Data Recovery Schemes in Mobile Broadcasting Services

Wen-Hsin Yang, You-Chiun Wang, and Yu-Chee Tseng

Abstract—The mobile broadcasting services such as mobile *television (TV)* and interactive social TV become more popular in wireless broadcasting networks and attract a lot of research attention in pervasive computing. However, due to the error-prone nature of wireless broadcast, how to efficiently recover packet loss at mobile devices is a big challenge. To solve this problem, many research efforts suggest adopting another IP-based wireless network to handle packet recovery. In particular, mobile devices are equipped with two interfaces: one for the broadcast network and the other for such a recovery network. Mobile devices will continually receive the broadcasting content from the broadcast network. When packets are lost in the broadcast network, these mobile devices will ask the recovery network for data retransmissions. In this way, the broadcast network can incur less computation complexity because it does not need to simultaneously deal with the regular broadcasting and the retransmission jobs. Taking the *digital video braodcasting–handheld (DVB-H)* system as an example, this chapter introduces three types of data recovery schemes for mobile broadcasting services. First, the DVB-H system is integrated with a cellular network, where the parity data are transmitted through either the DVB-H channel or the cellular channel for data recovery. Second, a WiMAX network is adopted to support both the request submission sent from the mobile devices and the packet retransmission to these mobile devices. Third, mobile devices will organize a wireless ad hoc network to exchange the lost DVB-H packets to realize data recovery through peer-to-peer communications.

Index Terms—broadcast, data recovery, DVB-H, DVB-IPDC, peer-to-peer communication, wireless network.

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1 INTRODUCTION

In the last decades, various mobile broadcasting technologies are developed to enrich the pervasive computing environments. Not only have many broadcasting networks such as DVB-H [1], ATSC-M/H [2], DMB [3], and MediaFLO [4] been widely deployed, but various mobile devices such as smart phones are also developed to receive the corresponding mobile broadcasting services such as mobile *television (TV)* and interactive social TV.

This chapter aims at a *digital video broadcasting–handheld (DVB-H)* system, which is developed to support the broadcasting service of IP multimedia content such as digital TV programs to mobile devices [5], [6]. DVB-H is based on the successful DVB-T (terrestrial) system with some special designs for mobile devices. For example, DVB-H adopts a time-slicing technique to reduce the energy consumption of mobile devices. However, because mobile devices are more vulnerable to packet loss in a wireless environment, it is necessary to provide some data recovery mechanisms [7]. There are three possible mechanisms:

1) To protect DVB-H packets against multipath fading or interference, some *error correction codes* can be appended in these packets. In this way, when few bits of a DVB-H packet are corrupted during transmission, the mobile device could fix these bits by the error correction codes. However, when the DVB-H packets are seriously corrupted, it is necessary to retransmit these packets. Besides, appending the error correction codes will increase the communication cost because the packet lengths are extended.
2) DVB-H provides a narrow *return channel* for mobile devices to feed back short control messages. Mobile devices may also use this return channel to notify the DVB-H server of packet loss. Then, the server can retransmit these DVB-H packets through the broadcasting channel. However, the return channel is quite narrow so that mobile devices may not be allowed to transmit a large number of requests. In addition, the DVB-H server could be overloaded because the server has to deal with both the regular broadcasting and the retransmissions of lost packets [8].
3) The *IP datacast over DVB-H (DVB-IPDC)* standard [9], [10] is developed to support the interaction mechanism of a DVB-H system. DVB-IPDC relies on a separate IP-based wireless network to provide bidirectional communications between mobile devices and the DVB-IPDC server. Such a network can also support the delivery of requests from the mobile devices and the retransmissions of lost packets to these mobile devices. In particular, there are two coexisting networks: one is the DVB-H network and the other is a recovery network. Mobile devices will continually receive the broadcasting content from the DVB-H network. However, when packets are lost in the DVB-H network, the mobile devices can request the recovery network to retransmit these DVB-H packets.

Many research efforts follow the DVB-IPDC architecture to realize data recovery in a DVB-H system by adopting an IP-based wireless network to serve as the recovery network. This chapter discusses three types of data recovery schemes in the DVB-H system:

1) A cellular network such as the 3G system or the *universal mobile telecommunications system (UMTS)* can be adopted to support bidirectional communications between mobile devices and the DVB-IPDC server. However, because the bandwidth of the cellular network is usually narrow, the parity data or the lost DVB-H packets may be (re)transmitted through either the DVB-H network or the cellular network. Through

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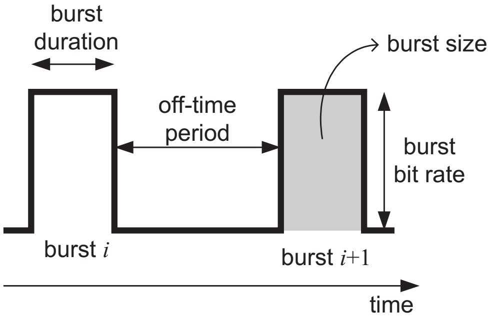

Fig. 1: The time slicing technique of a DVB-H system. Each cycle contains one burst duration and one off-time period. The mobile device will synchronize to the bursts that transmit its desired multimedia data and turn off its receiver during each off-time period. The maximum size of each burst is 2M bits.

