Layered Wireless Video Multicast using Omni-directional Relays

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Abstract— **Wireless video multicast enables delivery of popular events to many wireless users in a bandwidth efficient manner. However, providing good and stable video quality to a large number of users with varying channel conditions remains elusive. We propose to integrate layered video coding with cooperative communication to enable efficient and robust video multicast in infrastructure-based wireless networks. We determine the user partition and transmission time scheduling that can optimize a multicast performance criterion.**

Index Terms: layered video coding, omni-directional antennas, user cooperation, wireless video multicast

I. INTRODUCTION

In recent years, the demand for video applications over wireless networks rose with the increase in both the bandwidth of wireless channels and the computational power of mobile devices. To provide efficient delivery among a group of users simultaneously, multicast has been used as an effective solution, as it saves network resources by sharing the data streams across receivers. On the other hand, the higher packet loss ratio and bandwidth variations of wireless channels, along with heterogeneity of the users, makes video multicast over wireless networks a challenging problem.

Wireless channels can be characterized by their bursty and location dependent errors. Hence, each user in a multicast system will most likely lose different packets. Therefore, a simple ARQ (Automatic Repeat reQuest) based scheme is not appropriate for video multicast over wireless channels since it can cause a large volume of retransmissions. There are several studies discussing error control in video multicast over wireless networks [1],[2]. In a multicast scenario, heterogeneity among clients is another issue since each receiver has a different connection quality and power limitation. Scalable (layered) video coding is one approach to solve the heterogeneity problem. Several researchers have studied layered video multicast in infrastructure-based wireless networks, including [3]-[6]. Moreover, video multicast over adhoc networks have been considered in [7],[8], which proposes to use multiple description video to overcome the unreliability of wireless links. However, none of these papers consider the use of cooperation.

Generally, receivers may have very different channel qualities, with ones closer to the sender having better quality on average and far away receivers having poor quality. In a conventional multicast system, the sender adjusts its transmission rate to the user with the worst channel conditions. Hence, the system is severely affected by path loss and multipath fading. User cooperation is one effective technique to combat path loss and fading where terminals process and forward the overheard signal transmitted by other nodes to their intended destination [9]. Cooperation techniques have been extensively studied as a means to provide spatial diversity [10]. Cooperation of users can also be used to provide reduction in source distortion by providing unequal error protection. In our previous work we investigated both physical-layer and MAC-layer cooperation for point-to-point video communication [11]-[14]. User cooperation is especially attractive for multicast, because the relays are part of the intended recipients and hence are free from the incentive and security concerns that have hindered the practical deployment of cooperation for point-to-point communications.

In this paper, we propose to integrate layered video coding with cooperative communication to enable efficient and robust video multicast in infrastructure-based wireless networks. In conventional multicast design, the receivers with a good channel quality unnecessarily suffer and see a lower quality video than they would have if the system were targeted at good receivers. The basic idea behind the cooperative multicast is that we divide all the receivers into two groups such that receivers in Group 1 have better average channel quality than Group 2, and we let the sender choose its transmission rate based on the average channel quality of Group 1. Then, selected receivers in Group 1 will relay the received information to Group 2 users.

This paper is organized as follows. We introduce the system model in Section II. We formulate the optimum user partition and discuss time scheduling along with the multicast performance metric in Section III. Section IV analyzes the obtained results. We conclude the paper in Section V.

II. SYSTEM MODEL

In this paper we study an infrastructure-based wireless network (such as WLAN, 3G or WiMAX networks), and assume a sender (a base station or access point) is multicasting video to dense, uniformly distributed multicast receivers within its coverage area. We consider a path loss channel model where the channel condition solely depend on the distance

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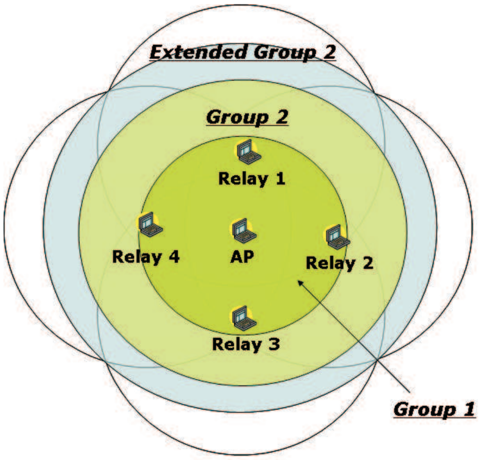

Fig. 1. System set up

between sender and receiver. In other words, the receivers closer to the sender have better channel qualities and hence can support higher transmission rates than the far away receivers. We divide all the receivers into two groups such that Group 1 receivers have better average channel quality than Group 2 receivers, and let the sender choose its modulation and channel coding schemes based on the average channel quality of Group 1. Selected receivers in Group 1 (to be called relays) will relay all or selected received packets from the sender to Group 2 receivers, with the modulation and channel coding schemes chosen based on the average channel quality of relays to Group 2 receivers. In general, Group 2 receivers can combine the received information from sender and the relays, but in this paper we consider the simple case where Group 2 receivers only listen to their designated relay. We show that even with such a multi-hop strategy, substantial gains in signal quality is achievable.

