Multi-Room IPTV Delivery through Pseudo-Broadcast over IEEE 802.11 Links

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Abstract—**The IEEE 802.11 wireless LAN (WLAN) is a time-tested technology, but it is still evolving towards even higher speeds and richer features. For multi-room IPTV delivery, where multiple IPTVs are fed from a main set-top box (STB), the IEEE 802.11 WLAN is an attractive choice for wirelessly connecting the STB and the IPTVs. In this paper, however, we first show that both the standard 802.11 unicast and broadcast/multicast delivery mechanisms have efficiency and reliability issues when they are applied to the multi-room IPTV delivery. In order to resolve the issues, we propose to use so called the pseudo-broadcast, where a unicast transmission is promiscuously received by multiple receivers. By dynamically changing the unicast destination based on the 802.11k measurement, the scheme also minimizes losses experienced by the promiscuous receivers. The scheme can be implemented without any change in the 802.11 standard, and provides a cost-effective solution to high-reliability and high-efficiency multi-room IPTV delivery.**

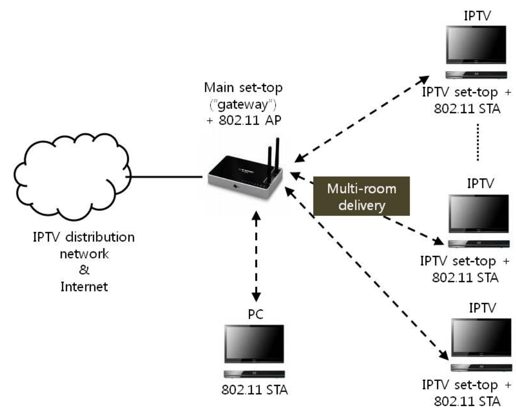

Fig. 1. Target system configuration (in bundled service).

I. Introduction

Live broadcast and on-demand video delivery through the Internet Protocol, IPTV in short, has become a promising new pay-TV platform. It is also a key application for so called the triple-play service, which bundles the IPTV with Internet telephony and high-speed Internet access.

As IPTV evolves into a major vehicle for live and on-demand video contents distribution, one practical issue it faces is *multi-room delivery*. In today's home and enterprise environments, an IPTV set-top box (STB) is usually connected to a single TV set. In case multiple TVs across the building need to be connected to the IPTV STB, wiring becomes a nuisance. Connecting the STB and multiple TVs using a wireless technology, therefore, can make the multi-room delivery configuration easier. Also, in bundled services, wireless connectivity would enable the STB to serve also as the attachment point for the wireless Internet access, supporting both functionalities with one wireless technology.

The IEEE 802.11 wireless LAN (WLAN) [1] is an attractive choice for the multi-room IPTV delivery over wireless configuration, as it has proven over time to be a dependable technology for short distance communication. It is also evolving towards even higher speeds and richer features. The looming 802.11n standard [2] for instance aims for up to 600Mbps, enough for tens of high-definition (HD) quality TV streams. Moreover, the recent 802.11e amendment [3] allows quality of service (QoS) differentiation to be made between voice, video, and data traffic.

In this paper, we consider the issues when the 802.11 WLAN is used as the vehicle for multi-room IPTV delivery. As depicted in Fig. 1, in the multi-room delivery system, there is a main set-top box, or gateway, connecting to the IPTV distribution network, and distributing IPTV streams inside the given building over the IEEE 802.11 link. The TVs can watch one of the channels through the gateway. Note that the gateway is not directly connected to the TVs, but instead to a STB functionality associated with each TV set. The STBs have the 802.11 functionality, so that they can use the 802.11 link to transport the TV contents and the control information (*e.g.* channel selection).

