BIT ALLOCATION OF WWAN SCALABLE H.264 VIDEO MULTICAST FOR HETEROGENEOUS COOPERATIVE PEER-TO-PEER COLLECTIVE

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ABSTRACT

By exploiting multiple network interfaces on one device, e.g., Wireless Wide Area Network (WWAN) and Wireless Local Area Network (WLAN), peers receiving different subsets of WWAN broadcast/multicast packets can perform Cooperative Peer-to-peer Repair (CPR) by exchanging received WWAN packets with their local WLAN peers. This effectively improves the transmission success from a WWAN broadcast/multicast source to a CPR collective.

In this paper, we propose an intelligent joint source/channel bit allocation scheme for WWAN scalable video multicast that leverages on the CPR paradigm. Key observation is that given a peer can successfully receive a packet either from the WWAN channel directly, or via a CPR neighbor using ad-hoc WLAN connections, more bits can be redistributed from channel to source coding out of a fixed WWAN bit budget to further minimize peer's expected visual distortion. In our proposal, groups of peers requiring different video resolutions are assigned to the same multicast group, and we perform one WWAN resource allocation and subsequent CPR over heterogeneous peers of different resolutions together. Our simulations show that our joint multicast group optimization can improve video quality by up to 2.84 dB, compared to a scheme where both WWAN resource allocation and WLAN CPR are separately performed for heterogeneous peers.

1. INTRODUCTION

Recent research on cooperative ad-hoc group of multi-homed devices [1, 2], each with multiple network interfaces like Wireless Wide Area Network (WWAN) and Wireless Local Area Network (WLAN), proved that useful transmission paradigms beyond traditional server-client model can be constructed. [1] showed that aggregation of an ad-hoc group's WWAN bandwidths can speed up individual peers' infrequent but bursty large content downloads. [2] showed that smart striping of FEC-protected (forward error correction) time-sensitive media packets across WWAN links can alleviate single-channel burst losses, while avoiding interleaving delay experienced in a typical single-channel FEC interleaver.

Cooperative Peer-to-peer Repair (CPR) is another construction of new paradigm exploiting peers' multi-homing property, and has proven to be effective in improving video quality [3]. With CPR, multi-homed peers listening to the same WWAN video broadcast/multicast and connected to each other via ad-hoc WLAN can exchange received WWAN packets locally via WLAN to repair WWAN losses. By imposing optimized structures on network coding [3] (SNC), we have also shown that performance can be further improved given limited WLAN resources.

Multi-homing property can also be exploited to improve WWAN joint source/channel bit allocation. Due to the well-known NAK implosion problem [4], many video broadcast/multicast schemes over WWAN [5] have forgone feedback-based error recovery schemes and opted instead for FEC. While FEC helps receivers with channels as good as the targeted nth-percentile receiver's, receivers with worse-than-targeted channels suffer great losses. CPR alleviates the problem by providing *packet transmission diversity*: a WWAN multicast packet can be delivered to a peer either directly from WWAN source through a WWAN link, or indirectly via a WLAN neighbor during CPR repair. This means a WWAN packet is lost by a peer *only if* it is lost via WWAN links by all CPR peers, *or if* CPR fails during recovery—a much stronger loss condition that non-CPR-performing peers. WWAN source can hence optimize joint source/channel bit allocation for the whole peer collective by exploiting this stronger loss condition: expend more resource for source coding and less for channel coding [6], in order to minimize peer's expected distortion due to combination of source coding loss (quantization noise) and channel coding loss (packet loss induced distortion).

At the media processing layer, technology for scalable video [7]—single encoded bitstream where different subsets can be extracted for video playback at different bitrates and/or different temporal and spatial resolutions—has continued to mature, and the latest reincarnation in H.264 has received both academic and industrial attention. Our previous joint source/channel bit allocation work has targeted a non-scalable, real-time video encoding scenario. In this paper, we target instead streaming of pre-encoded scalable video for store-and-playback applications.

