This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the IEEE CCNC 2010 proceedings

Transparent Unicast Translation to Improve Quality of Multicast over Wireless LAN

Yuki Tanigawa†, Kenta Yasukawa[1]‡ and Katsunori Yamaoka†
†Tokyo Institute of Technology
tanigawa@net.ss.titech.ac.jp, yamaoka@ss.titech.ac.jp
‡Ericsson Research Japan, Nippon Ericsson K.K.
kenta.yasukawa@ericsson.com

***Abstract*—Media broadcasting services using Internet protocol (IP) multicast are emerging and IEEE 802.11 wireless LAN (WLAN) has been widely deployed. Therefore, the opportunities to receive multicast streaming over WLAN are expected to grow. However, because of restrictions on the IEEE 802.11 standard, the transmission rate and the reliability of multicast over WLAN are lower than those of unicast. In this paper, we propose a transparent multicast / unicast translation method which translates a multicast packet into multiple unicast packets at the media access control (MAC) layer, so that we can utilize the higher transmission rates and retransmission function that are only available with unicast. Our theoretical analysis and experiment show that the proposed method improves the efficiency and reliability of multicast over WLAN.**

***Index Terms*—wireless LAN, multicast, unicast trasnlation, multimedia streaming, media occupation time, real-time communication**

I. Introduction

Media broadcasting services using Internet protocol (IP) multicast are emerging, and the number of subscribers to such services are increasing. Because of this, more and more multicast streams are reaching the end-users' local area networks (LAN). Moreover, IEEE 802.11 wireless LAN (WLAN) [1] has been widely deployed in homes, offices, public facilities and so on. Because of such backgrounds, the opportunities to receive multicast streaming over WLAN are expected to grow.

However, because of restrictions on the IEEE 802.11 standard, multicast over WLAN has two problems in the following.

One is that the transmission rate is lower than that of unicast because compatibility needs to be assured. Sending with a lower transmission rate set that is available for multicast results in keeping the media busy for a longer time and makes it harder to transmit high-bit-rate streams. Moreover, using low bit rate increases the risk of interference with other transmissions.

The other problem is that multicast packets on WLAN are not retransmitted even if errors and collisions occur. Acknowledgement (ACK) based retransmission is used for unicast transmission on WLAN because frames can collide and interference causes bit errors on WLAN. However, because multicast packets are received by multiple receivers, it can not use the same ACK-based retransmission mechanism. Therefore, packet losses due to radio noise, interference and collisions on WLAN directly affect the application layer's quality and degrade the media quality of multicast streaming over WLAN.

[1]Work performed while working at Tokyo Institute of Technology.

To solve such problems and improve the quality of multicast over WLAN, we propose a transparent multicast / unicast translation method that transparently translates and copies a multicast packet into multiple unicast packets at the MAC layer so that we can utilize the higher transmission rates and retransmission function that are only available with unicast.

II. Problems of Multicast over WLAN

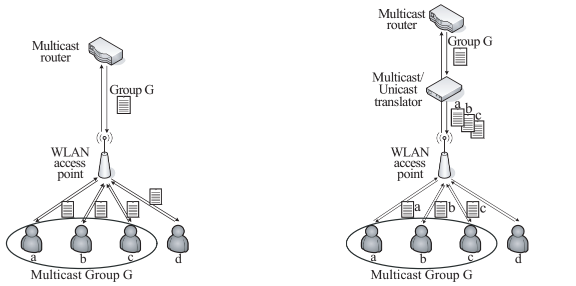
As we mentioned in Section I, there are two problems in the multicast over WLAN. One is restrictive transmission rate regulation, and the other is the lack of a lost data retransmission function. This section explains the problems in more detail.

In this paper, we assume that the WLANs are in the infrastructure mode of the IEEE 802.11 standard and the distributed coordination function (DCF) is used for coordinating mobile nodes. This configuration is the most widely deployed.

