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Loss Compensation Using Route Diversity in Wireless Multicast

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***Abstract*—The demand for content distribution services via wireless local area networks has been increasing. A multi-cell structure, which consists of multiple access points (APs), is more suitable for distributing content in wider areas. However, in multicast, there had been an unsolved issue; how to compensate for data-frame loss for each user. In particular, in wireless links, loss compensation techniques are essential because of the high loss-rate. To solve this problem, several loss-compensation methods have been proposed. Retransmission from AP, including automatic repeat request, is not always effective because the time-diversity effect cannot be obtained in static environments, where channel conditions are not time varying ones. Another approach for this problem is retransmission from other stations that have successfully received the data-frame, which is effective even in a static environment because of the route-diversity effect. In this paper, we propose a novel loss compensation method that uses retransmission from successful stations, and we also present the design of the medium access control layer. Our method aims at loss compensation for failure stations near borders between adjacent cells because the failed rate increases as the distance from APs is larger. The performance of the method is evaluated through computer simulations.**

I. INTRODUCTION

The demand for content distribution services via wireless local area networks (WLANs) has been increasing. When we send a single content to many recipients, wireless multicast, which uses point to multi-point (PMP) transmission in wireless links is an effective way to use radio resource efficiently[1][2]. Moreover, a multi-cell structure, which consists of multiple access points (APs), is more suitable than a single-cell structure for distributing content in wider areas. Such a system is expected to simultaneously provide live video streaming, advertising, and information to users across a wide area[3].

However, in multicast, there had been an unsolved issue: how to compensate for data-frame loss for each user. In particular, in wireless links, loss compensation techniques are essential because of the high loss-rate. To solve this problem, several loss-compensation methods have been proposed: hybrid automatic repeat request (ARQ), a combination of ARQ and forward error correction (FEC), which is well-known as an effective way of compensating for losses in wireless multicast[1]. However, retransmission from AP, including ARQ, is not always effective because the time-diversity effect[4] cannot be obtained in static environments, where channel conditions are not time varying ones. Another approach for loss compensation in wireless multicast is retransmission from other stations that have successfully received the data-frame, which is an effective one even in a static environment because of the route-diversity effect. Although this approach can be considered as an application of broadcast/multicast techniques in ad hoc networks[5][6], conventional methods in ad hoc networks were not designed to compensate for loss. Therefore, we need to discuss design and to evaluate the loss compensation that is done by using retransmission from successful stations in the medium access control (MAC) layer.

We propose a novel loss compensation method that uses retransmission from successful stations, and we also present the design of the MAC layer. Our method aims at loss compensation for failure stations near borders between adjacent cells because the failed rate increases as the distance from APs is larger. The performance of the method is evaluated through computer simulations.

II. PROPOSED METHOD: MRCS

We propose a new loss compensation method, wireless multicast using retransmission from successful stations with channel shift (MRCS), which compensates for data-frame loss using route diversity even in no time-diversity environments. Retransmission from the station near the failed station can reduce transmission time by using higher bit rate transmission. Furthermore, MRCS requires neither a complicated algorithm for scheduling and grouping nor an overhead for connection establishment and routing. A detailed description of the design is as follows.

A. Loss Compensation Area

A wireless multicast in a multi-cell WLAN environment is shown in Fig 1, where “Failed station” indicates stations that failed to receive a data-frame multicasted from an AP. Note that, we call radio broadcast from a wireless node to two or more destination stations “multicast”. In MRCS, first, every AP multicasts the same data-frame synchronously. Then, in the half-tone area in Fig. 1, stations that successfully received the data-frame multicast it to failed stations. Moreover in Fig. 1, this loss-compensation area is positioned to borders between adjacent cells. Compared with that of the single-cell case, the concentration of failed stations is higher, since stations located

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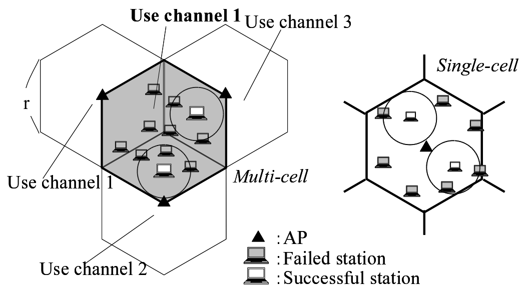

Fig. 1. Multicell environment.