In particular, in this paper we propose a joint source/channel bit allocation scheme for WWAN scalable video multicast to a CPR collective of heterogeneous peers, where a scalable video is disseminated in the same WWAN channel to all peers requiring different resolutions, and subsequent CPR repairs are performed jointly for all peers. Though optimized scalable video streaming over lossy networks has a fairly long history [8], in our work we perform resource allocation for an *entire* collective of heterogeneous peers using scalable video, where we drop temporal frames and add NC-based FEC packets to each spatial layer optimally.

Given peers are interested in the same WWAN multicast video but require different spatial resolutions, one system optimization approach is to first assign peers requiring the same resolution to the same WWAN multicast channel and the same CPR repair group, and then extract the right subset from a scalably encoded bitstream corresponding to the desired resolution for distribution. While this approach is simple in system setup, it suffers from transmission contention from the peers and opportunities for collaboration among different CPR groups are wasted. Our simulations show that our joint multicast group optimization can improve video quality over this separate group approach by up to 2.84dB.

Our paper is organized as follows. Section 2 describes the video source and network models, and overviews the CPR framework. We discuss SNC optimization for WWAN video multicast in Section 3. We report simulation studies that verify the effectiveness of our framework in Section 4 and conclude in Section 5.

2. VIDEO MULTICAST SYSTEM AND COOPERATIVE PEER-TO-PEER REPAIR

We assume N peers are watching video multicast simultaneously. WWAN source prepares a scalable video bitstream *a priori* for later WWAN multicast, and different peers subscribe to different spatial resolutions of video because of respective device display constraints. Devices are multi-homed and CPR enabled. They receive one Group of Pictures (GOP) of video through WWAN multicast in epoch of duration T, and then during the next epoch perform local CPR repair on that GOP via ad-hoc WLAN, while receiving the next GOP from WWAN multicast. Playback buffer delay is hence $2T$. Given this setup, the following questions must be addressed: 1) how should peers be organized into WWAN multicast channels for WWAN distribution and CPR groups for local repair? 2) how to perform joint WWAN source/channel bit allocation for given WWAN multicast and CPR group?

In this section, we present the video source model, network model, and our previously proposed Structured Network Coding (SNC) framework, with which we propose our resource allocation optimization across scalable video layers to address the above two issues. We also discuss how NC-based FEC is performed and how we model CPR capability.

2.1. Video Source Model & Assumptions

We use H.264 SVC for video encoding where *spatial* scalability is enabled. We assume two spatial layers: base layer L_0 and enhancement layer L_1. The base layer video is of QCIF resolution, and combining both layers can provide CIF resolution. Note that although we focus our discussion to two spatial layers for brevity, our model can be extended to multiple spatial layers. A H.264 video stream is a series of GOPs. Each layer in one GOP is composed of a starting I-frame followed by $M-1$ P-frames. Within each spatial layer, the frames can be tail-dropped from the end of the GOP, leading to fewer source coding bits selected. Layer L_i is encoded with source coding rates r_s^i, which is subsequently divided into $R_s^i = \left\lceil \frac{r_s^i}{S_{pkt}} \right\rceil$ packets for transmission, $\mathcal{P}_i = \{p_{i,1}, p_{i,2}, ..., p_{i,R_s^i}\}$. S_{pkt} is the maximum packet size.

2.2. Network Model & Assumptions

We assume peers listening to the same multicast channel experience different WWAN channel conditions, resulting in different subsets of received WWAN packets. For WLAN, though raw transmission rate like 802.11 is relatively large, peers need to contend for the shared medium. In this work, we rely on the underlying 802.11 MAC layer scheduling protocol to resolve the contention. Each peer always has packets to transmit whenever this is a transmission opportunity discovered by the MAC layer. We define R_n as the average number of packets that a peer can receive in an epoch time T.

