Spatial and Temporal Packet Recovery Schemes for DVB-H Systems through IP-Relay Wireless Networks

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Abstract—The DVB-H standard has been defined to provide digital video broadcast to mobile handheld devices. However, without a request channel, a handheld device may encounter data loss and thus it requires an additional recovery architecture to relieve this problem. In this paper, we follow the DVB-IPDC standard and propose combining a DVB-H system with an IP-relay wireless network. A handheld device losing DVB-H data can thus request the relay network for retransmission. Under this architecture, we identify two critical issues, *group packet loss (GPL)* and *broadcast data handover (BDH)*. The GPL problem occurs when there are bursty requests for retransmissions of the same data with high spatial and temporal locality, causing network congestion. The BDH problem occurs when these requesting devices move out of their current serving cells. In this paper, we propose a *bulk request recovery (BRR)* scheme to solve these problems by exploiting spatial and temporal locality of recovery requests. Our scheme can efficiently reduce duplicate requests and schedule retransmissions of lost packets, so both GPL and BDH problems are relieved. Simulations results are also presented to verify the effectiveness of our result.

Index Terms—broadcasting network, DVB-H, error recovery, scheduling, video broadcast, wireless network.

I. INTRODUCTION

The *DVB-H (digital video broadcasting–handheld)* standard [1], [2] has been proposed to support digital video broadcast for mobile *handheld devices (HDs)*. It adopts a mandatory time slicing technology and an optional MPE-FEC (multi-protocol encapsulation–forward error correction) method to broadcast multimedia contents to HDs. With time slicing, datagrams are transmitted as data bursts in small time slots. On the other hand, MPE-FEC can help tolerate some degrees of noises.

However, HDs are more vulnerable to packet loss due to their hardware constraints and high mobility [3]. There are two possible solutions. One solution is to retransmit lost packets using the DVB-H return channel. However, this may complicate the design of the DVB-H server because it will need to take care of both broadcast and retransmissions. Not only retransmissions need to share the bandwidth with regular broadcast [4], but also the return channel is relatively small. Another solution is *DVB-IPDC (IP datacast over DVB-H)* [5], which requires to provide a separate IP-based wireless network to offer a bi-directional interactive communication channel to
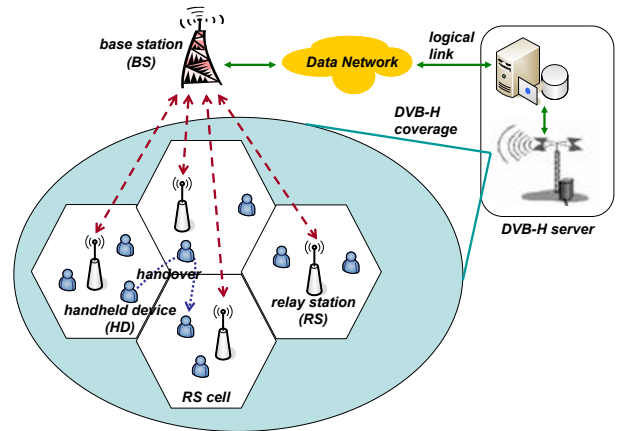

Fig. 1: The integrated architecture of a DVB-H system and an IP-relay wireless network.

request and send lost packets. This solution is more feasible because the broadcast and retransmissions are separated.

In this paper, we adopt the DVB-IPDC solution with a broadband wireless channel such as WiMAX [6], [7] to support packet recovery, as shown in Fig. 1. HDs will roam inside the coverage of both DVB-H and WiMAX networks. The DVB-H server continuously broadcasts digital video to HDs. However, since HDs are more vulnerable to broadcast packet loss and corruption, HDs can request nearby *relay stations (RSs)* to retransmit lost packets. Under this architecture, we identify two critical issues, *group packet loss (GPL)* and *broadcast data handover (BDH)*. The GPL problem occurs when there are bursty requests for retransmissions of the same data with high spatial and temporal locality. Thus, some RSs may be badly congested by incoming requests and outgoing retransmissions of lost packets. Such phenomena may even cause many packets to miss their deadlines. The BDH problem occurs when the requesting HDs handover to neighboring cells after making their requests. Duplicate requests and retransmissions thus may further congest the relay network.