II. Problem definition

In the multi-room IPTV system, each TV can watch a separate channel, but some popular channels could be watched by more than one TV at the same time. When IPTVs watch different channels, the most appropriate mode of transportation is unicast. The 802.11 unicast retransmits up to 4 times when the given frame is lost due to adverse channel condition or collision. In contrast, the 802.11 broadcast (or multicast) does not retransmit, so when the frame is lost, it can be directly reflected on the video quality. Note that the 802.11 frame retransmission time is much shorter than usual video inter-frame gaps, so even when multiple retransmissions are performed, it would not cause much more delay than the de-jittering buffer at the receiving STB could absorb.

When there are multiple TVs that watch the same channel, it offers an opportunity to save bandwidth by utilizing the 802.11 broadcast. Especially when the high-definition (HD) quality TV, or even ultrahigh definition (UHD) that is expected to have up to 16 times the resolution of HD [4], is used to carry the TV signal, saving bandwidth becomes an important issue in the

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multi-room IPTV delivery system. Instead of using the 802.11 unicast that would require transmitting the same contents as many times as there are TVs that watch the same channel, we could think of using the 802.11 broadcast. It would reduce the bandwidth requirement, possibly leading to the following advantages:

- Statistically, more IPTV client stations can be accommodated by the multi-room delivery system on the 802.11 medium.
- More residual bandwidth can be left for other applications such as data and voice communication.
- By reducing the MAC-level contention on the channel, collision losses can be reduced, leading to a better video quality.

But as we discussed earlier, the 802.11 broadcast has the fatal reliability issue as it is completely exposed to the effect of frame losses. In essence, we are in a situation where we should find a novel approach that overcomes the shortcomings of the two modes of transmission in the 802.11 networks. Specifically, in this paper we address the following two questions:

- How do we maintain the quality of service (QoS) that could be affected by frame losses, as are experienced in broadcasting on bad channel?
- How do we make the system scalable to the number of TVs unlike in the vanilla 802.11 unicast?

Below, we discuss an alternative mode of transmission called the pseudo-broadcast as the answer to the questions. The pseudo-broadcast combines the best of the two existing modes of delivery, by deliverying broadcast contents through unicast. We will show that it can simultaneously achieve high scalability and reliability so that the resulting QoS is maintained in the multi-room delivery of IPTV streams over the IEEE 802.11 medium.

III. Pseudo-broadcast for multi-room IPTV distribution

The essence of the pseudo-broadcast is using unicast to achieve, effectively, a multipoint delivery. The immediate question is how, because the IEEE 802.11 standard does not have such hybrid mode of transmission. The following are the list of technical issues to be resolved in the design of the pseudo-broadcast:

- Group management of the set of IPTVs watching the same channel
- Selection of the unicast target
- Multi-point reception of the unicast transmission

A. Group management

In today's IPTV distribution architecture, the STB asks for the TV channel contents by sending the Internet Group Management Protocol (IGMP) Join message to the immediate IP multicast router [5]. Each TV channel is mapped to an IP multicast address, and it identifies the requested channel in the IGMP message. When the user changes the channel, an IGMP Leave message is issued by the STB, immediately followed by an IGMP join for the new channel. In our configuration of Fig. 1, we assume the gateway performs the role of the IGMP host. An alternative configuration where the STBs on TVs are the IGMP hosts is also possible, and the gateway can work as the IGMP proxy [6]. For convenience of explanation, we assume the first configuration. But either way, it is the gateway that needs to distribute the IPTV video data streams over the 802.11 wireless medium.

When an IPTV A joins a new channel C_1, what its STB (say, S_A) does is let the gateway (say, S_X) know its identity and the newly selected channel. The gateway then generates appropriate IGMP messages towards the IPTV distribution network. If A is the first TV to watch C_1, then it is sent through the 802.11 unicast.[1] But if it is not the first subscriber to C_1, S_X adds S_A to the pool of targets for C_1. Now, take the case where S_A is the second subscriber to the channel. The first subscriber, say S_B, has been receiving the channel via the ordinary 802.11 unicast, but now we should change into the pseudo-broadcast upon the joining of S_A. Since the pseudo-broadcast is still unicast, it does not mean that we flip to the 802.11 multicast or broadcast. It is only that S_X should make a new decision who should be the apparent (unicast) receiver for C_1 now between S_A and S_B. In fact, the decision as to who should be the unicast receiver is made whenever there is member change (join or leave) or significant channel condition change. This decision making process is discussed below.