In the infrastructure mode, a wireless access point (AP) and its clients form a basic service set (BSS). For unicast transmission, the standard specifies that AP and each client must support a set of transmission rates, and each client tries to use the highest transmission rate possible in the rate set, that is available at both the sending and receiving nodes, taking into account the signal strength and electromagnetic interference. For multicast and broadcast, however, the same way cannot be applied since it is necessary to ensure compatibility among the receivers. Therefore, the standard specifies that all multicast and broadcast frames must be transmitted at one of the rates in the BSS basic rate set, whose transmission rates are supported by all nodes in the BSS. The transmission rates in the BSS basic rate set are generally lower than those of unicast transmissions. The lowest one is 1.0 Mb/s and many APs use this rate for multicast and broadcast if they are not configured to use higher one.

Moreover, in unicast on WLAN, an ACK frame is transmitted by the receiver upon a successful data frame reception and retransmission is performed when the ACK frame is not received for a transmitted frame. This retransmission mechanism on MAC layer is important since frame losses occur more often in wireless than in wired ethernet because of electromagnetic interference and collisions so that the effects of frame losses can be absorbed. In multicast and broadcast, however, the ACK-based retransmission is not applied since there are multiple receivers. Therefore, lost frames are not recovered and directly degrade the media quality in the application layer.

The consequences of the problems mentioned in Section I are thus streaming at a higher bit rate than the BSS basic



(a) Conventional multicast (b) Proposed

Fig. 1. Proposed Transparent Multicast / Unicast Translation

rate set is impossible; other transmissions are disturbed by multicast streaming since it takes longer to transmit packets; and frame losses in WLAN directly affect the media quality in the application layer.

III. Transparent Multicast / Unicast Translation

We propose a transparent multicast / unicast translation method to solve the problems mentioned in Section II and improve the efficiency and reliability of multicast over WLANs. The method is implemented by placing a node called a Multicast / unicast translator (MUT) on WLAN. The MUT is placed between multicast routers and WLAN APs, and it operates as a MAC layer entity. It acts as an ethernet bridge for non-multicast packets. In addition, MUT is also available if it is installed in APs. MUT transparently duplicates a multicast packet and changes the destination MAC address of each copy to each receiver and then forwards the copies to the wireless LAN segment.

The proposed method has three advantages in the following.

- It enables higher transmission rates than the conventional multicast does. Since same amount of data takes a shorter time to transmit, it can reduce media occupation and free up resources for other transmissions.
- It enables the retransmission function to be implemented in the media access control (MAC) layer. Because of this, frame losses are recovered at the MAC layer and higher layers do not have to suffer from poor reception quality; that is, reliability improves.
- It is feasible because the operation is transparently performed on the MAC layer. It does not need to change the standardized IEEE 802.11 protocol or to modify the sending and receiving nodes. Note that the protocol headers other than the MAC header and IP header are not modified. Therefore, the receiver applications do not notice the MUT is involved on the path and they can just simply join a multicast group and receive packets for the group.

It is both possible to implement MUT as a built-in function of a WLAN AP and to implement as an independent equipment. Because it is possible in theory for a single MUT to support multiple BSSs, there is no need to replace deployed APs if the MUT is a piece of independent equipment. Moreover, even if a node moves from one BSS to another, the node can continue to receive streaming data if it does not go out of the managing range of an MUT.

For MUT to work, it is necessary to specify receivers joining each multicast group. This can be achieved by snooping on the join and leave messages of multicast group management protocols such as the Internet group management protocol (IGMP) and multicast listener discovery (MLD) [2]. Such a way of determining the MAC addresses of receivers in multicast groups is feasible and the same mechanism has been already implemented in intelligent ethernet switches which are widely deployed.

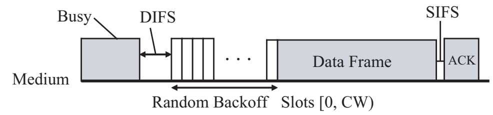


Fig. 2. DCF

We have described the advantages of our method; however, there might be domains for which the proposed method cannot improve transmission efficiency depending on the number of the receivers. Hence, in the next section, we evaluate the scope of our method.