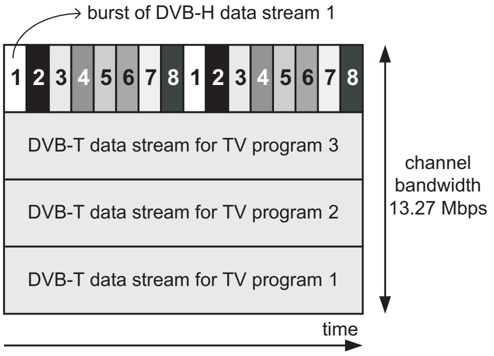

Fig. 2: Deliver DVB-T and DVB-H data streams through a common channel. Each DVB-T data stream uses a quarter of the channel bandwidth. Then, eight DVB-H data streams are multiplexed and use the remaining channel bandwidth for transmission.

the uplink channel of the cellular network, mobile devices can feed back their channel situations to the DVB-IPDC server to decide which network (DVB-H or cellular) should be adopted to conduct data recovery.

2) The DVB-H system can integrate with a WiMAX network for data recovery. Since the WiMAX network possesses a wider bandwidth, both the request submissions from mobile devices and the retransmissions of lost DVB-H packets can be delivered through the WiMAX network. However, the *group packet loss (GPL)* and the *broadcast data handover (BDH)* problems will arise due to the highly spatial or temporal correlation of the lost DVB-H packets. To solve both problems, the group acknowledgement scheme can be adopted.
3) When the infrastructured recovery network is not available, mobile devices can organize a wireless ad hoc network to exchange the lost DVB-H data. In particular, when a mobile device loses some DVB-H packets, this mobile device can query its neighboring devices for sharing these packets. Then, the packet retransmissions of lost DVB-H data can be realized in a peer-to-peer communication manner.

The rest of this chapter is organized as follows: Section 2 overviews the DVB-H standard, which includes the forward error correction scheme and the DVB-IPDC extension. Section 3 discusses the data recovery schemes by integrating the DVB-H system with a cellular network. In Section 4, a data recovery scheme in the hybrid DVB-H and WiMAX network is introduced. Section 5 addresses how to realize data recovery in a peer-to-peer communication manner among mobile devices. Finally, Section 6 concludes this chapter.

2 DVB-H SYSTEMS

DVB-H is developed from the DVB-T standard designed for the fixed and in-car reception of digital TV programs. To provide the same service for mobile devices, the DVB-H system employs a discontinuous transmission technique, called *time slicing*, to broadcast multimedia data to mobile devices. With the time slicing technique, multimedia data can be periodically transmitted through *bursts*, as shown in Fig. 1. Each burst indicates the time interval between two bursts of the same service. Therefore, mobile devices can synchronize to the bursts of their desired services (refer to the *burst duration*) and turn off their receivers when the bursts of other services are transmitting (refer to the *off-time period*). In spite of the discontinuous transmissions, mobile devices can still enjoy a constant data rate. The maximum allowable size of each burst is 2M bits. By the time slicing technique, the energy consumption of mobile devices can be significantly reduced, as compared with DVB-T systems. In addition, the off-time periods can also provide smooth handover when a mobile device move from one service cell to another cell.

DVB-H is backward compatible to the DVB-T system. Both DVB-H and DVB-T data streams can be simultaneously transmitted through the same channel. Fig. 2 gives an example of the service multiplex in a common DVB-T/DVB-H channel. The total channel bandwidth is 13.27 Mbps and one quarter of the channel is used to transmit eight DVB-H data streams. Then, the remaining channel bandwidth is shared among three DVB-T data streams.

Since bursts may be prone to error due to the wireless broadcast, the DVB-H standard adopts the *forward error correction (FEC)* mechanism to protect these bursts. On the other hand, the DVB-IPDC extension is proposed to handle the situation when data retransmissions are necessary. Below, we introduce FEC and DVB-IPDC.

2.1 Forward Error Correction (FEC)

To increase the robustness of data transmissions, two optional FEC mechanisms are proposed in the data link layer and the application layer of a DVB-H system. These FEC mechanisms are adopted to recover erroneous data at mobile devices (without data retransmission) but they cannot cooperate with each other. In particular, when the *data link layer FEC (LL-FEC)* is adopted, the *application layer FEC (AL-FEC)* should be disabled, and vice versa.

In the LL-FEC mechanism, bursts are protected by the *Reed-Solomon (RS) codes* [11], which are non-binary cyclic error-correcting codes used to describe a systematic manner to detect and correct multiple random symbol errors. Specifically, each burst consists of several *multi-protocol encapsulation (MPE) sections*, where each MPE section encapsulates one IP packet with a 12-byte header and a 4-byte *cyclic redundancy check (CRC-32)* tail. In addition, the RS parity data are also encapsulated into MPE-FEC sections and formed as a part of one *MPE-FEC frame*. An MPE-FEC frame is composed of one *application data table* and one *RS data table*, as shown in Fig. 3. The application data table encapsulates the IP data packets (possibly with padding) while the RS data table stores the corresponding parity