We consider transmission with omni-directional antennas where each relay targets a subgroup of Group 2 receivers as illustrated in Figure 1 and transmits at a different time slot. Here note that, both the sender-to-Group 1 receivers' links and relay-to-Group 2 receivers' links have better quality and hence higher sustainable transmission rates. We assume that at sustainable transmission rates, the packet loss is negligible. Furthermore, with the same sender transmission power, it is likely that we achieve a larger coverage area, which we name Extended Group 2.

The system described so far is applicable to the multicast of both data and video (or more generally audio-visual signals). A difference between data and video is that video does not need to be completely delivered to be useful. A video signal can be coded into multiple layers so that receiving more layers leads to better quality, but even just one layer (the base layer) can provide acceptable quality. Also, occasional packet loss in a delivered layer may be tolerable. On the other hand, the delivery of a video segment must be in time before its scheduled playback time. We exploit the advantage provided by layered coding in two ways. Firstly, the number of layers to be delivered by the sender should be adjusted based on the channel conditions of the sender-to-Group 1 links. Secondly, the relay nodes may forward only a subset of layers that they receive. This way, we can make users in Group 1 get much better quality than that offered by direct transmission, whereas users in Group 2 get video quality better than or similar to direct transmission. Considering that relays are spending their own resources (e.g. power) to help others, this differentiated quality of service may be justified. In general, a user may move from one location (Group 1) to another (Group 2) at different times. Hence, on average, every user in the system consumes an equal amount of power while getting better video quality. Furthermore, we can choose different users in Group 1 to be relays at different times and hence they will on the average spend same amount of power, rather than consuming all the power of only a fixed set of relays.

III. OPTIMUM USER PARTITION AND TIME SCHEDULING

With the set up described above, since each relay transmits at a different time slot for relay transmission, the rate observed by the receivers (to be called the received video rate) will be different from the physical layer transmission rate. We can express the received video rates for Group 1 and Group 2, Rv_1 and Rv_2, as

$$Rv_1 = \beta R_1 \tfrac{T_1}{T} \ , \ Rv_2 = \beta R_2 \tfrac{T_2}{T} \tag{1}$$

where β, $0 < \beta < 1$, is the effective payload ratio (i.e., it is the ratio of the payload size to the actual packet size which includes the headers, FEC, etc. as well as the payload). R_1 and R_2 stand for the sustainable transmission rates for Group 1 and Group 2, which depends on the coverage range for Group 1 and Group 2, r_1 and r_2, respectively. Note that, for a given physical layer parameters, path loss model and BER (Bit Error Rate), we can compute the coverage ranges for the corresponding transmission rates. We assume that the video data is sent in intervals of T seconds, and the sender and the relays use T_1 and T_2 seconds for their transmission, respectively such that $T = T_1 + NT_2$ where N represents the number of relays. Here, the additional delay introduced by the proposed relay mechanism due to time division multiplexing, is the time interval of one video packet.

In the above formulation, note that for a fixed T_1, as N increases, since the relays can not transmit simultaneously, the time interval that each relay can transmit, T_2, decreases. On the other hand, for a fixed r_1, as N increases, each relay only needs to send to a smaller subgroup and hence r_2 reduces and the transmission rate R_2 increases due to a better average channel. Therefore, while optimizing the system for a given performance criterion, we need to consider r_1, r_2, T_1, T_2, N jointly.

In order to find the configuration that optimizes a multicast performance criterion, we search in the space of (r_1, r_2). For a particular r_1 and r_2, we determine the optimum T_1, T_2 and N in two steps. We first determine the user partition with a minimum number of relays. Then for this user partition, we find the optimum T_1 and T_2 that maximizes the system performance index (to be discussed in Section III-B). By repeating the above procedure for all possible (r_1, r_2) we find the optimum user partition and time scheduling that maximizes

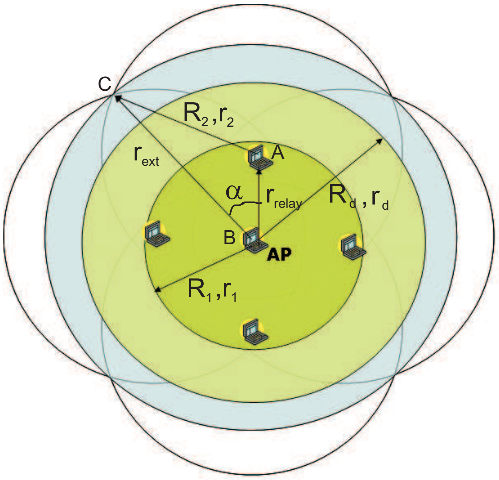

Fig. 2. Geometric model for the system

the performance. In the following subsections we will first formulate the user partition using a geometric approach and then discuss time scheduling along with the multicast performance criterion.