2.3. Structured Network Coding

We now overview structured network coding (SNC)—method in which WWAN-FEC and CPR repair packets are both generated. Consider first a peer n that is interested in CIF resolution, requiring both QCIF layer packets $\mathcal{P}_0$ and CIF layer packets $\mathcal{P}_1$ in a GOP for decoding. At the instant when there is a transmission opportunity reported from the MAC layer and peer n can transmit a packet, what repair packet should peer n send to its neighbors? Rather than raw received packets from source, we have shown [9] that NC-encoding a repair packet q_n, using raw received *native* packets $\mathcal{G}_n$ from source and repair packets $\mathcal{Q}_n$ from neighbors, can improve packet recovery performance:

$$q_n = \sum_{p_{i,j} \in \mathcal{G}_n} a_{i,j} p_{i,j} + \sum_{q_m \in \mathcal{Q}_n} b_m q_m, \tag{1}$$

where $a_{i,j}$'s and b_m's, random numbers in Galois Field $GF(O)$, are coefficients for the native packets and the received NC-coded CPR packets, respectively. We call this approach *Unstructured Network Coding* (UNC). The shortcoming of UNC is that if a peer receives fewer than $R_s^0 + R_s^1$ *innovative* (not a linear combination of previously received packets) packets, then peer n cannot recover *any* native packets using the received NC packets.

To address UNC's shortcoming, we proposed SNC [3]. By imposing structure on the coefficients, we seek to partially decode at a peer when fewer than $R_s^0 + R_s^1$ innovative packets are received; in particular, if R_s^0 innovative packets are received, one can decode the GOP in QCIF and spatially upsample it to CIF for viewing.

Mathematically, we define two *SNC groups*, $\Theta_0 = \mathcal{P}_0$ and $\Theta_1 = \mathcal{P}_0 \cup \mathcal{P}_1$, where $\Theta_0 \subset \Theta_1$. Corresponding to each group Θ_x is a *SNC packet type* x. Let $g(j)$ be the index of the smallest group that includes spatial layer L_j. Peer n can now generate NC packet $q_n(x)$ of type x given $\mathcal{G}_n$ and $\mathcal{Q}_n$ as:

$$q_n(x) = \sum_{p_{i,j} \in \mathcal{G}_n} U(g(i) \leq x)\, a_{i,j} p_{i,j} + \sum_{q_m \in \mathcal{Q}_n} U(\Phi(q_m) \leq x)\, b_m q_m, \tag{2}$$

where $\Phi(q_m)$ returns the SNC type of received CPR packet q_m, and $U(\mathtt{c})$ evaluates to 1 if clause $\mathtt{c}$ is true, and 0 otherwise. In words, peer n constructs NC packet of type x by linearly combining received or decoded native packets of frames in Θ_x and received NC packets of type $\leq x$. A peer can now decode QCIF layer when $|\mathcal{P}_0|$ innovative packets of type 0 are received.

Each SNC group x is associated with a *transmission time ratio* γ_x, which is the fraction of an epoch time T to transmit packets of SNC group x, i.e., SNC group 0 is transmitted during the first $\gamma_0 T$ time and SNC group 1 is transmitted during the rest of the epoch. Note that in this way the transmission of a CPR packet is deterministic in time once γ is decided.

2.4. NC-based CPR and NC-based FEC

We use SNC for the dual purpose of WLAN-CPR packet recovery and WWAN-FEC loss protection. The process works as follows. WWAN source first appends NC-encoded FEC packets to the source packets. During subsequent local repair, peers perform NC-based CPR and treat the received FEC packets from source the same as repair packets received from other peers through CPR. The benefit of this dual usage of SNC is that a peer can construct and exchange CPR packets without first decoding WWAN-FEC, and peers receiving insufficient number of WWAN packets for WWAN-FEC decoding can nonetheless participate and contribute to CPR. We describe WLAN-CPR and WWAN-FEC in more details next.