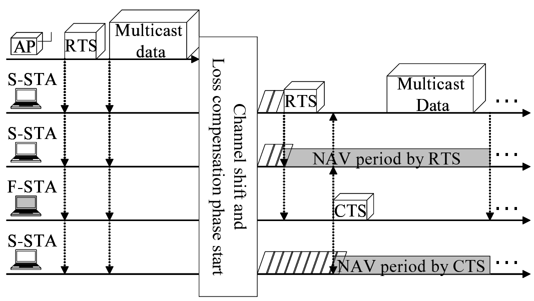

Fig. 2. Basic flow of MRCS.

at the edge of adjacent cells fail more frequently than ones nearer the APs.

B. Basic mechanism of MRCS

We now present the basic mechanism of MRCS represented as Fig. 2. The APs inform all stations in the service area of the start and end time of the loss-compensation phase and channel-selection table via a beacon before multicasting a data frame. The loss compensation phase is the time period during which successful stations compensate for the data-frame loss of failed stations. The channel-selection table shows which frequency channel each station has to choose during the loss-compensation phase.

As illustrated in Fig. 2, first, each AP sends a request to send (RTS) frame to stations in each cell and prohibits other transmissions by the stations. After that, every AP multicasts a data-frame at a transmission rate of R_1 Mbps. During the period reserved by the advance beacon, the wireless medium is monopolized by the first multicast transmission from the AP and the loss-compensation phase.

After the first multicast transmission from APs, each station switches its frequency channel to the new one on the basis of the channel-selection table, which is called channel shift and is explained in II-C. During the loss-compensation phase, stations that correctly received the data-frame by an AP retransmit the data-frame at transmission rate of R_2 Mbps based on medium access control described in II-D. After the loss compensation phase, all stations and APs are shifted back to their usual status which includes unicast communication. This procedure is repeated for a streaming service every time multicast data arrives.

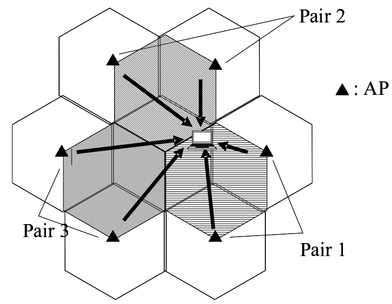

Fig. 3. Channel shift.

C. Channel shift

In a multi-cell environment, as shown in Fig. 1, to avoid interference, neighboring APs have to use a different frequency channel. In addition, MRCS has to unify the frequency channel used by stations in the loss-compensation area represented as the half-tone in Fig. 1. Therefore, in MRCS, each station selects the appropriate frequency channel on the basis of the channel-selection table included in the beacon, which is explained as follows.

We assume that, with the exception of the loss-compensation phase, each station connects to the AP from which it receives the strongest power, called the connected AP. When the loss-compensation phase begins, the frequency channels are slide to the loss-compensation areas. As shown in Fig. 3, the number of selectable frequency channels for stations is three in the loss compensation phase. To select the correct channel, six neighboring APs surrounding the connected one are paired into three groups. Each station selects the pair from which it receives the maximum sum of power and set its frequency channel to the one assigned to the loss-compensation area bounded by the selected pair and its connected AP. For example, as shown in Fig. 3, if a station connected to the center AP receives the maximum sum of power from Pair 2, in the loss-compensation phase, it belongs to the lower-right loss-compensation area, which is bounded by Pair 2 and the center AP.

The above channel shift can be applied to stations in the edges of a multi-cell. Moreover, in MRCS, because of the above channel shift, all APs in the service area have to send the RTS frame at the same time, which can be done when all of them are directly connected to a single multicast router via wired links.

D. Medium access control for station retransmission

In the loss compensation phase, successful stations compete for transmission opportunities based on a modified carrier-sense-multiple-access with collision-avoidance (CSMA/CA) protocol described as follows:

1) A successful station (S-STA) sends an RTS frame after a random back-off.
2) A failed station (F-STA) that receives the RTS frame from the S-STA sends back a CTS frame to the S-STA.

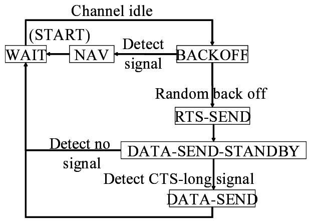

Fig. 4. S-STA Flow chart.

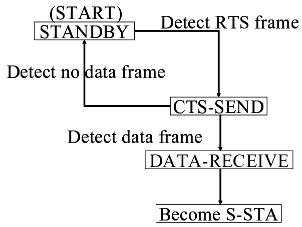

Fig. 5. F-STA Flow chart.