To solve these problems, we should inhibit HDs from submitting duplicate requests and properly deliver the lost

packets. We observe that recovery requests may exhibit some spatial and temporal locality. In the space domain, neighboring HDs may submit similar requests because they are interfered by the same noises. Moreover, the handover behavior of the HDs will extend this spatial feature to neighboring cells. In the time domain, HDs in the same cell may lose a similar sequence of packets because interference sources often exist for a period of time. Pre-fetch and pre-downloading are potential solutions. Therefore, there is a large space to merge redundant requests and retransmissions to improve efficiency.

In this paper, we propose a *bulk request recovery (BRR)* scheme by considering spatial and temporal locality of recovery requests. Each RS will collect HDs' requests for a short period of time, and then broadcast a *group-acknowledgement (gACK)* to announce what requests have already been received by the RS. This gACK exploits spatial and temporal locality to inhibit HDs from submitting duplicate requests, in both space and time domains. Then, the RS schedules and packs these requests into a bulk request and sends to the *base station (BS)*, which will in turn forward them to the DVB-H server. To exploit spatial locality, the BS will use broadcast to send these lost packets to neighboring RSs. In this way, the overheads are reduced. To exploit temporal locality, the BS will pre-fetch some correlated packets in the time domain from the DVB-H server to reduce the downloading latency. Our major contributions are two-fold. First, we address the GPL and BDH problems in an integrated architecture of DVB-H systems and IP-relay wireless networks. Second, we develop a novel BRR scheme to solve these problems by exploiting spatial and temporal locality of recovery requests and packet retransmissions. Simulation results have shown that BRR can efficiently reduce the amount of packet retransmissions.

In the literature, several studies have considered combining DVB-H systems with wireless networks. Automatic configuration of an IP-based interworking model among WLAN, 3G, and DVB-H is addressed in [8]. But it does not discuss the retransmission issue. Reference [9] proposes a multicast protocol to recover DVB-H loss with IEEE 802.11 WLANs. The work [10] discusses how to support mobile TV services by combining DVB-H and 3G networks, and evaluates the impact of delivering parity data through 3G networks. Reference [11] also considers a hybrid system of DVB-H and cellular networks, and discusses how to retransmit the corrupted data through the cellular network. However, all these works do not consider the GPL and BDH problems discussed in this paper.

The rest of this paper is organized as follows. Section II presents our system architecture. Section III proposes our BRR scheme. Section IV gives our simulations results. Conclusions are drawn in Section V.

II. INTEGRATED ARCHITECTURE OF DVB-H SYSTEMS AND IP-RELAY WIRELESS NETWORKS

Fig. 1 shows the integrated architecture of a DVB-H system and an IP-relay wireless network. Each HD is equipped with a DVB-H receiver and a wireless interface. Here, we adopt WiMAX as the IP-relay network, which consists of multiple
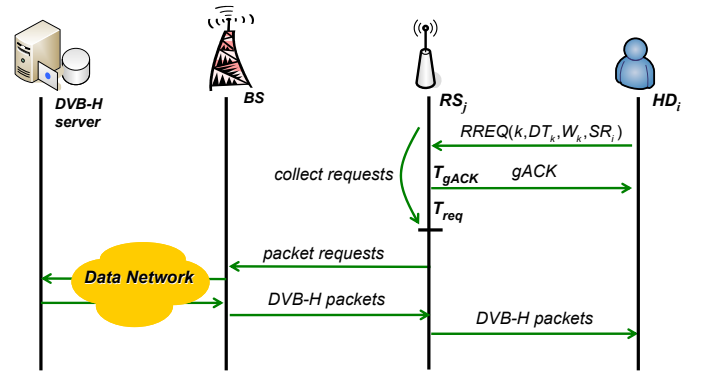

Fig. 2: The proposed BRR scheme.