B. Unicast target selection

The second step for the gateway is to decide on a single STB to be the destination of the 802.11 unicast transmission, among the targeted 802.11 endpoints (*i.e.*, STBs associated with the IPTVs watching an identical channel). Since each link between the gateway and the STBs can have a different channel condition, the frame loss rates will vary. Obviously, the safest heuristic would be to choose the STB with the worst link as the unicast destination, and we take the approach in this paper.

In order to compare the link qualities, the gateway should periodically poll the STBs. At the end of each period, the gateway asks each STB to report the number of correctly received frames in the period. This process is performed for all video channels that have more than one subscriber. After collecting the reports, the gateway computes the frame error rate (FER) for each member of the given channel to pick the unicast destination. For convenience, we call the selected STB with the worst channel condition the *designated receiver*.

C. Promiscuous reception

Since the non-designated STBs should be also able to receive the channel, ordinary unicast delivery is not sufficient.

[1] If we chose to use the 802.11 multicast instead, an IP group address would be translated to a 802.11 multicast address to which the video frames would be 802.11 multicast. But the whole idea of the pseudo-broadcast is not to use either multicast or broadcast that lacks retransmissions.

Therefore, the STBs perform *promiscuous* reception. First, if the outstanding destination on the 802.11 MAC header is its own, a STB receives it, and no further processing is necessary as to whether to receive it or not. But even if the destination address is other STB's, an STB does not discard the frame. Instead, it looks into the frame to check if the frame is for the channel that it currently subscribes to. If so, the STB processes the frame as if it is destined to it.

An interesting consequence of choosing the worst-channel STB is that the FER of the designated STB tends to become very low after the 802.11 retransmissions, whereas other STBs that showed better FERs (hence not selected) before the retransmissions may have relatively larger FERs than the designated receiver. This is because the 802.11 retransmission is performed with respect to the lost frames of the designated STB. Unless the lost frames by the designated STB is not a proper superset of those lost by the other STBs on the same IPTV channel, this will happen.

IV. Implementation

In this section, we describe how our pseudo-broadcast is implemented. The pseudo-broadcast relies on the promiscuous mode in which each node receives every received frame regardless of the destination address. Our prototype is implemented by modifying the MadWiFi [7] device driver on the Linux platform.

In pseudo-broadcast, the sender unicasts an IPTV channel but all STBs that watch the channel receive the frames using the promiscuous mode. In order to identify a specific channel or video, each channel is assigned a unique number called the pseudo-broadcast ID (PID).[2] The sender transmits the PID using the unused fields in the MAC header. Specifically, we set the `Type` in `Frame Control` field of the 802.11 MAC header to 11 as it is not used[3], and transmits the pseudo-broadcast ID using the `Subtype` field. Fig. 2 shows the modified MAC header format.

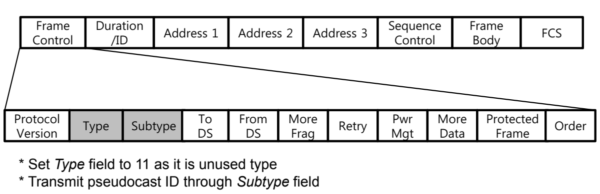

Fig. 2. 802.11 MAC header format with the shaded fields to mark pseudo-broadcast transmission.

The designated receiver serves as the reference for the transmissions to its group in two aspects. Firstly, its frame reception information is immediately fed back to the sender in the form of the MAC-level ACKs (or lack thereof), so lost frames of the designated receiver are robustly recovered by 802.11 retransmission. Secondly, the rate adaptation algorithm picks the best transmission rate based on the channel condition between the sender and the designated receiver. As the sender selects the designated receiver as the one in the worst channel condition, the rate chosen by the rate adaptation algorithm is safe for other STBs under better channel conditions.