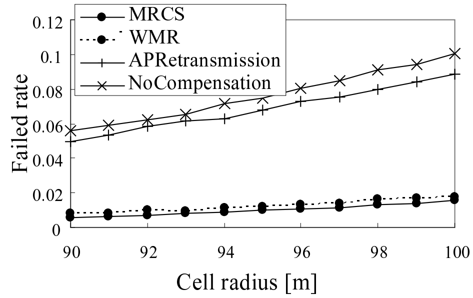

Fig. 6. Failed rate.

3) After the S-STA detects the CTS frame after sending its RTS frame, S-STA multicasts the data-frame which it correctly received.
4) If an S-STA detects a RTS frame, a CTS frame, or other signals, the S-STA freezes for the time equal to RTS-frame time + CTS-frame time + data-frame time, and it is then shifted back to step 1).
5) The S-STAs duplicate their contention windows (CWs) at every data-frame transmission.

The flow charts of S-STA and F-STA during the loss compensation phase are shown in Figs. 4 and 5. The F-STAs that have correctly received the data frame become S-STAs, and are shifted to step 1). In step 3), an S-STA may simultaneously receive CTS frames from multiple F-STAs. Therefore, in our medium-access-control mechanism, if an S-STA detects any signal with a time-length that is equal to that of the CTS-frame time, the S-STA recognizes that it received a CTS frame. Thus, in our mechanism, the RTS/CTS exchange is used for a different purpose from the original one: suppressing the hidden station problem.

When the loss-compensation phase ends, every station is forced to finish the loss compensation and resets their back-off counter to the default CW. As mentioned previously, the design of MRCS is simpler than conventional multicast/broadcast methods used in ad hoc networks because it requires neither a complicated algorithm for scheduling and grouping nor any overheads for a connection establishment and routing.

III. Simulation Model

The primary parameters used in our simulations are summarized in Table I. In our simulation, we set cell radius r 90$\sim$100 m. We allocated APs hexagonally shown in Fig. 1 but the position of each AP was randomly determined within 20 m from the center of each hexagon, and is thus similar to how AP allocation is usually done. We assumed that a constant number of stations connect to each AP, and all of them make requests to receive the multicast data-frame. We compared our MRCS with the AP Retransmission method and wireless multicast using retransmission from successful stations (WMR), which is similar to MRCS but without the channel shift function described in Sect. II-C. That is, the control unit of WMR is limited to individual cells. A comparison between MRCS and WMR leads us to declare the effectiveness of the channel shift in a multi-cell environment. On the other hand, in the AP Retransmission method, only APs are permitted to retransmit the data frame in the loss compensation phase. We found that MRCS is worked well when the parameters and the conditions listed in Table II were used. However, the parameters and conditions applicable for MRCS were not limited to these ones, and it was not sensitive to parameters and conditions.

TABLE I
Simulation parameters.

Wireless interface	IEEE802.11a
Path loss model	ITU-R LoS Upper Bound[7]
Co-channel interference	none
Frequency band	5[GHz]
Trans. power	10[dBm](AP, Station)
PHY trans.rate of AP, R_1	6[Mbps]
Noise power	-92[dBm]
AP height	4[m]
Station height	1[m]
Data frame length	1500[Bytes]
Max. of CW	1023
No. of simulation trials	1000

IV. Performance Evaluations

A. Effectiveness of Retransmission from Successful Station and Channel Shift

We evaluated the effectivenesses of retransmission from successful station and channel shift by analyzing the comparisons between WMR and AP Retransmission and between MRCS and WMR. Here, we set the length of the loss-compensation period to 4 ms, which is equivalent to two retransmissions from APs in the AP Retransmission method.

The failure rate after the loss compensation phase of MRCS, WMR and AP Retransmission vs. the cell radius of each cell is shown in Fig. 6. Also, the result in a no compensation scenario is plotted in the figure. The result shows that AP

TABLE II
Basic parameter set for MRCS.