IV. Theoretical Analysis

A. Mechanism of DCF

When DCF is used for the coordination function on WLAN, collision avoidance is performed according to the carrier sense multiple access with collision avoidance (CSMA/CA) mechanism. Let us here explain the mechanism of DCF to discuss the overheads of transmissions in WLAN.

A node using DCF has a backoff time counter $B_{counter}$ and a contention window CW. Every time it tries to transmit a packet, it sets $B_{counter}$ to a random integer obeying a uniform distribution over the interval $[0, CW]$ and checks whether or not the wireless media is busy. If the media is busy, the node waits until it observes the media being idle for the period, that is as long as DCF inter frame space (DIFS). As long as the wireless media is idle, $B_{counter}$ is decremented whenever the slot time T_{slot} specified by the IEEE 802.11 standard elapses. If the wireless media becomes busy while decrementing $B_{counter}$, the decrement ceases and the node waits until the next idle period as long as DIFS is observed. When $B_{counter}$ becomes 0, the node transmits the packet and resets $B_{counter}$ (Fig. 2). Therefore, the backoff time $T_{backoff}$ is given by

$$T_{backoff} = B_{counter} \times T_{slot}. \tag{1}$$

In addition, the standard specifies the initial value of CW CW_{min} and the maximum value CW_{max}. Whenever a frame loss is detected, CW is doubled, until it reaches CW_{max}. When a frame is received correctly, CW is reset to CW_{min}.

Data frame losses are detected by sending and receiving ACK frames. When a node receives a data frame without error, the node waits until the short inter frame space (SIFS) elapses and transmits an ACK frame to the sender. When the sender does not receive an ACK frame for a data frame transmission, it assumes that the data frame is lost, and tries to send it again, setting CW to double. Note that this is only performed in unicast transmission and no retransmission is available for multicast transmissions at least in the current standard as mentioned in Section II.

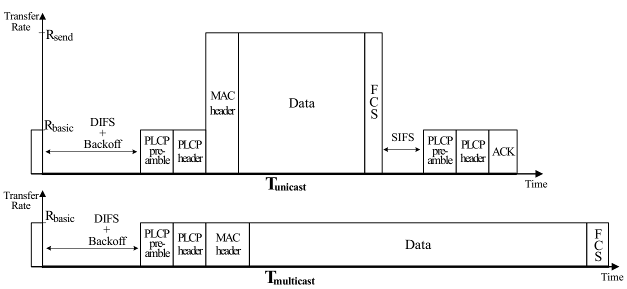


Fig. 3. Structures of unicast and multicast frames

B. Mathematical Calculation of Media Occupation Ratio

To evaluate the applicable scope of the proposed method taking into account the IEEE 802.11 standard explained in IV-A, we mathematically analyze the method's efficiency. When a packet is transmitted over WLAN, it is accompanied with overheads such as the backoff from CSMA/CA, inter frame space (IFS), physical layer convergence protocol (PLCP) header and MAC header. We define an efficiency measure called the "media occupation ratio" in order to compare the conventional multicast and the proposed method. The media occupation ratio refers to the time ratio per unit time that a multimedia stream occupies the wireless media including the above overheads and the backoffs.

The frame structures of unicast and multicast packets are shown in Fig. 3. In unicast trasmission, the time taken to transmit a packet, $T_{unicast}$, is given by

$$\begin{aligned} T_{unicast} &= T_{DIFS} + T_{backoff} + \{T_{PLCP} \\ &\quad + (P_{MAC} + P_{data} + P_{FCS} + P_{tail})/R_{send}\} \\ &\quad + T_{SIFS} + (T_{PLCP} + P_{ACK}/R_{basic}), \end{aligned} \tag{2}$$

where T_{DIFS}, T_{SIFS}, $T_{backoff}$ and T_{PLCP} are DIFS, SIFS, the backoff time and the transmission durations of the PLCP preamble and header, P_{MAC}, P_{data}, P_{FCS}, P_{tail} and P_{ACK} are the lengths of the MAC header, data, frame check sequence (FCS), tail bits and ACK frame, and R_{basic} and R_{send} are the basic rate and transmission rate in unicast.

