used, a retransmission mechanism is possible. The AP can disable retransmission if desirable (e.g. too much background traffic). If multicast frames are retransmitted, legacy 802.11 stations will receive duplicated multicast frames without any knowledge. To support compatibility with legacy 802.11 stations, the AP should employ some encryption mechanism (e.g. TKIP, CCMP in IEEE 802.11i [2]) only for retransmissions. In this way, the legacy 802.11 stations cannot decrypt and hence ignore duplicated frames. We assume that the duplicated and encrypted multicast frames can be decrypted only by IEEE 802.11v stations. If the decrypted frame is not received before, then the frame will be delivered to the upper layer; otherwise, the frame is discarded.

To perform rate adaptation efficiently, it is viable to differentiate the cause of transmission failures. To this end, the AP can initiate an RTS/CTS exchange prior to a multicast frame. If the wireless channel is idle during SIFS just after the RTS frame, the AP concludes that the channel is being unused. The receiver address of the RTS frame is set to not the multicast address of the pending multicast frame but the MAC address of any active multicast receiver, which will reply with an CTS frame. The RTS frame may be sent at a non-basic rate if used not as a protection frame but for collision detection as described in [10]. In that case, the duration field is set to a value large enough to cover until the end of the RTS/CTS exchange. In summary, depending on per-flow policies defined in LBMS, multicast frames are transmitted in the form of (RTS/CTS/)Multicast(/LeaderACK), and each multicast group has a different retry limit according to requirements of corresponding multicast applications.

IV. Performance Evaluation

We evaluate the LBMS and legacy 802.11 multicasting by using ns-2 [11]. In a 200x200m^2 square, multicast receivers are randomly moving at the pedestrian speed of 5m/s. The AP is fixed at the corner of the square and multicasts the CBR traffic of 512Kbps. The transmission rate of multicast frames in legacy multicasting is 2Mbps; while in LBMS, the transmission rate is adapted according to ARF [9]. Multicast frames are transmitted according to IEEE 802.11b, while the LBMS Request/Report frames are transmitted with the AC_VI priority according to IEEE 802.11v. To reflect a wireless channel error caused by the short-term fading, the Ricean model is used with Rician parameter K 6. Fig. 3 shows a frame loss ratio at 2 Mbps bit rate as the distance between an AP and a STA increases with the Rician channel in ns-2. In our simulation, the maximum distance between the AP and a multicast receiver is about 280m, at which the frame loss ratio is about 0.9.

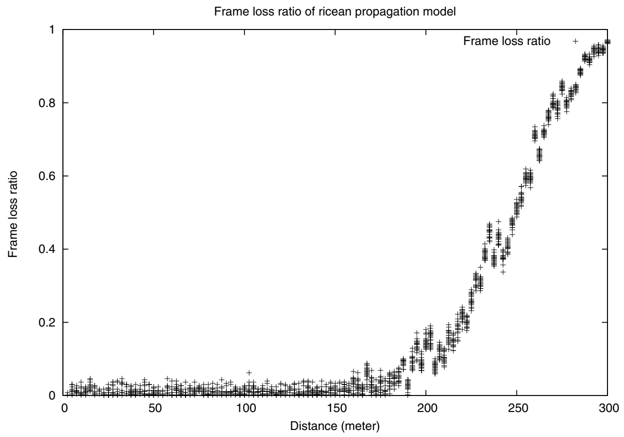

Fig. 3. Frame loss rate changes as the distance between an AP and a STA increases.

A multicast receiver sends an LBMS report frame when it does not receive any multicast frame for a report timeout 80ms. An AP will select the STA that sent the LBMS Report frame as a new leader. Once the leader changes, the AP ignores other LBMS Report frames during a resume timeout 320ms.

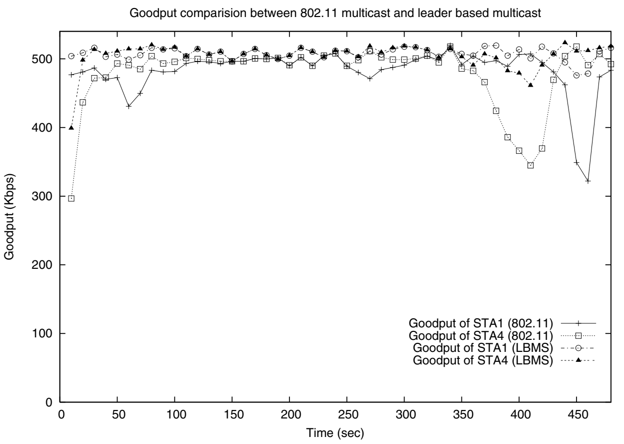

Fig. 4. Goodputs of STA1 and STA4 in LBMS and legacy multicasting with the same mobility scenario. Each point is the goodput for 10 seconds.