2.4.1. WWAN-FEC

WWAN source first determines the number of video frames to be sent at each spatial layers, and groups selected QCIF frames into SNC group Θ_0, and selected QCIF and CIF frames into group Θ_1. For each SNC group Θ_x, appropriate number of SNC packets $q(x)$'s of type x are then generated using native packets $p_{i,j} \in \Theta_x$ as FEC for WWAN transmission:

$$q(x) = \sum_{p_{i,j} \in \Theta_x} c_{i,j} p_{i,j}, \tag{3}$$

where $c_{i,j}$ are random coefficients. Note that WWAN-FEC packets are generated using only native packets in frame group Θ_x, all of which are available at the source.

2.4.2. WLAN-CPR

Suppose there are Ω packets needed to be repaired through CPR and these packets are in the SNC group range from x_s to x_e. The probability that CPR can help deliver the Ω packets can be written as:

$$Q_n(\Omega, x_s, x_e) = \frac{LP_R(x_s, \Omega)}{LP_A(x_s, \Omega)}, \tag{4}$$

where $LP_A(x_s, \Omega)$ is the total number of *all* possible packet loss patterns in SNC groups starting from x_s till SNC group x_e. $LP_A(x_s, \Omega)$ can be recursively calculated using $LP_A(x, \omega)$, the number of packet loss patterns starting from SNC group x till SNC group x_e with a total of ω lost packets.

$$LP_A(x, \omega) = \begin{cases} \sum_{lo}^{hi} LP_A(x+1, \omega - i), & x! = x_e \\ 1, & \text{otherwise} \end{cases} \tag{5}$$

lo is the minimum number of lost packets that must reside in SNC group x, which is calculated as:

$$lo = \max\{0, \omega - \sum_{j=x+1}^{x_e} R_s^j\} \tag{6}$$

hi is the maximum number of lost packets that can be in SNC group x, which is bounded as follows:

$$hi = \min\{\Omega, R_s^x\}. \tag{7}$$

$LP_R(x_s, \Omega)$ is the total number of loss patterns that are *recoverable*, i.e., those loss patterns can be recovered through CPR. $LP_R(x_s, \Omega)$ has the same shape as Eq. (5), with lo and hi updated as

$$lo = \max\{0, \omega - \sum_{j=x+1}^{x_e} N_j\}, \tag{8}$$

$$hi = \min\{\Omega, N_x\}, \tag{9}$$

where N_x is the maximum number of packets in SNC group x given the SNC structure. These N_x packets are *recoverable* packets and can be represented as

$$N_x = \begin{cases} R_s^x, & R_n \sum_{j=x}^{x_e} \gamma_j \geq \Omega \\ \min\{R_s^x, \quad R_n \gamma_x\}, & \text{otherwise} \end{cases} \tag{10}$$

Due to the definition of SNC, we know that all the received CPR packets from SNC group i to x_e can be used to recover packets in SNC group i. Therefore, as long as $R_n \sum_{j=i}^{x_e} \gamma_j \geq \Omega$, *any* number of the Ω lost packets can fall in SNC group i, and they can be recovered. Thus all the R_s^i packets in SNC group i are recoverable packets, which gives the first condition in Eq. (10)

When $R_n \sum_{j=i}^{x_e} \gamma_j < \Omega$, it implies that in SNC group i, there is chance that we cannot hold all the Ω lost packets. The actural number of packets that these SNC groups can hold is the mininum of the two numbers: the number of CPR packets that is available in SNC group i: $R_n \gamma_i$, and the number of recoverable packets in SNC groups i *only*: R_s^i. Note here we are not using any CPR packets of SNC group greater than i to help with SNC group i.

Note also when we plug in $R_s^{x_s}$ in the above equations, $R_s^{x_s}$ needs to be updated as $R_s^{x_s} - 1(x_s, x_e)$, where $1(x_s, x_e)$ evaluates to 0 if $x_s = x_e$, and 1 if x_s is different from x_e. This is used to accommodate the usage of Eq. (4) in different scenarios, as will be shown in the next section.