For the selection of the designated STB for a given channel, the sender periodically requests frame error rate (FER) measurement result from the receivers. In our current implementation, the initial interval for measurement is set to 100ms. When the channel state is stable in which the designated receiver is not changed, the request interval can exponentially grow up to 3200ms (*i.e.*, 100ms $\rightarrow$ 200ms $\rightarrow$ 400ms $\rightarrow \cdots$ 1600ms $\rightarrow$ 3200ms $\rightarrow$ 3200ms $\rightarrow \cdots$) to reduce the measurement-related overhead. If the channel state becomes unstable, meaning some other station than the current designated receiver gets to have a higher FER in the given measurement period, the request interval returns to 100ms. Upon receiving the measurement request frame, the receivers transmit the FER report to the sender. For each measurement, a receiver counts the number of frames that the sender has transmitted using the `Sequence Control` field in the MAC header, and it measures FER by dividing it by the number of received frames. Based on this FER feedback, the sender selects the receiver with the highest FER as the designated receiver (Fig. 3).

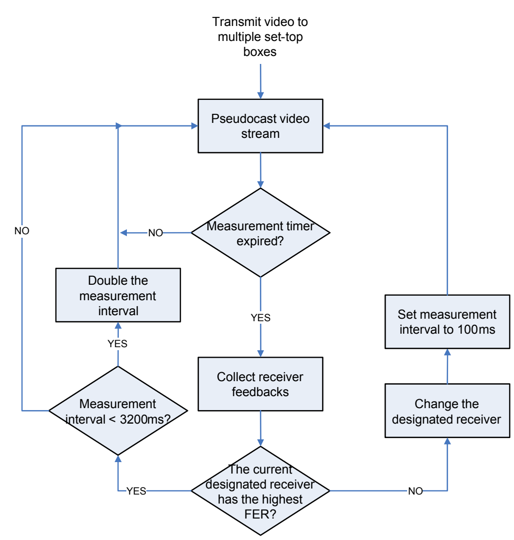

Fig. 3. Flow chart for pseudo-broadcast design.

For channel measurement request and response, we utilize the Measurement Request and Measurement Report frames that are standardized in the IEEE 802.11k [8]. The `Element ID` field for Request is 38, and for Report, 39. The MadWifi driver does not yet implement the 802.11k, so we modify it to add the logic to process the measurement request and report messages. The simplified frame formats that we use are shown in Fig. 4 (the pseudo-broadcast is marked "pseudocast" in figures for brevity).

[2]Note that distinguishing the channel through the multicast IP address inside the frame is irrelevant here since we do not use 802.11 multicast.

[3]The other three values, 00, 01, and 10, are used to mark management, control, and data frames, respectively.

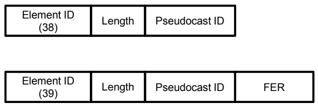

Fig. 4. A Measurement Request (above) and Report (below) format in our implementation.

V. Experiments

In this section, we evaluate the three modes of transmission for multi-room IPTV delivery discussed so far, in terms of efficiency and reliability. Fig. 5 is the laboratory setup used for the study. The thick lines represent concrete walls. Node A feeds UDP data stream to Node B, C, and D. Node B and C are in the same room with Node A, but Node D is outside the room and it is blocked by two concrete walls from the sender. Therefore the channel condition of the link A-D is the worst in our configuration. Each UDP datagram is 1,460 bytes, and Node A transmits them in constant bit rate (CBR). In order to measure the impact of the IPTV feed on the cross traffic, we set up two nodes F and G. Node F is the TCP sender that runs the `netperf` 2.4.4 to send a large file to Node G. For the TCP transfer, we used the segment size of 1,460 bytes, and sufficiently large socket buffer sizes of 16K bytes so that the throughput is only limited by the wireless medium. Finally, Node E is used to measure the performance of the IPTV and the TCP traffic.