A. *User partition*

For fixed r_1 and r_2, we find the minimum number of relays which covers all the receivers within coverage range of direct transmission, r_d, following a geometric based approach. We define r_{relay} as the distance between the base station and the relay, and r_{ext} as the radius of the Extended Group 2, as illustrated in Figure 2.

User partition is defined by r_1, r_2 and the separation angle α where the number of relays can be computed as $N = \frac{2\pi}{2\alpha}$. We define α_{max} as the maximum angle which satisfies the constraints below,

$$r_{relay} \leq r_1 \tag{2}$$

$$r_{ext} \geq r_d \tag{3}$$

More specifically, Equation (2) states that the relay is selected from the Group 1 receivers and Equation (3) states that all the receivers in Group 2 are guaranteed to be covered. The separation angle will be maximum (hence the number of relays will be minimum) when $r_{relay} = r_1$ and $r_{ext} = r_d$. Note that, the triangle, ABC, in Figure 2 has sides r_1, r_d and r_2. Applying the cosine theorem, we can compute α_{max} as,

$$\alpha_{max} = \arccos \frac{r_1^2 + r_d^2 - r_2^2}{2r_1 r_d} \tag{4}$$

then the minimum number of relays can be calculated as,

$$N = \lceil \frac{2\pi}{2\alpha_{max}} \rceil \tag{5}$$

After calculating the minimum number of relays, since we assume a symmetric structure, the relays are equally spaced at an angle $2\alpha = \frac{2\pi}{N}$, and in order to have the maximum coverage area the relays are placed at $r_{relay} = r_1$. Then we calculate r_{ext} using the cosine theorem on the triangle ABC, by solving for the roots of the following second order equation,

$$r_{ext}^2 - 2r_1 \cos\alpha \; r_{ext} + r_1^2 - r_2^2 = 0 \tag{6}$$

B. *Time Scheduling and Performance Metric*

We define $D_1(Rv_1)$ as the distortion of Group 1 receivers and $D_2(Rv_2)$ as the distortion for Group 2 receivers. Note that D_1 is a function of the received video rate, Rv_1, and for a given video file if we know Rv_1, we can compute D_1. We use an exhaustive search over a discretizied space of feasible T_1 and T_2, for each candidate T_1 and T_2, determine Rv_1 and Rv_2 and the corresponding D_1 and D_2.

We consider three different performance metrics. First we will discuss the minimum average distortion criterion. The average distortion can be computed as,

$$D_{avg} = \frac{N_1 D_1(Rv_1) + N_2 D_2(Rv_2)}{N_1 + N_2} \tag{7}$$

where N_1 and N_2 are the number of users in Group 1 and Group 2, respectively. We can approximate N_1 and N_2 as $N_1 \sim r_1^2$ and $N_2 \sim (r_d^2 - r_1^2)$. Here, in order to have a fair comparison with direct transmission, we only consider the receivers in the coverage range of direct transmission, r_d.

The minimum average distortion is not always a good metric to evaluate the system performance. Thus, we also consider the case where we require all the receivers have the same distortion. In other words, we find the optimum user partition and time scheduling that minimizes $D_1(Rv_1) = D_2(Rv_2)$.

Furthermore, considering the fact that relays are spending their own resources to help others, we also investigate the case where the system favors Group 1 receivers. Here, we minimize $D_1(Rv_1)$ while providing Group 2 users the same quality as with direct transmission. In this case, we find the optimum user partition and time scheduling that minimizes $D_1(Rv_1)$ while guaranteeing $Rv_2 = \beta R_d$.

IV. Results

We utilize an IEEE 802.11b based WLAN. In order to obtain the coverage range for each transmission rate of 802.11b, we used the following procedure. First, we get the BER versus SNR (Signal-to-Noise Ratio) curves for all transmission modes of 802.11b. Then, for a BER threshold of 10^{-4} and PLE (Path Loss Exponent) of 4, we obtain Table I. Here, we assume a channel model where the signal propagated from the transmitter is only subject to path loss and Gaussian noise, and the base rate of 802.11b ($1Mbps$) can be supported up to 100 meters away from the access point.