3. OPTIMAL RESOURCE ALLOCATION FOR COOPERATIVE MULTICAST GROUP USING SVC

With the discussed models and network loss protection mechanism using network coding for both WWAN multicast and WLAN CPR, we now address the questions raised in Section 2. For group formation, we propose to use a *single* WWAN multicast channel and form a corresponding *single* WLAN CPR group for *all* heterogeneous peers requiring video of different resolutions. The reason is twofold. First, a single WWAN multicast channel would mean base layer L_0 is transmitted only once, while creating two separate WWAN multicast groups for QCIF and CIF peers would mean L_0 is transmitted twice, creating bandwidth inefficiency.

3.1. Optimization Objective

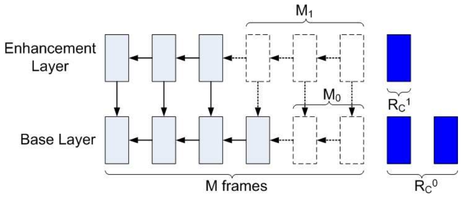


Fig. 1. Two Spatial Layers SVC with NC-FEC.

We first assume among the N peers in the multicast group, N_0 (N_1) of them are subscribed to QCIF (CIF) video. Frame dependencies for two spatial layers are shown in Fig. 1. Among a total of M frames in a GOP, trailing M_0 (M_1) frames will not be transmitted for QCIF (CIF) resolution. Because of spatial dependency, we enforce requirement $M_0 \leq M_1$.

For each layer FEC packets are appended by applying NC to the source packets that are selected for transmission. Given the WWAN transmission budget is fixed, selection of M_0 and M_1 directly influence the possible number of FEC packets that can be appended.

Given the structure above, the expected distortion for the QCIF video peer group is:

$$D_n^{QCIF} = D^{QCIF} - \left(\sum_{i=1}^{M-M_0} d_i^{L_0} \right) \alpha_n^0, \tag{11}$$

where D^{QCIF} is the total distortion if no frame is recovered from the base layer. It is calculated as the reconstructed QCIF frame upsampled to CIF resolution and compared to the original CIF video. $d_i^{L_0}$ is the video distortion reduction for each frame i at the base layer. α_n^0 is the probability that all the packets transmitted in layer L_0 (total $M - M_0$ frames) can be recovered at a peer, either through WWAN multicast or through WLAN-CPR. Note that the frames in the base layer can be recovered either through the decoding of SNC group 0, i.e., base layer itself, or through the decoding of SNC group 1. α_n^0 is related with WWAN-FEC and WLAN-CPR packet recovery capability. The latter is related with the WWAN collective packet loss probability as we discussed in Section 2.

Similarly, the expected distortion for CIF video peer group is:

$$D_n^{CIF} = D^{CIF} - \left(\sum_{i=1}^{M-M_0} d_i^{L_0} \right) \alpha_n^0 - \left(\sum_{i=1}^{M-M_1} d_i^{L_1} \right) \alpha_n^1. \tag{12}$$

where D^{CIF} is the total distortion if no frame is recovered from the base layer and the enhancement layer. $d_i^{L_0}$ is the CIF video distortion reduction for frame i in the base layer. $d_i^{L_1}$ is the *additional* distortion reduction for frame i in the enhancement layer. It is generated by comparing the reconstructed CIF frame to the original CIF frame, minus $d_i^{L_0}$.

Combining Eq. (11), (12), we minimize the total distortion from the two resolution groups as:

$$\min_{M_0,M_1,R_C^i,\Theta_x,\gamma_x} \frac{N_0}{N_0+N_1} D_n^{QCIF} + \frac{N_1}{N_0+N_1} D_n^{CIF}, \tag{13}$$

with total rate constraint as follows

$$\sum_{i=1}^{M-M_0} \left\lceil \frac{r_s^{i,0}}{S_{pkt}} \right\rceil + \sum_{i=1}^{M-M_1} \left\lceil \frac{r_s^{i,1}}{S_{pkt}} \right\rceil + R_c^0 + R_c^1 \;\leq\; \bar{R} \tag{14}$$