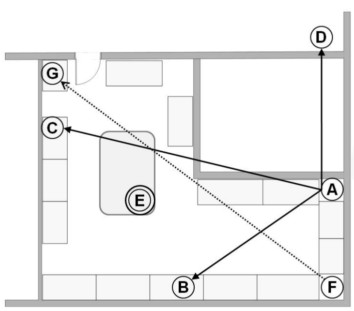

Fig. 5. Testbed topology— solid arrows: video feed, dashed arrow: TCP cross traffic.

A. Channel loss and bandwidth consumption

Fig. 6 compares the loss rate performance of the three schemes for video delivery on the 802.11g WLAN with 54Mbps as the nominal maximum. With 4Mbps video stream (top), the frame loss rate for the unicast is very low for all links, including the link A-D. This shows that the IEEE 802.11 retransmission mechanism is quite effective to recover lost frames through retransmission(s). For broadcast, on the other hand, the loss rates are slightly larger than the pseudo-broadcast for link A-B and A-C. The increase in the loss rate is due to the lack of retransmissions in the IEEE 802.11 broadcast. It is acutely pronounced in the case of link A-D. The broadcast is fully exposed to the degraded channel condition.

As to pseudo-broadcast, the destination is set to the node with the worst-quality link, namely A-D. So if the link A-D loses any frame, the IEEE 802.11 retransmission kicks in and recovers it. This is because for the link A-D, the pseudo-broadcast is simply unicast. Apparently, the sets of lost frames for the two other links A-B and A-C are not entirely included by that of the link A-D, so the loss rates on the links is higher than in A-D.

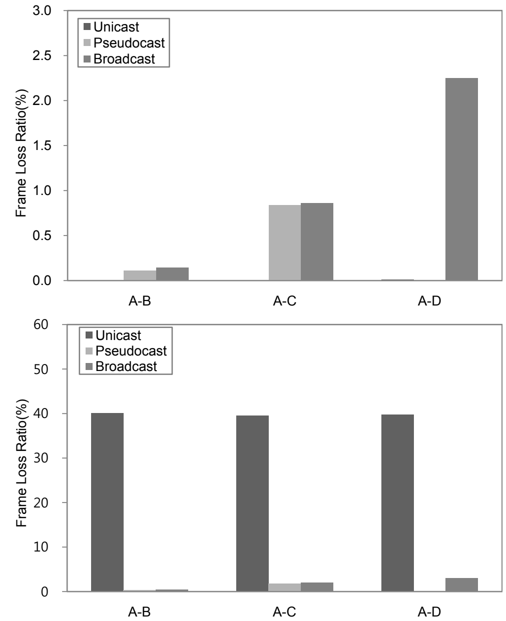

Fig. 6. Frame loss rate of video stream with the raw media rate of 4Mbps (top) and 12Mbps (bottom).

The few leftover frame losses for the promiscuous receivers is an inevitable cost associated with the pseudo-broadcast, but it is a trade-off for a possibly much larger benefit. The 12Mbps video stream case (bottom) testifies to it. While the broadcast and pseudo-broadcast show almost identical loss performance to the 4Mbps case, the loss rate for the unicast is unbearably high due to the excessive bandwidth demand. The unicast traffic load is directly proportional to the number of receivers subscribing the same channel, and it apparently exhausted the 802.11g radio resource as this experiment demonstrates. The soaring queueing loss will result in prohibitively high quality degradation. In contrast, the pseudo-broadcast maintains the FER below 1% in both cases.

Fig. 7 further illustrates the problem of the unicast from the perspective of the channel idle time. First, in the 4Mbps video case, only 30% of channel time is idle in broadcast. This might seem strange, but it is because the broadcast lacks the rate adaptation as well as retransmission. The 802.11 broadcast simply chooses the lowest basic rate in order to ensure that the worst-case link is supported. Although only a single transmission occurs for each video frame, the transmission rate is the lowest, and it takes more time than both unicast and pseudo-broadcast that make use of the rate adaptation.