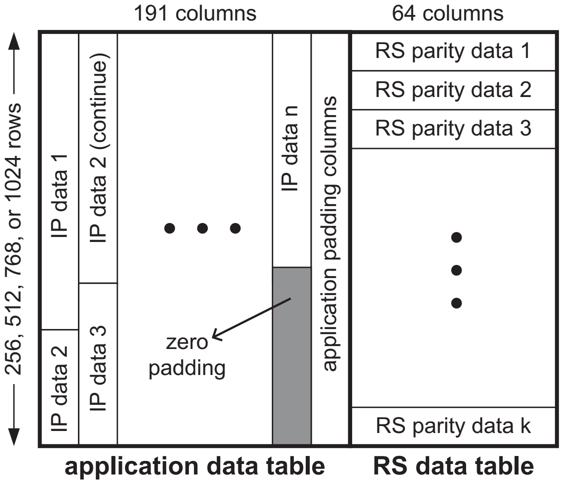

Fig. 3: The MPE-FEC frame used in the LL-FEC mechanism. Each MPE-FEC frame is composed of one application data table that encapsulates multiple IP data packets (and possibly with zero-bit padding in the end) and one RS data table that contains the corresponding parity data in each row. LL-FEC adopts the Reed-Solomon RS(255, 191) code to calculate the parity data.

data. The number of rows in an MPE-FEC frame can be 256, 512, 768, or 1024, which is indicated in the service information. On the other hand, the number of columns in an MPE-FEC frame is 255, where the application data table and the RS data table occupy 191 and 64 columns, respectively. The maximum size of an MPE-FEC frame is 2M bits to fit into one burst. Starting from the upper left corner, the IP data packets (of the same burst) are inserted column by column in the application data table. When the IP data packets of a burst cannot completely fill with the application data table, the remaining table space is padded with zero bits. On the other hand, by using the Reed-Solomon RS(255,191) code, the 64-byte parity data in each row of the RS data table can be calculated from the 191-byte IP data in each row of the application data table. Because writing and reading the IP data in the application data table is conducted in a column-wise direction while the parity data are calculated in a row-wise direction, the MPE-FEC frame structure can result in a block interleaving effect over the whole frame data and thus provide a certain degree of data robustness.

The AL-FEC mechanism is based on the digital fountain coding scheme [12], which can generate an infinite amount of parity data on the fly (that is, *rateless*). Theoretically, with an ideal fountain code, the source file can be reliably constructed after receiving a certain amount of encoded data. The digital fountain codes allow efficient asynchronous file downloading over broadcasting channels without any feedback mechanism, and can also be used in data delivery in wireless broadcast systems. The Raptor coding scheme [13] is one practical implementation of the digital fountain codes and its systematic version is also standardized in DVB-H.

AL-FEC is more efficient than LL-FEC when transmitting large-sized files that are distributed over more than one burst [14]. The reason is as follows: With LL-FEC, each burst must be decoded successfully in order to recover the whole file. When the mobile device loses one burst, it has to wait until the mobile device can receive that burst again (through retransmission). Meanwhile, the bursts containing data that have already been received will be discarded by the mobile device. On the contrary, in AL-FEC, all source data and parity data received correctly are useful to the mobile device, which can accelerate the delivery of the file. On the other hand, when transmitting small-sized files that can fit into one burst, LL-FEC can perform as well as AL-FEC.

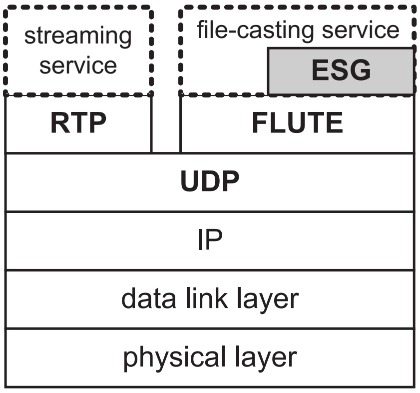

Fig. 4: The DVB-IPDC protocol stack. UDP is used as the transport-layer protocol to provide connectionless data transmission. However, to support the streaming and the file-casting services, RTP and FLUTE are adopted on the top of UDP, respectively.

2.2 IP datacast over DVB-H (DVB-IPDC)

DVB-IPDC provides an end-to-end architecture between service applications and mobile devices, where multimedia content is delivered as either a *streaming* service or a *file-casting* service. In the streaming service, a continuous data flow carrying the audio, video, and subtitling content is delivered to the mobile device and will be directly consumed by the user. Occasional and slight data errors could be tolerated. On the other hand, in the file-casting service, a finite amount of data are delivered and stored in the mobile device as a file. This file can be consumed either immediately or at a later time. However, the transmission of the file-casting service should be reliable.

In order to support both the streaming and the file-casting services, a DVB-IPDC protocol stack is developed, as illustrated in Fig. 4. The *user datagram protocol (UDP)* [15] is adopted as the transport protocol to provide the connectionless data transfer service. Since UDP may not satisfy the requirements of the streaming and the file-casting services, DVB-IPDC requires other higher-layer protocols on the top of UDP. In particular, for the streaming service, the *real-time transport protocol (RTP)* [16] is adopted to guarantee the *quality of service (QoS)* requirements of the service. On the other hand, for the file-casting service, the *file delivery over unidirectional transport (FLUTE) protocol* [17] is adopted to provide flexible transmissions of data carousel sessions and single file transfers. In addition, DVB-IPDC adopts the *electronic service guide (ESG)* [18] to provide some detailed system information for mobile devices, such as the available services and the access information needed to use these services. ESG is a file-casting service and should be handled by FLUTE.