Parameter	Basic parameter
PHY trans.rate of stations, R_2	36 [Mbps]
Loss compensation phase$t$	4 [ms]
CWmin in loss compensation phase	255
The number of station in each cell$n$	100
Shadowing s	Log-normal (standard dev.) = 5dB
Cell radius r	90$\sim$100 [m]

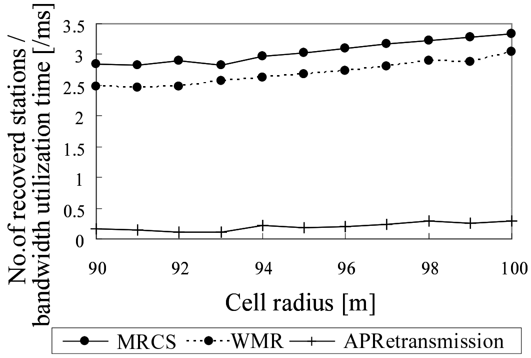

Fig. 7. Efficiency of Bandwidth utilization.

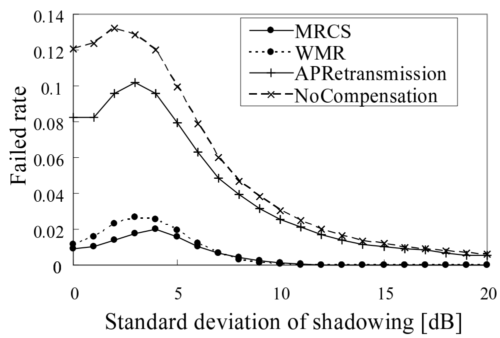

Fig. 8. Failed rate vs. standard deviation of shadowing.

Retransmission can slightly decrease the failure rate, while the method using retransmission from successful station achieved the significant decrease. Moreover, the performance of MRCS is superior to that of WMR. Even in a 100 m cell radius, the failure rate of MRCS was less than 1.6%, while that of WMR is about 1.8%.

The bandwidth utilization efficiency is shown in Fig. 7. We define bandwidth utilization efficiency as the number of stations that receive the data in the loss compensation phase divided by the consumed bandwidth utilization time. The bandwidth utilization efficiency of AP Retransmission was a tenth of the efficiencies of MRCS and WMR, while the efficiency of MRCS was about 20% superior to that of WMR. This superiority results from the channel shift while increasing the number of successful stations covered by one retransmission.

Thus, MRCS compensates for loss much more effectively than AP Retransmission does and as a result of the channel shifts is superior to WMR.

B. Effect of Shadowing on Performance

We investigated the effect of shadowing on the performances of each method. We used the basic parameters listed in Table II and fixed cell radius r to 100 m. The failed rates of MRCS, WMR, AP Retransmission, and no compensation scenario vs. shadowing are plotted in Fig. 8. The horizontal axis of the figure indicates the standard deviation of shadowing. The failed

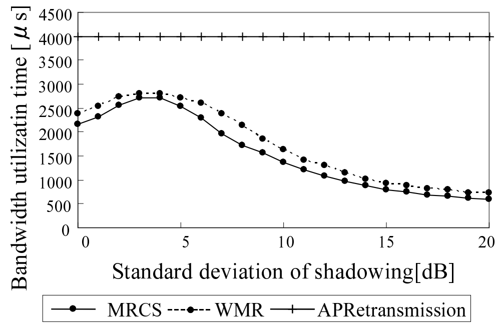

Fig. 9. Bandwidth utilization time vs. standard deviation of shadowing.

rates of all the methods decreased as the standard deviation of shadowing increased; even in a no compensation scenario, the link diversity caused by shadowing in turn causes stations to receive data-frames from one at least AP. The superiority of MRCS to WMR is larger in the small-shadowing environment than in the large-shadowing environment. This is because, as the deviation of shadowing increases, the link quality becomes less dependent on geometric distance, and these results in the decrease of benefit from the loss-compensation area explained in Sect. IV-A.

Bandwidth utilization time vs. shadowing is shown in Fig. 9. The result shows that the bandwidth utilization time of MRCS is 10 to 20% lower than WMR regardless of the deviation of shadowing; the bandwidth utilization efficiency of MRCS is higher than that of WMR.