BSs that can communicate with the DVB-H server through a data network. Each BS can support multiple RSs. HDs will continuously receive the DVB-H broadcast data. When an HD experiences packet loss, it can request a neighboring RS to resend these lost packets. Then, the BS will collect these requests and query the DVB-H server for the lost packets. Finally, the BS will transmit them to the requesting HDs through the corresponding RSs.

III. THE BULK REQUEST RECOVERY (BRR) SCHEME

As pointed out earlier, recovery requests from HDs may exhibit some spatial and temporal locality. Neighboring HDs will likely lose the similar sequences of DVB-H packets since they may experience the same noises over the same durations. As these HDs handover to other cells, neighboring RSs may also observe the same locality. With these observations, we propose our BRR scheme below (refer to Fig. 2).

1) Each HD_i has three states, as shown in Fig. 3(a). Initially, HD_i is in the *listening* state, where it does nothing but continuously receives broadcast packets from the DVB-H server. However, when HD_i detects the loss of any DVB-H packet, it switches to the *submitting* state.

2) In the submitting state, HD_i maintains a buffer B_i to store the indices of the lost packets and then submits recovery requests according to B_i's content. Specifically, suppose that HD_i loses a DVB-H packet p_k, it will store the index of p_k (i.e., k) in B_i and then unicast a recovery request $RREQ(k, DT_k, W_k, SR_i)$ to its associating RS_j, where DT_k is p_k's due time, W_k is p_k's weight, and SR_i is HD_i's subscriber right. Here, we use DT_k, W_k, and SR_i to reflect the priority of packet p_k to HD_i. (For example, W_k may range from 1 to 4 and SR_i may range from 1 to 3. A higher value means a higher priority.) After confirming that RS_j has received the request (by receiving a lower-layer ACK message from RS_j), HD_i will remove the index of p_k from B_i. HD_i will repeat the above operation if there are other entries in B_i. However, two cases will make HD_i leave the submitting state: First, a timer T_{req} expires. Second, RS_j does not reply after several tries of submissions. We will discuss these two cases later in step 6.

(a) the case of each HD_i
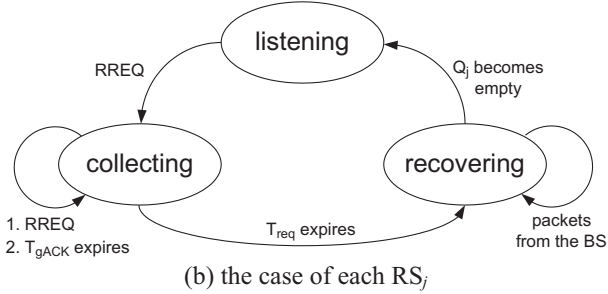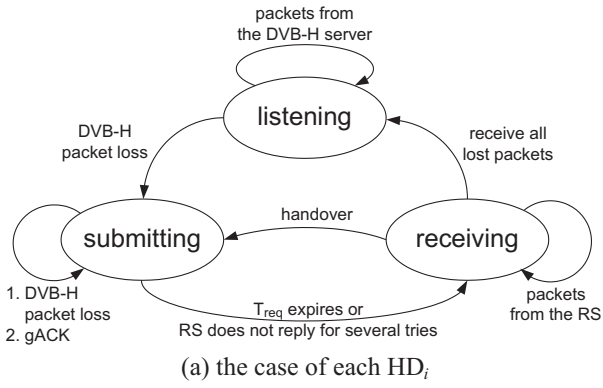

(b) the case of each RS_j

Fig. 3: State transition diagrams of HDs and RSs.

3) Each RS_j also has three states, as shown in Fig. 3(b). Initially, RS_j is in the *listening* state, where it will continuously listen if there is any recovery request from any HD. If so, RS_j will switch to the *collecting* state.