Besides the above, the time taken to transmit a packet in multicast, $T_{multicast}$, is given by

$$\begin{aligned} T_{multicast} &= T_{DIFS} + T_{backoff} + T_{PLCP} \\ &\quad + (P_{MAC} + P_{data} + P_{FCS})/R_{basic} \\ &\quad + T_{SIFS}. \end{aligned} \tag{3}$$

In Eqs. (2) and (3), variables excluding $T_{backoff}$ are static; i.e., some are defined in the IEEE 802.11 standard and others depend on the streaming traffic. $B_{counter}$ in Eq. (1) is a random integer, uniformly distributed between $[0, CW]$; since CW is reset to CW_{min} upon every successful transmission, CW mostly stays at CW_{min}. Therefore, we can reasonably assume that the average backoff time can be written as

$$\bar{T}_{backoff} = T_{backoff} \tag{4}$$

by substituting $CW_{min}/2$ to $B_{counter}$ in Eq. (1).

Thus, the media occupation ratios of multicast streaming using the proposed method, $M_{proposed}$ and that of the conventional multicast, $M_{conventional}$, are given by Eqs. (5) and (6), where R_{packet} is the packet rate and n is the number of a stream. If the media occupation ratio is 1, however, we regard it as 1.

$$M_{proposed} = \bar{T}_{unicast} \times R_{packet} \times n \tag{5}$$

$$M_{conventional} = \bar{T}_{multicast} \times R_{packet} \tag{6}$$

TABLE I
LIST OF PARAMETERS

	802.11b	802.11a	802.11g
T_{DIFS}	50 μs	34 μs	50 μs
T_{SIFS}	10 μs	16 μs	10 μs
$T_{backoff}$ (w/o packetloss)	310 μs	67.5 μs	310 μs
T_{PLCP}	96 μs	20 μs	96 μs
P_{MAC}	24 bytes		
P_{FCS}	4 bytes	–	4 bytes
P_{tail}	–	6 bits	–
P_{ACK}	14 bytes		
P_{data}	1500 bytes		

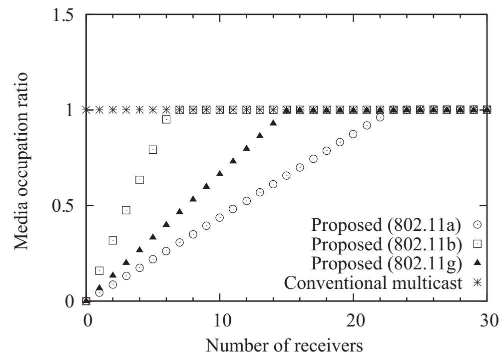


Fig. 4. Media occupation ratio of streaming at 1.0 Mb/s

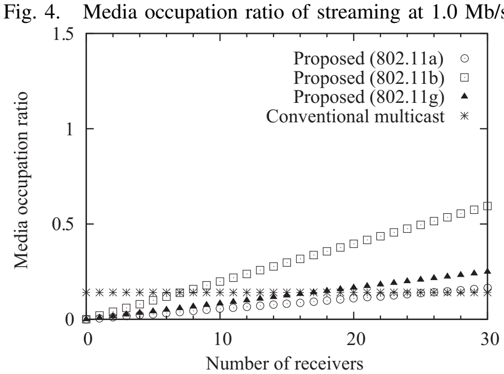


Fig. 5. Media occupation ratio of streaming at 128 kb/s

C. Mathematical Calculations

We now perform mathematical calculations using these equations and evaluate the proposed method. Table I shows the parameters used in the calculations. Although IEEE 802.11 defines short and long PLCP preambles, we will use the short preamble in Table I since it is the most popular. The basic transmission rate R_{basic} for control frames is assumed to be 1.0 Mb/s. In evaluating the proposed method with 802.11g, we assume that DSSS-OFDM is used on the physics layer.