The DVB-IPDC architecture is illustrated in Fig. 5, which is composed of several *functional entities* and a set of *reference points*. These functional entities will cooperate together to provide some system capabilities:

- *Content creation:* The content creation entity provides

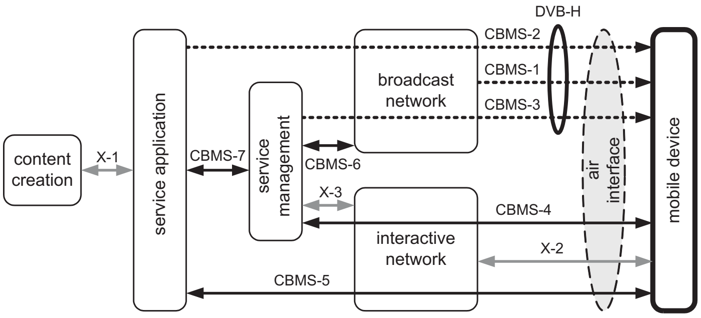

Fig. 5: The DVB-IPDC architecture consists of several functional entities (marked by blocks) and the corresponding reference points (marked by arrows). Each functional entity can communicate with other functional entities through different reference points. Note that the reference points CBMS-1, CBMS-2, and CBMS-3 are also adopted in the DVB-H system.

the source of content for the streaming and the file-casting services.

- *Service application:* The service application entity offers a logical link between the content provider and the mobile device so that the service content can be delivered to the mobile device over multiple radio access technologies. In addition, the service application entity generates the meta-data for service description used by ESG.
- *Service management:* The service management entity is to control the services transmitted from the service application entity to the mobile device, which involves the following four functionalities:
  1) Register the services to the system and allocate network bandwidth for these services.
  2) Collect and aggregate the meta-data of service description (from the service application entity) into ESG and then transmit ESG to the mobile device.
  3) Provide the security mechanism to protect the services.
  4) Support the location service.
- *Broadcast network:* The broadcast network provides a unidirectional channel to deliver service content to the mobile device through point-to-multipoint communications.
- *Interactive network:* The interactive network provides a bidirectional channel to allow the mobile device to interact with (or feed back to) the service management and the service application entities.

Two functional entities can communicate with each other through reference points, as shown in Fig. 5. These reference points include CBMS-i (CBMS stands for "convergence of broadcast and mobile services") and X-j ('X' stands for "extended"), $i = 1..7$ and $j = 1..3$. Specifically, CBMS-1 delivers the program specific information and the service information to the mobile device through the broadcast network. CBMS-2 delivers audio and video streams and the necessary files from the service application entity to the mobile device. CBMS-3 transmits the ESG meta-data from the service management entity to the mobile device in a point-to-multipoint communication manner. CBMS-4 exchanges some data such as the access control information and the ESG meta-data between the service management entity and the mobile device in a point-to-point communication manner. CBMS-5 exchanges some point-to-point transport services such as *short message service (SMS)*, *multimedia message service (MMS)*, and IP connectivity between the service application entity and the mobile device.

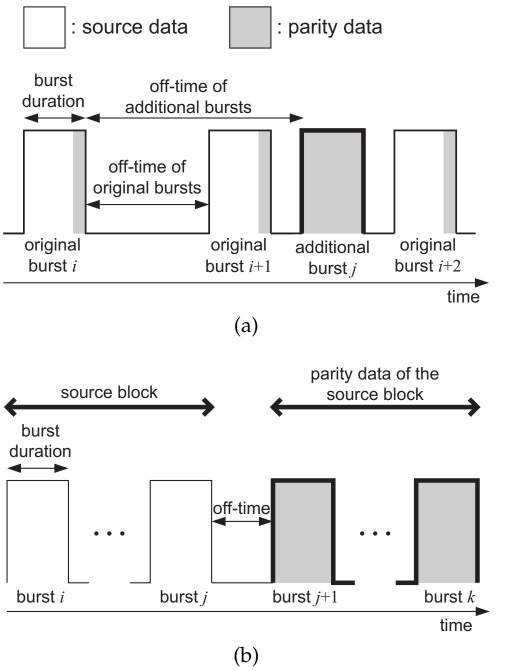

Fig. 6: Transmitting additional bursts for data recovery through the DVB-H broadcast channel: (a) For the streaming service, each original burst is appended with parity data. Besides, one additional burst that contains only parity data is transmitted after a fixed number of original bursts. (b) For the file-casting service, the parity data of the source block will be transmitted through additional bursts, where the source block is composed of a fixed number of data bursts.

DVB-IPDC adopts an interactive network to support bidirectional communication between the system and mobile devices. Therefore, when packets are lost in the broadcast network, mobile devices can ask the interactive network for data retransmissions. Many research efforts follow the DVB-IPDC architecture by adopting an IP-based wireless network to realize data recovery in a DVB-H system. Below, we discuss some representative studies, where the interactive network can be either an infrastructured network (for example, a cellular system or a WiMAX network) or an ad hoc network.