4) In the collecting state, RS_j sets up a timer T_{gACK} and maintains a counter c_j to record the number of recovery requests that it has received. Then, two operations will be conducted:

a) RS_j keeps on collecting recovery requests from HDs. These requests are maintained in a *request queue* Q_j, in which each entry consists of five-tuple $(k, minDT_k, N_k, W_k, PF_k)$, where N_k is the number of HDs that have requested packet p_k and PF_k is the expected profit of rebroadcasting p_k. Supposing that devices HD_{α_1}, HD_{α_2}, $\cdots$, and $HD_{\alpha_{N_k}}$ have requested p_k with due time $DT_k^{\alpha_1}$, $DT_k^{\alpha_2}$, $\cdots$, and $DT_k^{\alpha_{N_k}}$, we set $minDT_k = \min_{i=1}^{N_k}\{DT_k^{\alpha_i}\}$. Also, one way to define the profit is $PF_k = W_k \times \sum_{i=1}^{N_k} SR_{\alpha_i}$.

b) When c_j exceeds a predefined threshold δ_{gACK} or timer T_{gACK} expires, RS_j will set up another timer T_{req} and broadcast a *group-acknowledgement* $gACK((\beta_1, \beta_2, \cdots, \beta_{|Q_j|}), (\beta_{|Q_j|+1}, \beta_{|Q_j|+2}, \cdots, \beta_{|Q_j|+\gamma}), T_{req})$, where $(\beta_1, \beta_2, \cdots, \beta_{|Q_j|})$ are the indices of the lost packets recorded in Q_j, $(\beta_{|Q_j|+1}, \beta_{|Q_j|+2}, \cdots, \beta_{|Q_j|+\gamma})$ are the indices of the predicted lost packets, and T_{req} is the expected time that RS_j will stop collecting the recovery requests sent from HDs. RS_j will also create the corresponding entries of these predicted

packet indices $\beta_{|Q_j|+1}$, $\beta_{|Q_j|+2}$, $\cdots$, and $\beta_{|Q_j|+\gamma}$ in Q_j. The due time of these new entries may be approximated by a linear interpolation. One way to define the weight and profit values of these new entries is to take the average weight and profit of original entries.

When timer T_{req} expires, RS_j will switch to the *recovering* state.

5) On receiving $gACK$, each HD_i in the submitting state removes those packet indices that appear in $gACK$ from its buffer B_i. Then, before timer T_{req} expires, HDs will still submit their requests to RS_j. Here, we can exploit spatial and temporal locality to reduce the number of submitting recovery requests by $gACK$. In the space domain, $gACK$ will inhibit HDs from submitting duplicate requests. When one HD successfully submits the request of lost packet p_k, other neighboring HDs that also lose p_k but have not submitted the corresponding requests yet will cancel their submissions when they hear $gACK$. In the time domain, we expect HDs will lose a continuous sequence of packets in the near future if they have already done so. For example, supposing that a continuous sequence of packet indices $(\beta_{|Q_j|} - k, \beta_{|Q_j|} - k + 1, \cdots, \beta_{|Q_j|})$ have appeared in Q_j, RS_j will add the following packet indices $(\beta_{|Q_j|} + 1, \beta_{|Q_j|} + 2, \cdots, \beta_{|Q_j|} + \gamma)$ in $gACK$, where $\gamma < k$. In this way, HDs will cancel some of their future submissions if their requests possess temporal locality.

6) For each HD_i in the submitting state, after timer T_{req} expires, it changes to the *receiving* state to wait for the retransmission of lost DVB-H packets from RS_j. In this case, if there still remains packet indices in its buffer B_i, HD_i clears B_i since these packets may exceed their deadlines. However, in the case that an HD_i does not hear $gACK$ in step 5, it will still submit its requests to RS_j even though timer T_{req} has expired. In this case, RS_j will not confirm the receipt of these requests. After several tries of failed submissions, HD_i will realize that timer T_{req} has expired and thus it will switch to the receiving state. An HD_i in the receiving state will continue receiving DVB-H packets from the RS, and will go back to the listening state when it has received all its lost DVB-H packets. Note that it is possible for HD_i to go back to the submitting state when a handover event occurs, and we will discuss this later.