3.2. SNC Group Recovery Probability

To assist the derivation for the SNC group recovery probabilities for α_n^0 and α_n^1, we first consider a simplified case where there is only one SNC group and R_s source packets are protected by R_c FEC packets. The probability that the CPR *cannot* recover the single SNC group can be represented as

$$p_{n,grp}(R_s,R_c)=\sum_{i=R_c+1}^{R_s+R_c} \binom{R_s+R_c}{i} l_n^i (1-l_n)^{R_s+R_c-i} p_{n,col}(i,R_c), \tag{15}$$

where $p_{n,col}(i,R_c)$ is the *collective loss probability*—the probability that the collective cannot recover sufficient number of packets for recovery given i packets were lost by peer n via WWAN transmission. $p_{n,col}(i,R_c)$ depends on $p_{n,isuf}(i,R_c)$, the *collective insufficient probability* that insufficient number of packets have been delivered via WWAN to the collective for CPR to operate at all, given peer n has i WWAN losses already:

$$\begin{aligned} p_{n,col}(i,R_c) \;&=\; p_{n,isuf}(i,R_c) \\ &+\; \left[1-p_{n,isuf}(i,R_c)\right]\left[1-Q_n(i-R_c,0,0)\right], \end{aligned} \tag{16}$$

The collective insufficient probability, $p_{n,isuf}(i,R_c)$, can be written as:

$$p_{n,isuf}(i,R_c) = \sum_{j=0}^{i-R_c-1} \binom{i}{j} (1-l'_{n,col})^j (l'_{n,col})^{i-j}, \tag{17}$$

where $l'_{n,col}$ is the *collective loss probability*. In words, (17) states that only j of the i WWAN lost packets by peer n are received by the collective. Hence the collective cannot recover sufficient number of packets for peer n to recover the whole frame group.

Now for two SNC groups, suppose R_s^0, R_s^1 are the source packets *available* for the two SNC groups. Define $C_0(C_1)$ as the event that SNC group $0(1)$ is recoverable. Define $B_0(B_1)$ as the event that packets *only* in SNC group $0(1)$ are recoverable. Obviously $B_0 = C_0 \cup C_1$ and $B_1 = C_1$. We derive the probabilities of the events as follows:

$$\begin{aligned} Pr(\bar{B}_0) &= Pr(\bar{C}_0)Pr(\bar{C}_1|\bar{C}_0) \\ &\approx p_{n,grp}(R_s^0,R_c^0) \times p_{n,grp}(R_s^0+R_s^1-1, R_c^1-1), \end{aligned} \tag{18}$$

where the "-1" indicates that we know SNC group 0 cannot be recovered with their own WWAN-FEC packets, so SNC group 1 must expend at least one WWAN-FEC packet to help SNC group 0.

$$Pr(\bar{B}_1) = Pr(\bar{B}_0) + (1-Pr(\bar{B}_0))Pr(\bar{B}_1|B_0), \tag{19}$$

where

$$\begin{aligned} Pr(\bar{B}_1|B_0) \;&=\; Pr(\bar{C}_1|C_0 \cup C_1) \\ &=\; Pr(\bar{C}_1|C_0)\frac{Pr(C_0)}{Pr(B_0)} \\ &\approx\; p_{n,grp}(R_s^1,R_c^1)\frac{Pr(C_0)}{Pr(B_0)}. \end{aligned} \tag{20}$$

With the derivations above, we have $\alpha_n^0 = 1 - Pr(\bar{B}_0)$ and $\alpha_n^1 = 1 - Pr(\bar{B}_1)$. Note that if the SNC optimization returns only one SNC group, then $\alpha_n^0 = \alpha_n^1$.

Eq. (13) involves the optimization of four sets of variables: number of dropping packets M_i's, NC groups Θ_x's, WWAN-FEC R_c^i's, and γ_x's. Exhaustively searching for the best solution has exponential complexity and is not scalable when spatial layers number increases. Hence we use the following method to solve the problem.