. The bit rates of the stream for Figs. 4 and 5 are 1.0 Mb/s and 128 kb/s, respectively. We assumed no packet loss occurs for these figures. As Fig. 4 shows, the media occupation ratio when sending a stream of 1.0 Mb/s with the conventional multicast would be 1. This means that the wireless medium would be totally occupied and that streaming

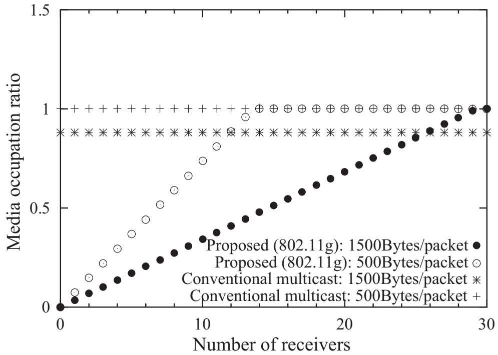


Fig. 6. Media occupation ratio for different packet sizes

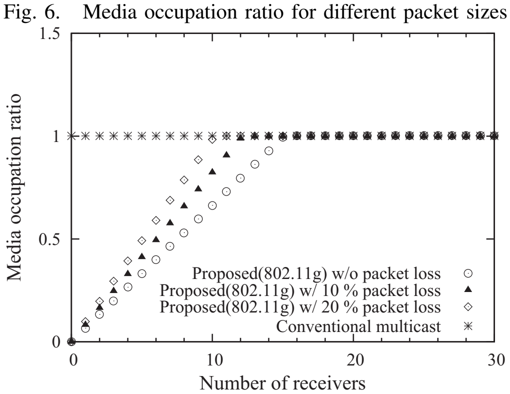


Fig. 7. Media occupation ratio for different packet loss rates

at that rate is impossible with the conventional multicast. The proposed method, in contrast, reduces the media occupation ratio to less than 1 at certain numbers of receivers, meaning that streaming can be received if the number of receivers is limited. In other words, there is a domain in which the proposed method enables streams to be transmitted but the conventional multicast does not. Moreover, in situations where the media occupation ratio of the proposed method is lower than that of conventional multicast, other transmissions can utilize the released bandwidth. Therefore, the proposed method is beneficial not only for multicast streams, but also for other communications.

Let us now focus on Fig. 5. The figure shows that the media occupation ratio of streaming of 128 kb/s is less than 1. This means the stream can be transmitted with the conventional multicast. However, since the proposed method reduces the media occupation ratio, we can say the proposed method should be applied even for streams that the conventional multicast can transmit, if the number of receivers is small enough.

Let us focus on Fig. 6. The figure shows the media occupation ratio for different packet sizes of a stream, while keeping streaming bit rate at 800 kb/s. Although Fig. 6 only shows the results for 802.11g, the same conclusions can be drawn for 802.11b. As Fig. 6 shows, the smaller the packet size is, the larger the media occupation ratio becomes, and the applicable scope of the proposed method becomes less. This is because the overheads of transmitting data become larger. However, this is not a significant disadvantage of the proposed method for the following reasons. In multicast streaming systems, the restriction on the delay is looser than that of interactive

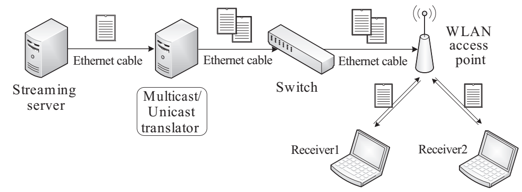


Fig. 8. Experiment

TABLE II
LIST OF NETWORK INTERFACES

Receiver1	AirPort Extreme (0x168C, 0x86)
Receiver2	Intel PRO/Wireless 2200BG Network Connection
Receiver3	AirMac Extreme (0x14E4, 0x4318)
Receiver4	Intel PRO/Wireless 2915ABG Network Connection
Receiver5	Intel PRO/Wireless 2200BG Network Connection
Streaming Server	RTL8168C(P)/8111C(P) PCI-E Gigabit Ethernet NIC
MUT	Yukon Gigabit Ethernet 10/100/1000Base-T Adapter, Copper RJ-45

communications such as voice calls. Because of this, the packet size of streams does not have to be extremely small and it can be set large. Moreover, when the number of receivers is limited by the small packet size, merging packets is a way to reduce the overheads and improve the scope of the proposed method. One such method is studied and evaluated by Shinomiya et al. [3].