3 DATA RECOVERY THROUGH CELLULAR NETWORKS

Cellular networks such as 3G and UMTS have been widely deployed in many areas. Therefore, several studies suggest adopting a cellular network to serve as the recovery network. However, because the bandwidth of a cellular network is narrow compared with the DVB-H network, these studies consider transmitting the parity data or retransmitting the lost packets through the DVB-H network (via broadcast) or the cellular network (via unicast or broadcast), depending on the system situations such as the number of mobile devices and the amount of data to be transmitted.

The work of [19] considers a hybrid DVB-H and cellular system, and adopts AL-FEC for data recovery. In particular, parity data can be transmitted through either the DVB-H network or the cellular network. For the DVB-H network, these parity data are transmitted through *additional* DVB-H bursts, as shown in Fig. 6. There are two cases to be considered:

- When transmitting the streaming service, not only will each original burst be append with parity data, but also additional bursts filled with only parity data will be transmitted after a fixed number of original bursts. Thus, mobile devices that fail to decode an original burst can have an opportunity to recover the lost data by synchronizing to the additional bursts.
- When the file-casting service is delivered, each file is first divided into multiple *source blocks* and then AL-FEC is adopted independently to each source block to calculate the corresponding parity data. The maximum size of source block is recommended to 32M bits (that is, up to 16 bursts). The amount of parity data to be transmitted should depend on the network conditions, service characteristics, target users, and the amount of available transmission time. In particular, a small amount of parity data may not help mobile devices recover their source blocks, while a larger amount of parity data will waste the network bandwidth.

On the other hand, the cellular network can also help transmit the parity data through either the dedicated point-to-point connections (called *high-speed downlink packet access (HSDPA)*) or the cell broadcasting scheme (called *multimedia broadcast multicast services (MBMS)*) [20]. However, the capability of the cellular network to deliver parity data heavily depends on the network load and the distance between the mobile device and the cellular *base station (BS)*. To avoid burdening the cellular network with heavy load, these parity data can be delivered *on request*. In particular, mobile devices can notify the DVB-IPDC server of the amount of required parity data (depending on the network situations) through the uplink channel of the cellular network. Then, the server can transmit these parity data to the mobile devices through the downlink channel of the cellular network.

The studies of [21], [22] propose a *content delivery protocol (CDP)* for data recovery in a DVB-IPDC system. In CDP, mobile devices can inform the DVB-IPDC server of the lost or unrecoverable packets through the uplink channel of the recovery network. Then, according to this feedback information and the *file repair cost*, the sever can decide whether to transmit the lost packets individually to each requested mobile device through the recovery network (called a *point-to-point repair session*) or to broadcast these packets through the DVB-H network (called a *point-to-multipoint repair session*). In particular, CDP involves the following steps:

1) The mobile device continually receives the broadcasting content from the DVB-H network. When encountering the lost or unrecoverable packets, the mobile device sets up a timer using the random backoff scheme.
2) After the timer expires, the mobile device transmits a *repair request message* to the DVB-IPDC server for the lost or unrecoverable packets.
3) The DVB-IPDC server then transmits a *repair response message* to the mobile device. In particular, when the point-to-point repair session is adopted, the server directly replies the requested packets to the mobile device. On the other hand, when the point-to-multipoint repair session is adopted, this repair response message contains the necessary information used to access the session. The mobile device then can use this information to obtain its packets through the DVB-H network.

By simulations, the work of [23] points out some guidelines to determine whether the point-to-point repair session or the point-to-multipoint repair session should be adopted in CDP under different network situations (which can be evaluated by the file repair cost):

- The file repair cost of the point-to-point repair session rises linearly with the number of mobile devices. On the other hand, the file repair cost of the point-to-multipoint repair session rapidly converges to the cost of retransmitting the complete file.
- When there are no more than 100 mobile devices, the file repair cost of the point-to-multipoint repair session can be kept small.
- LL-FEC has a strong impact on the file repair cost. A larger-sized MPE-FEC frame can help reduce the amount of *rise* in the file repair cost. With LL-FEC, the file repair cost of the point-to-point repair session is smaller than that of the point-to-multipoint repair session.
- The size of the encoding symbols has a strong impact on the file repair cost. The medium-sized symbols (for example, 500 bytes) can help reduce the file repair cost. Either too large-sized or too small-sized symbols will increase the file repair cost.

The above guidelines can help adjust the system parameters of CDP to improve the network performance.

4 DATA RECOVERY THROUGH WIMAX NETWORKS

WiMAX networks are deployed to support wide-range broadband wireless access in metropolitan areas [24], [25]. A WiMAX network consists of multiple BSs that are connected with each other through a backbone network. Each BS can manage several *relayed stations (RSs)* and the communication between the BS and each RS is through a wireless link. Compared with the cellular network, the WiMAX network possesses a wider bandwidth so that it can transmit a large amount of multimedia content. Therefore, the work of [26] proposes an integrated architecture of the DVB-H system and the WiMAX network to support error recovery of DVB-H data, as shown in Fig. 7. In particular, mobile devices will roam inside both the DVB-H signal coverage and the WiMAX network. Each mobile device is equipped with a DVB-H receiver to continually receive the DVB-H broadcasting content and a WiMAX wireless interface to communicate with the neighboring RS. When a mobile device encounters the DVB-H data loss, the mobile device can ask its associating RS to retransmit the lost packets. Then, the BS will collect these requests from the RSs and query the DVB-H server for the lost packets. Finally, the BS will transmit these DVB-H packets to the requesting mobile devices through the corresponding RSs.