We measure the goodput of each of 5 moving multicast receivers without background traffic at 10s intervals in legacy 802.11 multicast and the LBMS. For sake of illustration, only the goodputs of STA1 and STA 4 are plotted in Fig. 4 and Table I. Note that STA4 and STA1 happen to be far from the AP and their channel conditions are poor around 400s and 450s, respectively. Other 3 STAs are relatively close to the AP and achieve almost 512Kbps during the above period and hence omitted. Here, G_{Legacy} is the goodput of legacy multicast; $Gain$ is the goodput gain of the LBMS, which is given by (the goodput of a receiver in LBMS) - (the goodput of the same receiver in legacy multicast). Table I shows the goodput gains of STA1 (the leader between 440s and 470s) and STA4 (the leader between 360s and 430s) as time goes on in this experiment. Note that the leader STA has a substantial goodput gain due to ACK feedback/retransmissions to/from the AP.

TABLE I

GOODPUT GAINS OF STA1 AND STA4 IN LBMS COMPARED TO LEGACY MULTICASTING. GAINS IN ITALIC FONT INDICATE THE GOODPUT GAIN OF THE LEADER.

Time (sec)	STA1		STA4	
	G_{Legacy}	$Gain$	G_{Legacy}	$Gain$
360	516.9888	5.8464	492.768	*11.6928*
370	516.9888	9.1872	489.4272	*17.5392*
380	509.472	11.6928	442.656	*41.76*
390	521.1648	9.1872	422.6112	*54.288*
400	520.3296	13.3632	384.192	*69.3216*
410	533.6928	-10.8476	364.1472	*60.9696*
420	513.648	5.0112	381.6864	*60.9696*
430	510.3072	2.5056	491.0976	*18.3744*
440	476.064	*14.1984*	516.9888	7.5168
450	358.3008	*71.8272*	520.3296	4.176
460	337.4208	*74.3328*	516.9888	-0.8352
470	486.9216	*25.056*	518.6592	4.176

Fig. 5 plots the goodput gain of every moving receiver in the LBMS at 10s intervals over the legacy multicasting on the y-axis, where the goodput of corresponding receiver with the same mobility in legacy multicasting is on the x-axis. For instance, when the goodput of legacy 802.11 multicast is around 400Kbps, the upper limit of the goodput gain of the LBMS will be 112Kbps, which is the difference between 512Kbps and 400Kbps. The achieved goodput gain of the LBMS at that point is about 50Kbps due to the retransmission limit and the lack of wireless resource. The upper limit of 512Kbps is drawn by the dashed line. Note that some points go beyond the dashed line since there are jitters in frame transmission times in measuring goodputs at 10s intervals. In the 2^{nd} scenario, in addition to 5 moving multicast receivers, each of 5 static STAs nearby the AP is transmitting 512Kbps CBR background traffic at 11 Mbps bit rate. Fig. 6 shows the goodput gain of the LBMS in the 2^{nd} scenario. Comparing Figs. 6 and 5, the goodput gain of the LBMS is remarkably increased as the background traffic competes with the multicast traffic. This is mainly because collided multicast frames are recovered by retransmissions. Moreover, higher channel efficiency is achieved by rate adaptation. The cases of 20 moving multicast receivers for the two above scenarios are tested in Figs. 7 and 8. The overall goodput gains in these cases show the similar trend; however, the deviation of goodput gains becomes somewhat larger since the number of receivers with worse/better channels than the leader is greater. In our simulation, leader selection is designed for simplicity purposes; if we use additional information such as channel conditions, it is possible to enhance the gain.