7) For each RS_j in the collecting state, after timer T_{req} expires, it will switch to the *recovering* state and clear its counter c_j. Then, two operations will be conducted:

a) RS_j sorts the entries of Q_j in an increasing order of packets' due time DT_k. When two packets have the same due time, we use their profits PF_k to break the tie. The packet with a larger profit will have a higher priority. Fig. 4 gives an example.

b) RS_j dequeues m packets from Q_j at a time and transmits them to the BS. After collecting packet

p_k	5	4	3	1
DT_k	1009	1009	1007	1005
N_k	2	1	1	1
W_k	3	4	2	4
PF_k	15	12	2	12

$W_k = 3$ $W_k = 4$ $W_k = 2$ $W_k = 4$
$SR = 3+2$ $SR = 3$ $SR = 1$ $SR = 3$

p_k	4	5	3	1
DT_k	1009	1009	1007	1005
N_k	1	2	1	1
W_k	4	3	2	4
PF_k	12	15	2	12

$W_k = 4$ $W_k = 3$ $W_k = 2$ $W_k = 4$
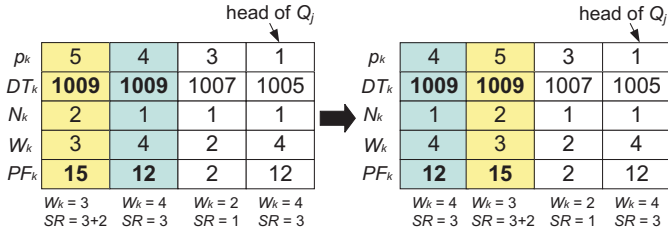$SR = 3$ $SR = 3+2$ $SR = 1$ $SR = 3$

Fig. 4: An example of scheduling the request queue Q_j.

requests from RSs, the BS will query the DVB-H server for the lost packets, through the data network. Then, the BS will transmit these DVB-H packets to the requesting RSs. Here, we can also exploit spatial and temporal locality to reduce the transmission amount and latency of DVB-H packets from the BS to RSs. In the space domain, we can first group neighboring RSs into clusters. Then, for each cluster, the BS will broadcast their requesting DVB-H packets together. Since packet requests of neighboring cells may overlap with each other (due to spatial locality), the amount of DVB-H packets broadcasted by the BS can thus be reduced. In the time domain, when the BS finds that RSs request a continuous sequence of DVB-H packets, it can pre-fetch the following packets from the DVB-H server. In this way, the latency to reply packets to RSs can be reduced.

RS_j will repeat operation (b) until Q_j becomes empty. In this case, RS_j will go back to the listening state.

We then discuss the handover issue. When an HD_i submits its recovery requests to an RS_j but later handovers to another RS_l, HD_i will switch to the submitting state and try to resubmit its requests to RS_l. However, due to spatial locality, some HDs in RS_l's cell may have already submitted the same requests. Thus, by step 5, HD_i would cancel its submissions when it hears $gACK$ sent by RS_l. In addition, in step 7, the BS will broadcast the requesting DVB-H packets to neighboring RSs. This also guarantees that HDs can receive their requesting packets when they handover to adjacent cells.

Fig. 5 gives an example of the BRR scheme, where each RS dequeues two packets at one time (i.e., $m = 2$). Suppose that HD_3 handovers from RS_1 to RS_2 after submitting a recovery request of packet p_1. In Fig. 5(a), after RS_2 broadcasts $gACK$, HD_3 will cancel its submission because p_1 has already been requested by HD_5. Then, RS_1 and RS_2 will schedule their request queues and send the requests $RREQ(2,1)$ and $RREQ(1,4)$ to the BS, respectively. After obtaining packets p_1, p_2, and p_4 from the DVB-H server, the BS will broadcast them to RS_1 and RS_2, as shown in Fig. 5(b). Since p_1 is requested by both RS_1 and RS_2, we can avoid duplicate retransmissions and thus reduce the amount of DVB-H packets transmitted by the BS.