C. Interference Power Characteristics

Compared to WMR, MRCS decreases interference power between cells from WMR by using its channel shift function; the channel shift in MRCS mean that, transmissions from stations occur only near the center of the loss compensation area, unlike transmissions in WMR. The model used to calculate the interference power is shown in Fig. 10. We assumed that, as in Fig. 10, a loss compensation area uses the same frequency channel as the alternate adjacent area. We measured the interference power at the midpoint of these two areas, the observed spot. Similarly, in WMR, we measured the interference power at the midpoint of two areas that use the same frequency channel. We compared the interference power in the cases of no shadowing and the situation that the standard deviation of shadowing is 5 dB. The cumulative distribution of the total received energy at the observed spots during the loss compensation phase obtained from 1000 simulation trials is shown in Fig. 11. In a no shadowing situation, MRCS performed more highly than WMR and AP Retransmission did, meaning that MRCS retransmits data frame mainly near the center of the loss-compensation areas. On the other hand, when there is larger shadowing, the superiority of MRCS decreases. This is because, as explained in the previous section, the benefit from the channel shift decreased in this situation. However, the total interference power of AP Retransmission was much

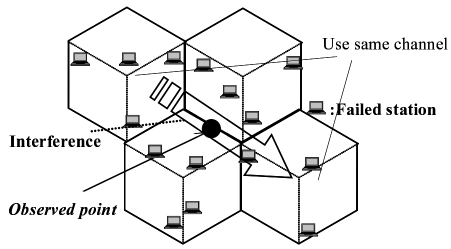

Fig. 10. Observed point for interference power.

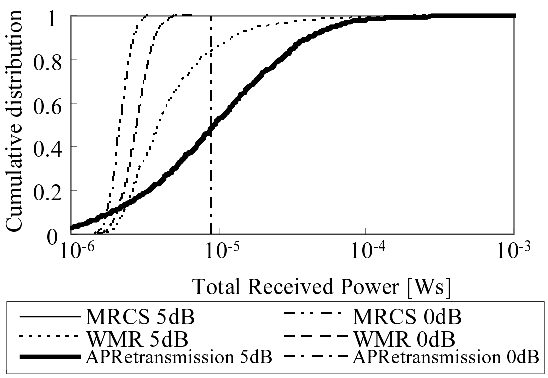

Fig. 11. Cumulative distribution of total received energy.

larger than that of MRCS and of WMR. This is because the lower transmission rate means that one retransmission on AP Retransmission required longer to send a data frame because of the lower transmissions rate.

Thus, we can conclude that even when considering only interference power, MRCS is a better loss compensation method than WMR and AP Retransmission.

D. *Quality of Stream*

The performance of MRCS in one data-frame delivery is evaluated in IV-A to IV-C. In this section, we evaluate how well it performs during streaming. We measured the number of received data-frame during 500 data-frame delivery. The simulation parameters shown in Table II were used and the cell radius r was set to 100 m.

The cumulative distribution of the number of received data-frame obtained from 100 simulation trials is shown in Fig. 12. The performance of WMR, AP Retransmission, and a no compensation scenario as well as that of MRCS show that MRCS performed the best for the number of received data-frames; in particular, about 98% stations received over 400 data-frames, and about 90% stations were able to receive all the data-frames. Although WMR also performed well, it was inferior to MRCS. On the other hand, AP Retransmission was unable to effectively compensate for failed stations in bad channel condition, and this resulted in the small number of received data-frames. Thus, MRCS is also a superior loss compensation method from the standpoint of streaming.

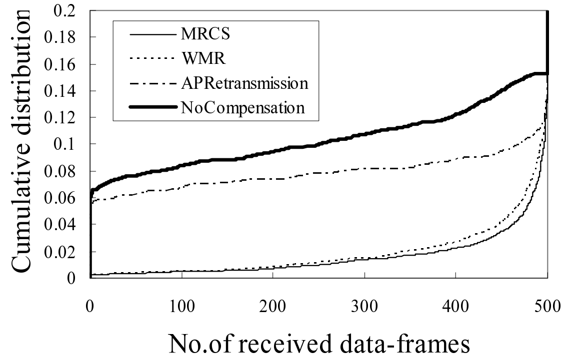

Fig. 12. Cumulative distribution of no. of received data-frames in stream.

V. CONCLUSION

We introduced the need to compensate the data-frame loss in wireless multicast and also proposed a novel loss compensation method that uses retransmission from successful stations. The proposed method effectively compensates the data-frame loss by improving route diversity. To make our method suitable for a multi-cell, we designed a MAC layer system that minutely differs from conventional retransmission from the successful station method. The results from the simulation show that retransmission done with the station method is a better loss compensation method than retransmission done with the AP method. We suggest that compensating in the area positioned to borders between adjacent cells by channel shift function is a superior method in terms of compensation effectiveness, bandwidth utilization efficiency, and interference power. However, carrying out this method does require that each AP send multicast start RTS at the same time. On the other hand, even without using the channel shift function, we achieved decent performance without the needing to control timing precisely.

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