Two critical problems, namely GPL and BDH, will arise in the above network architecture. GPL occurs when there is a large number of requests for retransmitting the same DVB-H data with highly spatial or temporal correction. In

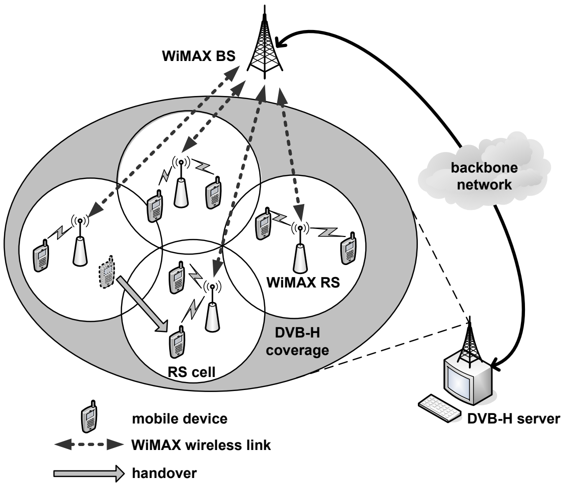

Fig. 7: The integrated architecture of a DVB-H system and a WiMAX network. Mobile devices will roam inside both the DVB-H signal coverage and the WiMAX network. Each mobile device is equipped with a DVB-H receiver to receive the multimedia data broadcasted from the DVB-H server and a WiMAX interface to communicate with the associating RS for data recovery.

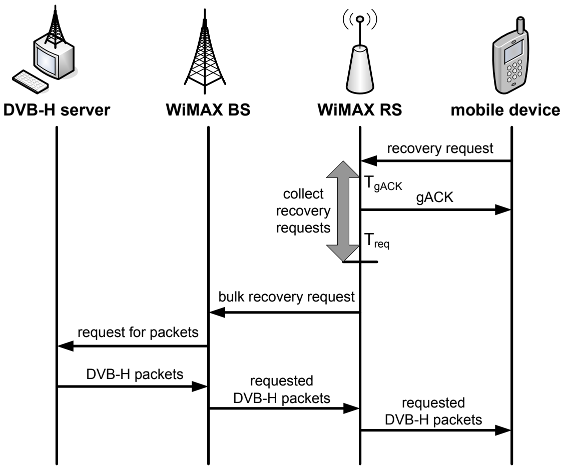

Fig. 8: The message flows in the BRR scheme. Each mobile device will transmit recovery requests when it loses DVB-H packets. After collecting sufficient requests or timer T_{gACK} expires, the RS will broadcast a group acknowledgement $gACK$ to announce the requests received by it. Then, the RS transmits a bulk recovery request to the BS, which in turn forwards these bulk requests to the DVB-H server for the lost packets. Finally, the BS transmits the DVB-H packets to the requesting mobile devices through the corresponding RSs.

the space domain, neighboring mobile devices may submit similar recovery requests because they are interfered by the same noise. In the time domain, mobile devices in the same RS cell could lose a similar sequence of DVB-H packets because the noise often exists for a period. Therefore, some RSs may be heavily congested by the incoming requests and the outgoing retransmissions of the lost DVB-H packets. Such phenomena may even cause many DVB-H packets to miss their deadlines. On the other hand, BDH occurs when the requesting mobile device handovers to a neighboring RS cell after submitting its recovery requests to the originally associating RS. Such a handover behavior will extend the spatial feature to neighboring RS cells. In this case, duplicate requests and retransmissions will further congest the WiMAX network.

To solve both the GPL and BDH problems, the work of [26] proposes a *bulk request recovery (BRR)* scheme, as shown in Fig. 8. The idea is to prevent mobile devices from submitting duplicate requests and properly deliver the lost DVB-H packets. In the BRR scheme, each RS will collect the recovery requests from the mobile devices for a short period, and then broadcast a *group acknowledgement* to announce the requests that have been collected by the RS. This group acknowledgement exploits the spatial and temporal correlation of the lost DVB-H packets to prevent mobile devices from submitting duplicate requests. Then, the RS schedules and packs these recovery requests into a *bulk request* and sends it to the BS, which will in turn forward these bulk requests (from multiple RSs) to the DVB-H server. Then, the BS sends these DVB-H packets to the requesting RSs, which will further broadcast the packets to their mobile devices. Specifically, the BRR scheme involves the following steps:

1) Each mobile device continually receives the packets broadcasted from the DVB-H server and maintains a buffer to record the indices of the lost DVB-H packets. When a mobile device encounters DVB-H packet loss, it will transmit a *recovery request* $RREQ(k, DT_k, W_k, SR_i)$ to the associating RS, where k, DT_k, W_k are the index, the deadline, and the weight of the lost DVB-H packet, respectively, and SR_i is the subscriber right of the mobile device. The values of DT_k, W_k, and SR_i together decide the *priority* of the lost packet. Then, the mobile device removes the index of the lost packet from its buffer. Note that the buffer of a mobile device may record many packet indices when the mobile device experiences serious DVB-H data loss and has to contend with many other mobile devices to send its requests in the WiMAX network.
2) Each RS continually checks whether there is any recovery request sent from its mobile devices. When receiving the first request, the RS initiates a timer T_{gACK} and sets up a counter c_j to record the number of the received requests. The RS also maintains a *request queue* to record these requests. Each entry of the request queue is a five-tuple $(k, minDT_k, N_k, W_k, PF_k)$, where N_k is the number of mobile devices that ask packet k and PF_k is the expected profit of packet k, which can be calculated by
$$PF_k = W_k \times \sum_{i=1}^{N_k} SR_i.$$
Supposing that N_k mobile devices ask packet k with the deadlines DT_k^1, DT_k^2, $\cdots$, and $DT_k^{N_k}$, the value of $minDT_k$ is calculated by $\min_{i=1}^{N_k}\{DT_k^i\}$. When counter c_j exceeds a predefined threshold or timer T_{gACK} expires, the RS initiates another timer T_{req} and broadcasts a group acknowledgement $gACK((p_1, p_2, \cdots, p_\alpha, p_{\alpha+1}, p_{\alpha+2}, \cdots, p_{\alpha+\beta}), T_{req})$, where p_1, p_2, $\cdots$, and p_α are the packet indices stored in the request queue, $p_{\alpha+1}$, $p_{\alpha+2}$, $\cdots$, and $p_{\alpha+\beta}$ are the indices of the *predicted* DVB-H packets that would be lost in the near future (due to temporal correlation), and T_{req} is the expected time that the RS will stop collecting the requests in this round.
3) One receiving $gACK$, each mobile device removes those packet indices that appear in $gACK$ from its buffer. Then, before timer T_{req} expires, the mobile device continues submitting the recovery requests if necessary. When T_{req} expires, the mobile device waits for the retransmission of DVB-H packets from the RS

and removes all entries from its buffer.

4) For each RS, when timer T_{req} expires, the RS sorts all entries of its request queue in an increasing order according to the packet deadlines $minDT_k$. When two packets have the same deadlines, their profits PF_k are used to break the ties. Then, the RS dequeues the first m packets from its request queue at a time and transmits them to the BS. After collecting packet requests from the RSs, the BS will query the DVB-H server for the lost packets. Then, the BS transmits these DVB-H packets to the requesting RSs, which further relay these packets to their mobile devices. The above operations are repeated until the request queue is empty.

The group acknowledgement $gACK$ exploits the spatial and temporal correction of the lost DVB-H packets to reduce the number of request submissions. In the space domain, $gACK$ prevents mobile devices from submitting duplicate recovery requests. When a mobile device successfully submits the request for packet k, neighboring mobile devices that also lose packet k but have not submitted their requests yet will cancel their submissions when receiving $gACK$. In the time domain, the RS expects that mobile devices will lose a continuous sequence of packets in the near future if they have already done so and thus inserts its predicted (future) packets into $gACK$. In this way, the mobile devices will cancel some of their future submissions due to duplication.

The BS can also exploit the spatial and temporal correlation of the lost DVB-H packets to reduce the transmission amount and latency of packets from the BS to RSs. In the space domain, the BS can first divide the adjacent RSs into multiple groups and then for each group of RSs, the BS can broadcast their requesting DVB-H packets together. In this way, the amount of DVB-H packets transmitted by the BS can be reduced because most of recovery requests sent from neighboring RS cells may usually duplicate. In the time domain, the BS can prefetch some future DVB-H packets from the DVB-H server. Therefore, the latency of replying the DVB-H packets to the requesting RSs can be reduced.

The above BBR scheme can also help solve the BDH problem. In particular, when a mobile device submits its recovery requests to one RS but later handovers to another RS cell, the mobile device may try to resubmit its requests to the new RS. However, because of the effect of spatial correlation, some mobile devices in the new RS cell may have already submitted the same requests. Therefore, the mobile device will cancel its submissions when it hears $gACK$ sent from the new RS. In addition, the BS broadcasts the requesting DVB-H packets to neighboring RSs. This behavior also guarantees that mobile devices can receive their packets when handover to the adjacent RS cells.

5 DATA RECOVERY THROUGH AD HOC NETWORKS

When the infrastructured recovery network such as cellular or WiMAX is not available, the work of [27] suggests letting mobile devices organize a wireless ad hoc network for data recovery, as illustrated in Fig. 9. Each mobile device is equipped with two radio interfaces: one interface is to receive the DVB-H content and another interface is to organize the ad hoc network for data recovery (called the *ad hoc assistant network*). Mobile devices will continually receive the broadcasting DVB-H content. Meanwhile, these mobile devices will dynamically organize the ad hoc assistant network to exchange the lost packets.

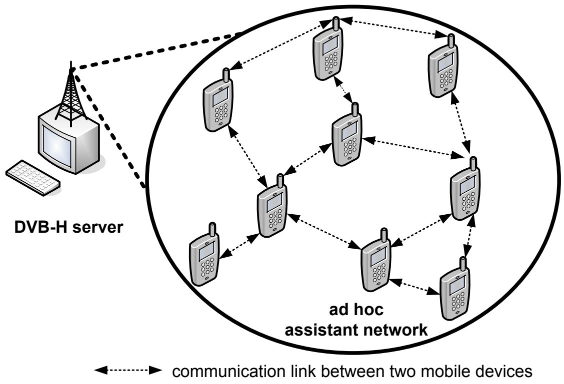

Fig. 9: Achieve data recovery through an ad hoc assistant network. The mobile devices continually receive the broadcasting DVB-H content. They will also organize an ad hoc assistant network to exchange the lost DVB-H packets.