We finally comment on the timing for an RS_j to broadcast $gACK$. Recall that RS_j will broadcast $gACK$ when either its

(a) submit recovery requests
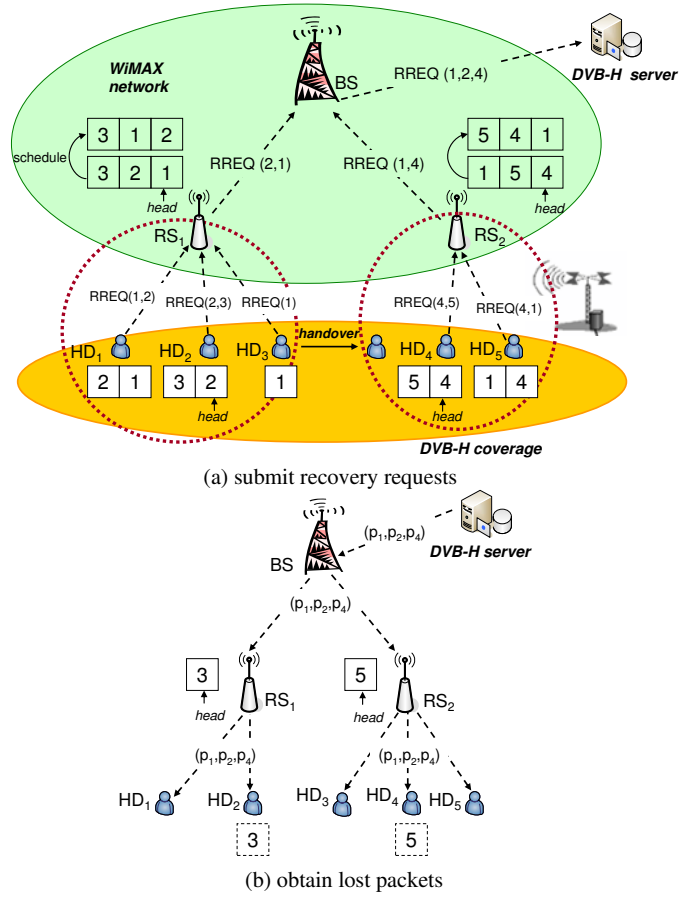
(b) obtain lost packets

Fig. 5: An example of the BRR scheme.

timer T_{gACK} expires or $c_j > \delta_{gACK}$. There are two possible scenarios. In the first scenario, all serving HDs submit their requests very sparsely. In this case, it means that the recovery requests exhibit very less spatial and temporal locality, so RS_j prefers broadcasting $gACK$ after collecting more requests. Since c_j may be always less than δ_{gACK} before T_{gACK} expires, RS_j can thus collect more requests at the expiration of T_{gACK}. In the second scenario, some HDs submit a continuous sequence of requests (i.e., high temporal locality) or many HDs submit their requests in a short duration (i.e., high spatial locality). In this case, since c_j will exceed δ_{gACK} before T_{gACK} expires, RS_j can thus fast broadcast $gACK$ to reflect the spatial and temporal locality of recovery requests.

IV. PERFORMANCE EVALUATION

In this section, we verify the effectiveness of our BRR scheme by simulations. We measure the average amount of packets delivered from an RS to its serving HDs, under different distributions of DVB-H packet loss $\mathcal{E}$ and locality features $\mathcal{L}$ of recovery requests. Specifically, the distribution $\mathcal{E}$ indicates the necessity of submitting recovery requests by HDs, while the distribution $\mathcal{L}$ indicates the inhibited submissions of recovery requests after the RS broadcasts $gACK$. In the simulations, we assume that $\mathcal{E}$ and $\mathcal{L}$ are normal distributions

and independent with each other. We set $\mathcal{E}$ and $\mathcal{L}$ as follows:
(1) packet loss (skew left): $\mathcal{E}(x = 0 \sim T, \mu = \frac{1}{4}T, \sigma = \frac{1}{5}T)$,
(2) packet loss (balance): $\mathcal{E}(x = 0 \sim T, \mu = \frac{1}{2}T, \sigma = \frac{1}{5}T)$,
(3) packet loss (skew right): $\mathcal{E}(x = 0 \sim T, \mu = \frac{3}{4}T, \sigma = \frac{1}{5}T)$,
(4) locality (middle): $\mathcal{L}(x = 0 \sim T, \mu = \frac{1}{2}T, \sigma = \frac{1}{6}T)$, (5)
locality (late): $\mathcal{L}(x = 0 \sim T, \mu = \frac{3}{4}T, \sigma = \frac{1}{6}T)$, where x,
μ, and σ are variable, mean value, and standard deviation of
the distribution, respectively, and $T = T_{gACK} + T_{req}$. For
the distribution $\mathcal{E}$, three cases of *skew left*, *balance*, and *skew
right* indicate that the most packet loss occur at $0.25T$, $0.5T$,
and $0.75T$, respectively. For the distribution $\mathcal{L}$, two cases of
middle and *late* indicate that the most locality of recovery
requests occur at $0.5T$ and $0.75T$, respectively.