We iterate through all possible combinations of M_0 and M_1. For each combination, we find the R_s^i, the number of packets in each layer given our video is pre-encoded. We also find the maximum number of FEC packets can be generated for the whole video. With R_s^i and the number of FEC packets, we allocate FEC packets and γ to each SNC group by doing a local search optimization, i.e., starting from evenly allocating the resources to all the SNC groups, we first increase resource for one SNC group and decrease for the others. Once the total video distortion is no longer reducing, we switch the direction and decrease the resource for the SNC group and increase for the others. We do this for each SNC group. The resource allocation scheme that results in the most distortion reduction is returned.

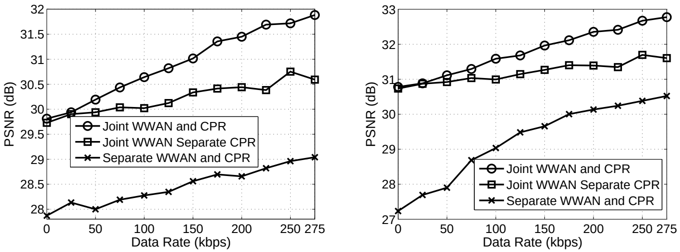
4. EXPERIMENTATION

Two test video sequences `city` and `foreman` were used for simulations with both QCIF (176 × 144) and CIF (352 × 288) resolutions. The GOP size was chosen at 15 frames: one I-frame followed by 14 P-frames, for both of the QCIF and CIF spatial layers.

We performed simulations using QualNet. The underlying CPR scheduling was 802.11 CSMA/CA with broadcast enabled. Peers always had packets to transmit whenever the MAC layer decided to make a transmission. We set up a compact CPR network by uniformly placing 25 QCIF video peers and 25 CIF video peers in a $200 \times 200m^2$ area and the WLAN transmission range was set to 280m so that each transmission could cover all the rest peers. CPR repairs one GOP at a time: after a media source transmits a GOP via WWAN in time duration T, peers exchange CPR packets via WLAN to repair this GOP in time T during WWAN multicast of the next GOP. Given one GOP was 15 frames and video was encoded at 15 fps, T was 1s. The maximum packet size was set to 1000 bytes.

We compared the performance of our single WWAN multicast channel, single CPR collective optimization scheme with two other schemes which we call *joint-WWAN* and *separate-WWAN*. In both of these two alternate schemes, we assumed peers subscribed to different video resolutions were in different CPR groups. In *joint-WWAN*, there was only one multicast channel and all WWAN transmission budget was used for the CIF video group while the QCIF video group utilized the base layer resource allocation from the CIF video. In *separate-WWAN*, there were two multicast channels that were completely separated and the WWAN transmission budget was shared between the two channels, i.e., $\bar{R}^{QCIF} + \bar{R}^{CIF} = \bar{R}$. For both *joint-WWAN* and *separate-WWAN*, since peers in different resolution groups were in different CPR groups, each CPR group will not help the other group in delivering the packet.

As shown in Fig. 2a, the top two curves are far apart from the bottom curve. This is because the resource allocation for separate-WWAN is distinct for the two multicast channels and the WWAN transmission budget cannot be reused and hence wasted, resulting in bad performance. Our proposed scheme is better than joint-WWAN due to the collaboration between the two CPR groups by merging the CPR collectives together. At its maximum we get 1.29 dB improvement over the joint-WWAN scheme and 2.84 dB improvement over the separate-WWAN scheme. In Fig. 2b, we observe similar trend for



a) *City* b) *Foreman*

Fig. 2. Joint WWAN-CPR optimization versus joint WWAN separate CPR optimization.

the `foreman` sequence and the PSNR improvements were 1.17 dB and 2.25 dB, comparing to the joint-WWAN and separate-WWAN schemes respectively.

5. CONCLUSION

In this paper, we propose an optimal resource allocation scheme of WWAN scalable video multicast to CPR collectives. In our scheme, peers belonging to different resolution groups are optimized jointly to take advantage of the collaboration between CPR groups and thus less contention for the peers. We show through simulations that our joint optimization can improve video quality by 2.84 dB comparing to a scheme where both WWAN and WLAN CPR are separately performed for heterogeneous peers.

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