Fig. 7 shows the situation with packet losses. The figure shows the media occupation ratio taking into account retransmissions due to packet losses when the bit rate of the steam is 1.0 Mb/s and the packet size is 1500 bytes. Since frames can collide and interference causes bit errors in WLANs, the packet loss rate depends on the environment and every node experiences different packet loss rates. The figure has plots for two packet loss rates: 10%, which is almost the same as the rate observed in our laboratory, and 20%. Note that our theoretical analysis is valid for any packet loss rate.

As Fig. 7 shows, the media occupation ratio increases when we take into account retransmissions due to packet losses. However, the increase in overheads of retransmission is not significant. Since the proposed method enables the retransmission procedure of the IEEE 802.11 standard, we should utilize it in order to improve the reliability of multicast over WLAN.

The above evaluation premises that all nodes can use the highest transmission rate in the IEEE 802.11 standard and the packet loss rate is the same at all receiving nodes. Therefore, the above gives calculations us the guideline for the best performance we could get. In reality, even though each node has a different transmission rate and packet loss rate, our method can still improve performance if the average transmission rate is high enough.

V. Experiment

For verifying the proposed method actually improves the media quality, we performed an experiment in a setup depicted in Fig. 8. With varying the number of receivers from 1 to 5, we observed packet loss rates under conditions where MUT is placed between a multicast router and a WLAN AP and where there was no MUT. The network interfaces and devices we used in this experiment are listed in Tables. II and III.

TABLE III
LIST OF DEVICES

	Model
WLAN AP	CG-WLRGNX
Switch	CentreCOM 9424T/SP

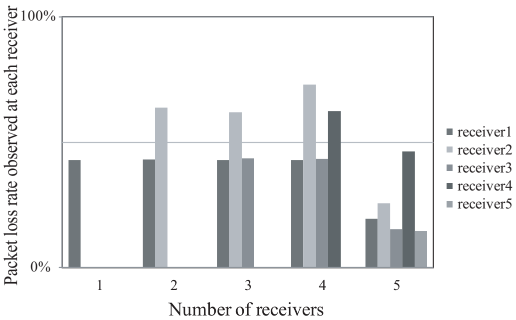


Fig. 9. Packet loss rate of streaming at 1.0 kb/s without MUT

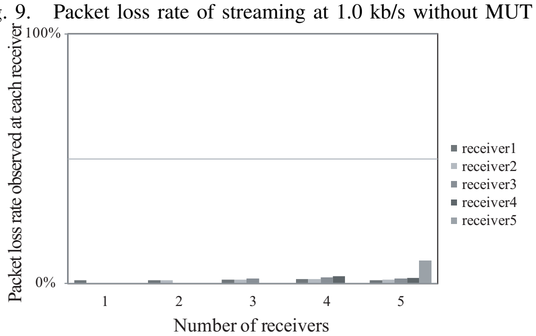


Fig. 10. Packet loss rate of streaming at 1.0 Mb/s with MUT

Figs. 9 and 10 show the mean packet loss rate of streaming at 1.0 Mb/s when using conventional multicast and proposed method. The plotted values are the average of ten trials. As Fig. 9 shows, almost packets were lost in case of conventional multicast. Compared with that, Fig. 10 shows that the proposed method reduced packet losses and improved reliability.