For the 12Mbps video case, the unicast almost fully use

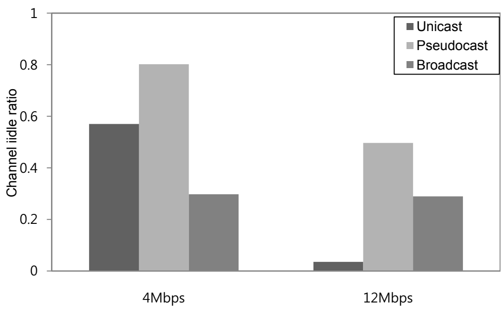

Fig. 7. Channel idle ratio.

up the channel. But broadcast, using the same basic rate, remains the same. The pseudo-broadcast leaves most bandwidth in both 4Mbps and 12Mbps cases, since it transmits once (except for retransmissions) like in broadcast *and* performs rate adaptation. The gap between the pseudo-broadcast and the broadcast will narrow as the video rate goes up, but the broadcast can never outperform the pseudo-broadcast due to the rate adaptation.

B. Loss under cross traffic

As the pseudo-broadcast leaves the most channel idle time, the cross traffic is interfered the least. In our second set of experiments, we run a TCP connection on which we transport large data concurrently with the IPTV transmission. Fig. 8 and 9 show the TCP throughput and the loss rate of the 4Mbps IPTV stream under the TCP activity, respectively.

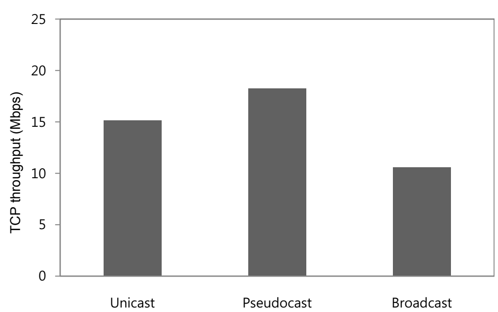

Fig. 8. Throughput of the TCP cross traffic under compared video distribution schemes.

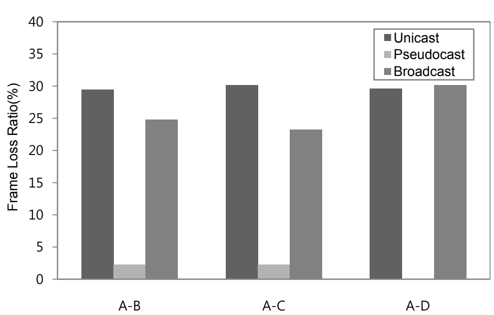

Fig. 9. Loss under TCP cross traffic.

As expected, the TCP throughput is the highest with the pseudo-broadcast, followed by unicast and broadcast. It reflects the channel idle times under each scheme. But what is impressive is the spectacular loss rate of the media stream in face of TCP cross traffic (Fig. 9). The unicast shows the worst loss performance, even worse than broadcast. This is because of the poor bandwidth scalability. With the addition of the TCP cross traffic, the combined 12Mbps video streams have to compete with the greedy TCP for bandwidth. Note that the existence of competing TCP traffic is realistic in home or enterprise environment where we frequently use the Internet over Wi-Fi. The pseudo-broadcast reduces the chance that the competing data traffic affects the quality of the IPTV. Its loss rate is just over 2% on all links. And as shown in Fig. 7, the broadcast has high channel utilization, which leads to the high loss rate in Links A-B and A-C in face of the competing TCP traffic. For link A-D, the channel condition further adds to the loss.

VI. Conclusion

In this paper, we show that pseudo-broadcast is a better alternative to the traditional unicast and broadcast for multi-room IPTV delivery over IEEE 802.11 wireless medium. The pseudo-broadcast uses less wireless channel time than broadcast, but with retransmissions and rate adaptation as in unicast it has much higher delivery rate. Consequently, it can cope better with bandwidth shortage and wireless channel quality degradation, leading to improved video quality for the IPTV receivers.

Acknowledgment

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