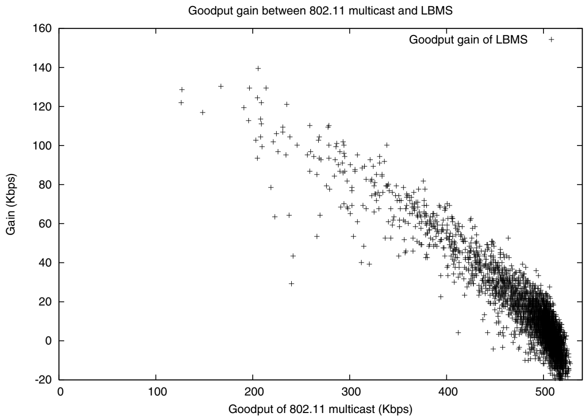

Fig. 5. Goodput gain between IEEE 802.11 multicast and LBMS, with 5 multicast receivers and no background source.

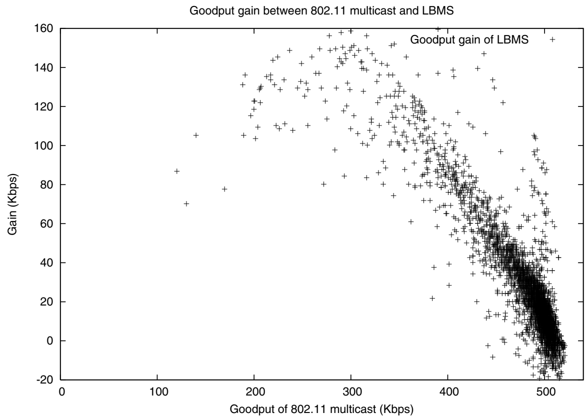

Fig. 6. Goodput gain between IEEE 802.11 multicast and LBMS, with 5 multicast receivers and additional 5 STAs with background traffic.

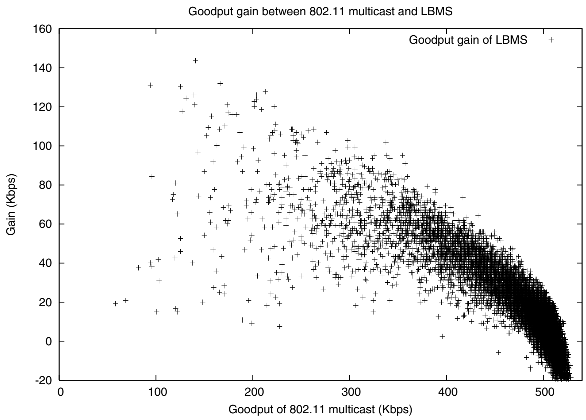

Fig. 7. Goodput gain between IEEE 802.11 multicast and LBMS, with 20 multicast receivers and no background source.

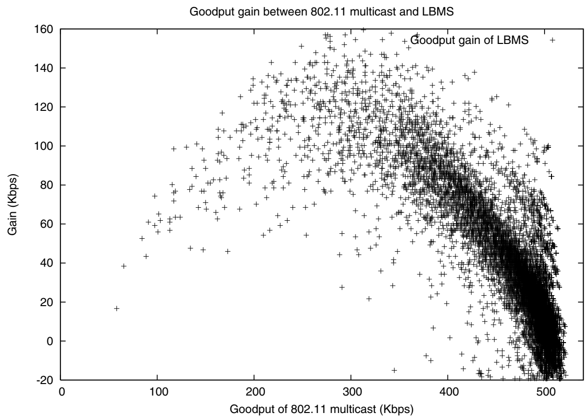

Fig. 8. Goodput gain between IEEE 802.11 multicast and LBMS, with 20 multicast receivers and 5 STAs with background traffic.

V. Conclusion

In this paper, we propose the leader-based multicast service (LBMS), which can be readily implemented by leveraging the upcoming IEEE 802.11v standard. Retransmissions, exponential backoff, and rate adaptation in the LBMS help to achieve reliability for multicast, fairness between multicast and unicast, and wireless channel efficiency, respectively. Simulations reveal that the goodput gain of the LBMS over the legacy multicasting becomes higher as the transmission error rate due to collisions and/or poor link conditions increases. Moreover, the LBMS allows legacy 802.11 STAs to receive multicast frames with two limitations; (i) legacy STAs cannot serve as a leader, and (ii) they cannot receive retransmitted frames. Currently, LBMS provides just some level of reliability and cannot control the reliability level. Therefore, our future works include how to control the level of reliability according to the requests of multicast receivers.

VI. Acknowledgment

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