The performance of the ad hoc assistant network highly depends on the dependence degree of the lost DVB-H packets at mobile devices. One can consider the following analysis: Suppose that there are two mobile devices that receive the DVB-H content and their erroneous reception probabilities are p_1 and p_2. Let these two probabilities be independent with each other and $p_1, p_2 \ll 1$. Then, the probability that a particular DVB-H packet is lost by both mobile devices will be $p_1 \cdot p_2$, which is quite small. Then, consider an ad hoc assistant network that consists of k mobile devices. The probability that at least one of these k mobile devices successfully receives a particular DVB-H packet is

$$1 - \prod_{i=1}^{k} p_i \approx 1.$$

This analysis shows that it is feasible to organize an ad hoc assistant network for data recovery. In this case, mobile devices in the assistant network can exchange their received DVB-H packets by establishing peer-to-peer connections.

A *cooperative recovery protocol (CRP)* is proposed to help mobile devices receive the lost DVB-H packets from the ad hoc assistance network, which consists of the following phases:

- *Peer discovery and partnership establishment:* A mobile device that wants to join the ad hoc assistant network (called a *requester*) will broadcast a *partnership request (PREQ)* message to the assistant network. The PREQ message contains the source address, the destination address, the message *identification (ID)*, the session ID for cooperative recovery, and the *time-to-live (TTL)* field. The source address is the IP address of the requester and the destination address is the broadcast IP address in the assistant network. The session ID points out the broadcasting session of the DVB-H network that the requester wants to recover. The TTL field indicates the maximum number of hops that this PREQ message can be propagated in the assistant network.

  When a mobile device receives a PREQ message from the ad hoc assistant network, it will decide whether it should serve as a partner candidate for the requester. Such a decision can be made according to some criteria such as how many other partnerships that the mobile device has already established for data recovery. If the mobile device accepts to serve as a partner candidate, it unicasts a *partnership reply (PREP)* message to the requester. The PREP message contains the ID of the original PREP message, the session ID, and the message ID.

After collecting PREPs, the requester unicasts a *partnership acknowledgement (PACK)* message to each mobile device that replies the PREP message. The PACK message contains the message ID, the original PREP message ID, the session ID, the acknowledge flag, and the confirmation flag. The acknowledge flag indicates whether this mobile device has been selected as a partner by the requester and the confirmation flag indicates whether this mobile device needs to return a *partnership confirmation (PCOM)* message. If the confirmation flag is set, the mobile device that receives the PACK message has to reply the PCOM message to the requester. After the above messages are successfully exchanged, the partnership between the requester and the partner is established. Any mobile device in the partnership can terminate the partnership by sending a *partnership termination (PTER)* message to its partner.

- *Partnership maintenance:* After a partnership is established, a *keep-alive (KA)* message is periodically transmitted from the requester to each of its partners to maintain the partnership. The KA message contains the source and the destination addresses, the message ID, the session ID, and the TTL field. Each partner then replies a *keep-alive-reply (KAR)* message to the requester when it receives the KA message. When the requester cannot hear back from a partner after retransmitting a predefined number of KA messages, the corresponding partnership is terminated.
- *Data Recovery:* To recover the lost DVB-H packets from the ad hoc assistant network, the requester sends a *recovery request (RECR)* message to one or multiple partners. The RECR message contains the source address, the destination address, the message ID, the session ID, and the requested packet map or list, which identifies the packets that the RECR originator requests from the partners. After receiving the RECR message, the partner determines which requested packets it can offer and then sends a *recover reply (RECP)* message to the requester. The RECP message contains the source address, the destination address, the original RECR message ID, the session ID, and the offered packet map or list. Then, the requester determines which lost DVB-H packets can be recovered from a specific partner according to the offered packet map in the RECP message. If more than one partner can offer the DVB-H packet, the requester arbitrarily select one partner and then sends a *recovery acknowledgement (RECA)* message to the partner to obtain the packet. The RECA message contains the source address, the destination address, the message ID, the session ID, and the packet map or list. The partner then sends the corresponding DVB-H packets to the requester according to the packet map in the received RECA message.

6 CONCLUSION

The deployment of wireless broadcasting networks has promoted the development of various mobile broadcasting services such as mobile TV. Due to the error-prone nature of the wireless broadcast, mobile devices may encounter serious packet loss. This chapter takes the DVB-H system as an example to discuss various data recovery schemes for mobile broadcasting services. Following the DVB-IPDC architecture, the data recovery schemes dopt an IP-based wireless network to recover the lost DVB-H packets. To summarize, the work of [19] considers a hybrid DVB-H and cellular network, where the parity data are transmitted through either the DVB-H network or the cellular downlink channel. CDP [21], [22] is proposed to make mobile devices inform the DVB-IPDC server of the lost DVB-H packets and the simulation results in [23] indicate several guidelines to select either the point-to-point repair session or the point-to-multipoint repair session to retransmit the lost packets. Under the intergraded architecture of a DVB-H system and a WiMAX network, the work of [26] addresses the critical GPL and BDH problems and proposes the BRR scheme to solve both problems. Finally, the study of [27] discusses how to realize error recovery of DVB-H data through an ad hoc assistant network.

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