Sustainable Rate(Mbps)	11	5.5	2	1
Distance (m)	61	72	88	100

TABLE I
Sustainable Rates vs. Distance with IEEE 802.11b

We consider a coverage range of 100m radius, $r_d = 100m$, where the sustainable rate with direct transmission to all users is $R_d = 1Mbps$. Based on our experiments, we assume $\beta = 0.25$, so at $1Mbps$ transmission, the payload rate is $250kbps$. We used H.264/SVC codec and encode 240 frames of the (352x288) Soccer video whose rate distortion curve is given in Figure 3. The PSNR value of the video with direct transmission is 29.55 dB.

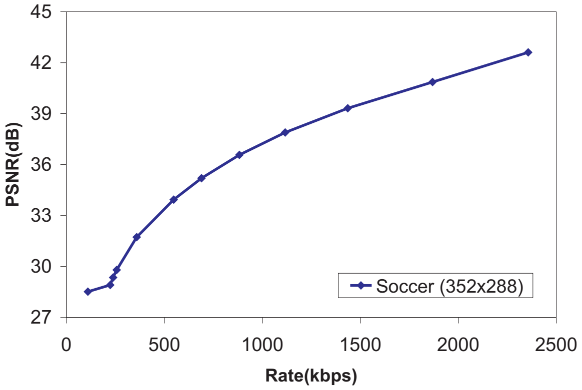

Fig. 3. Rate-distortion curve for Soccer video, obtained by using H.264/SVC encoder [15] using the MGS quality scalability mode with a base layer rate of 110 kbps.

In Table II, we compare the optimum configurations for three different performance metrics discussed in Section III-B. For all three metrics, the optimum configuration has the same user partition with $r_1 = r_2 = 61m$ $(R_1 = R_2 = 11Mbps)$, and $N = 6$ with $r_{ext} = 105.7m$. Note that when we minimize the average distortion, we improve the average quality $\triangle = 2.91$ dB compared the direct transmission. We can alternatively have equal quality at all users in which case we achieve a quality improvement of $\triangle = 2.56$ dB at all receivers compared to direct transmission. Finally, when we favor Group 1 users, we achieve a quality improvement of $\triangle = 9.10$ dB for Group 1 receivers compared to direct transmission while keeping the quality of Group 2 receivers the same as direct transmission. Also note that with the optimum configuration we not only improve the average video quality but also slightly extend the coverage range.

V. CONCLUSION

In this paper, we propose to integrate layered video coding with cooperative communication to enable efficient and robust video multicast in infrastructure-based wireless networks. We determine the user partition and transmission time scheduling that can optimize a multicast performance criterion. We argue that cooperative communication improves the multicast system performance by providing better quality links (both for sender and relay) and hence higher sustainable transmission rates.

This paper only considers omni-directional relay transmission where the relays cannot transmit simultaneously in time which reduces the system efficiency. To circumvent this problem, a future direction is to explore the use of directional antennas where we can achieve efficient spatial reuse. Additionally, directional transmission increases the signal energy towards the direction of the receiver resulting in a further increase of the coverage area. Although directional antennas are more expensive to operate at present, we believe the potential performance gain is significant, and worth pursuing. Another research direction is to consider multipath fading along with the case where Group 2 receivers can combine the received information from the sender and the relays.

	Minimum average distortion	*Equal distortion at all users*	*Best quality in Group 1*
Optimum T_1/T	2.42/11	1/7	5/11
Optimum T_2/T	1.42/11	1/7	1/11
$Rv_1(Mbps)$	0.61 $(\triangle = 0.36)$	0.39 $(\triangle = 0.14)$	1.25 $(\triangle = 1.00)$
$Rv_2(Mbps)$	0.36 $(\triangle = 0.11)$	0.39 $(\triangle = 0.14)$	0.25 $(\triangle = 0.00)$
$PSNR_1(dB)$	34.57 $(\triangle = 5.02)$	32.11 $(\triangle = 2.56)$	38.66 $(\triangle = 9.10)$
$PSNR_2(dB)$	31.57 $(\triangle = 2.02)$	32.11 $(\triangle = 2.56)$	29.55 $(\triangle = 0.00)$
$PSNR_{avg}(dB)$	32.46 $(\triangle = 2.91)$	32.11 $(\triangle = 2.56)$	31.27 $(\triangle = 1.72)$

TABLE II

COMPARISON OF DIFFERENT PERFORMANCE CRITERIA (WITH OPTIMUM USER PARTITION $r_1 = r_2 = 61m$, $N = 6$ AND $r_{ext} = 105.7m$ FOR ALL THREE CASES. $\triangle$ IN RATE IS THE INCREASE (IN MBPS) FROM THE DIRECT TRANSMISSION PAYLOAD RATE OF 250 $kbps$, $\triangle$ IN PSNR IS THE DIFFERENCE FROM THE PSNR ACHIEVABLE WITH DIRECT TRANSMISSION, 29.55 dB.)

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