VI. RELATED WORK

There are many studies on the transmission reliability of multicast over WLANs. Leader-based acknowledgement, which selects one of the receivers to send back ACK and NACK (negative ACK) frames to the sender, was proposed in [4] and [5]. This approach, however, needs to change the standardized MAC protocol or to modify the sending and receiving nodes, and it merely realizes data transmission without errors. Moreover, these studies do not focus on transmission-rate constraints that are specific to multicast over WLAN; thus, they do not reduce the media occupation ratio. In addition, the constraints still interfere with other transmissions such as other high-bit-rate multimedia streams.

For improving reliability and efficiency, Auto Rate Fallback, an approach that is used in unicast, can be used in multicast for maintaining higher transmission rates [6]. However, this method does not always improve transmission efficiency, because all nodes in the system must support the protocol and use the same transmission rate.

Xcast (Explicit Multi-Unicast) [7] is similar to our approach since it also utilizes unicast transmission to achieve multicast, i.e. Xcast enables multicast transmissions through multiple unicast transmissions. Xcast is an alternative protocol to the group address based multicast. In the group address based multicast, each multicast group has its own group address. On the other hand, in Xcast, the sender holds a list of receivers in advance and all unicast addresses of the receivers are explicitly specified in the packet header. Although our method and Xcast have a certain similarity, the important difference is that out method utilizes the group address based multicast. As we can see from its principle, Xcast is more suited to comparatively small multicast groups and not suited to large multicast groups, and not suitable for media broadcasting. Another difference is that in Xcast the sender and receivers must support the Xcast protocol and such support is unnecessary in our model.

Compared with the previous studies, our proposal has advantages that it is transparently performed, and that it can be feasible for reducing the media occupation ratio and packet losses, without modifying end nodes or changing the standardized MAC protocol.

VII. CONCLUSION

In this paper, we proposed the transparent multicast / unicast translation method and showed that it improves the efficiency and reliability of multicast over WLAN through a theoretical analysis. We also showed the result of an experiment and confirmed that the method actually improves the media quality. When our proposed method is deployed in large scale, a new problem is raised, i.e. handover issues when receiving multicast streaming over WLAN. Since IP multicast packets are mapped to broadcast on WLAN, IP multicast packets are currently sent to all nodes belonging to the same layer 2 segment of WLAN APs. Therefore, there has been little discussion about the terminal handover among multiple WLAN BSSs so far because packets are transmitted anyway. However, since our method only delivers packets to the joined receivers, layer 2 handover issues are raised for multicast streaming. Solving these issues are also reserved for our future work since it is a new issue raised by our proposed method.

REFERENCES

[1] IEEE 802.11 Working Group, “Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications”, ANSI/IEEE Std 802.11-2007.

[2] M. Christensen, K. Kimball, and F. Solensky, “Considerations for Internet Group Management Protocol (IGMP) and Multicast Listener Discovery (MLD) Snooping Switches”, RFC 4541 (Informational), May 2006.

[3] Shinomiya Shunsuke, Nakagawa Shinichi, Yamaoka Katsunori and Sakai Yoshinori, “Numerical Analysis of Packet Merge Technique: The QoS Improvement and the Application Domain”, IEICE Transactions on Communications, vol.J88-B, no.3, March 2005 (Japanese).

[4] Richard Akester, “Reducing Multicast Collision Loss for Digital TV Over 802.11 Wireless Networks”, WSEAS Transactions on Information Science and Applications, Issue 3, Vol. 1, 2004.

[5] Diego Dujovne and Thierry Turletti, “Multicast in 802.11 WLANs: An Experimental Study”, MSWiM ’06: Proceedings of the 9th ACM international symposium on Modeling analysis and simulation of wireless and mobile systems, pp. 130–138, 2006.

[6] Sungjoon Choi, Nakjung Choi, Yongho Seok, Taekyoung Kwon and Yanghee Choi, “Leader-based Rate Adaptive Multicasting for Wireless LANs”, Global Telecommunications Conference, pp. 3656–3660, Nov. 2007.

[7] R. Boivie, N. Feldman, Y. Imai, W. Livens and D. Ooms, “Explicit Multicast (Xcast) Concepts and Options”, RFC5058, Nov. 2007.