Fig. 6 shows the transmission amount of lost packets under
different distributions of $\mathcal{E}$ and $\mathcal{L}$. When BRR is not adopted,
HDs will sequentially submit their recovery requests to the
RS (even though the requests have already been submitted
by other HDs) and the RS will then unicast the lost packets
to the requesting HDs. The length of T_{gACK} is set to 0,
$0.1T$, $0.2T$, $\cdots$, and T. In Fig. 6, we can observe that the
proposed BRR scheme can significantly reduce the amount
of packet retransmissions, thereby conserving the network
bandwidth. BRR can reduce the most packet retransmissions
in the cases of locality (middle) and packet loss (skew right)
in the simulations. The capability of such reduction depends
on the locality of recovery requests. In particular, the lowest
points of three cases of skew left, balance, and skew right
in Fig. 6(a) locate at $T_{gACK} = 0.4T$, $T_{gACK} = 0.5T$,
and $T_{gACK} = 0.6T$, respectively, which are all close to the
most locality of recovery requests (i.e., $0.5T$). Similarly, in
Fig. 6(b), the lowest points of three cases of skew left, balance,
and skew right locate at $T_{gACK} = 0.6T$, $T_{gACK} = 0.7T$, and
$T_{gACK} = 0.8T$, respectively, which are all close to the most
locality of recovery requests (i.e., $0.75T$).

V. CONCLUSIONS

The DVB-H system provides the service of digital video
broadcast to handheld devices in a mobile environment, but it
suffers from a more serious packet loss problem. In this paper,
we propose combining a DVB-H system with an IP-relay
wireless network to support the recovery mechanism. Under
the proposed architecture, we have addressed two important
GPL and BDH problems, and developed a novel BBR scheme
to solve these two problems. Our BRR scheme exploits the
spatial and temporal locality of recovery requests, and can
efficiently reduce duplicate submissions of recovery requests
while merging retransmissions of lost packets. It is verified
that our BRR scheme can significantly reduce the transmission
amount of lost packets by simulations.
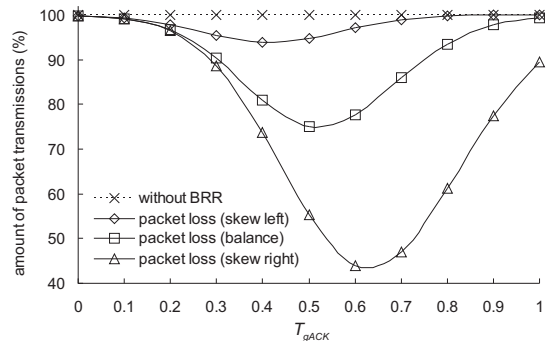
(a) locality (middle)
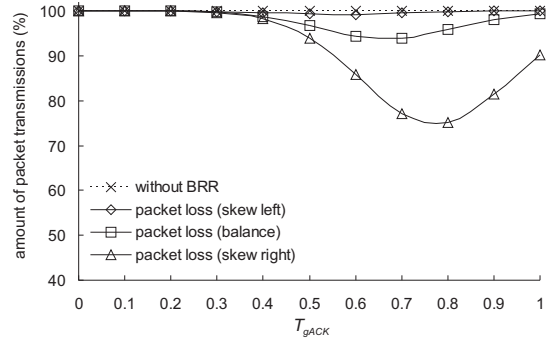
(b) locality (late)

Fig. 6: The transmission amount of lost packets under different
distributions of $\mathcal{E}$ and $\mathcal{L}$.

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