Extensions of a TV Playout System to Support Dynamic Broadcast

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Abstract

In this paper we present our approach to extend current TV playout systems to fulfil the requirements posed by the Dynamic Broadcast system. After a review of the Dynamic Broadcast system we analyze the new flexibilities in the content delivery and study the challenging use cases. The key requirement on the playout system deduced from the use cases is the support of a flexible delivery of individual packetized content fragments. In our solution we modify the workflow in the playout system, but reuse current playout devices and published standards for data transfer and schedule messaging. A delivery schedule optimized by the decision logic and represented in a BXF message structure is used to control the actions of the components in the playout system. Necessary changes to the signalling, packetizing and multiplexing modules are discussed and practical proposals for realization are presented. The concepts of our proposal have been implemented in a demonstrator.

1. Introduction to Dynamic Broadcast

The architecture of the Dynamic Broadcast system [1] is depicted in Fig. 1. For simplicity some unchanged conventional function blocks in the playout centre such as broadcast scheduling and media content storage are not shown in this figure. The system involves a terrestrial broadcast network, a broadband network, user terminals connected to these networks and other wireless communication networks as secondary spectrum users. Their cooperation is managed by the decision logic through various control channels. In this section, the function blocks in Fig. 1 are explained firstly. Then we analyze the use cases of the playout system and the requirements for the development of a dynamic playout system.

Dynamic Broadcast introduces diverse flexibilities into the delivery of TV programs. Firstly, network flexibility is created. The TV events may be transmitted in either the broadcast or the broadband network and the delivery network can be switched during the transmission. The parameters of the broadcast network may be modified online. Secondly, time flexibility is added. The content may be pre-downloaded if the content is available in advance of the on-air time and users who have not stored the pre-download are allowed to get the content via the broadband network during the on-air time. The delivery schedule may be updated and changes in the transmission time are possible. Thirdly, content flexibility in the content delivery is also allowed. This includes for instance that the TV events may be fragmented and individual fragments may be transmitted separately; during replay of pre-downloaded TV events, commercials may be substituted as required by the broadcasters. But these modifications should not be noticed by the users.

Through these new flexibilities the benefits created by Dynamic Broadcast are manifold. For the broadcasters and the broadcast network operators the overall cost to deliver the TV programs to the users is reduced, since the cost savings in the broadcast network operation outweighs the extra cost introduced by employing the broadband network for the content delivery. Through pre-download the spectrum resource in low-traffic hours, e.g. at night, can be utilized and can ease spectrum scarcity during

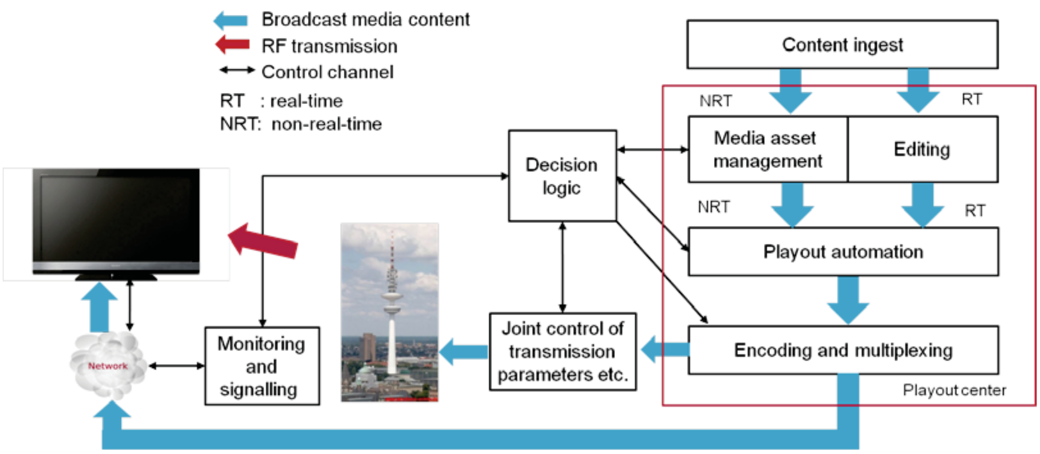

Figure 1 Overview of Dynamic Broadcast system

high-traffic hours, e.g. during daytime. As the "long-tail" TV events are delivered via the broadband network, the capacity in the broadcast network can be freed, so that additional TV programs or data services can be provided without increase in spectrum demand. By controlling the transmission parameters and transmitter power Dynamic Broadcast manages the availability of TV White Spaces. For the operator of broadband networks Dynamic Broadcast creates new revenue, but without increasing the peak traffic, for the reason that during the prime-time hours the popular TV programs are broadcasted like before. Because the pre-downloaded content can be delivered via the broadband network as well, the efficiency of resource usage in the broadband network is also increased. For the operators of cellular networks and Wi-Fi (etc.) networks additional spectrum resource is made available. As the conflict with broadcast network is managed through communication, the interferences with the broadcast signal can be avoided [3].

1.1. System Components

The decision logic is in charge of managing the Dynamic Broadcast system at a high level and it aims to provide an operation with the highest efficiency while assuring the required broadcast-type QoS. The goals of the optimization are reduction of transmission cost, minimizing energy consumption, and/or increase of the efficiency in the terrestrial spectrum usage. Information from all system components, including the user terminals, is aggregated at the decision logic. Facilitated with this detailed information, and based on additional business rules, cost functions, realistic constraints etc., the decision logic schedules the delivery of the TV program content. The resulting delivery schedule defines how the TV events will be packetized and transmitted and the parameter settings of the broadcast networks for each defined time period. This delivery schedule is used to control the operations of all system components including user terminals.

1.1.1 Playout Centre

In Dynamic Broadcast, the playout centre is responsible for supplying the decision logic with information about the media content, managing the media content and executing the optimized delivery schedule. The content of TV events is provided by broadcasters and is categorized into real-time (RT) and non-real-time (NRT) events. RT events are edited online and forwarded directly to the playout automation for transmission. At the same time, the RT events are recorded in the media asset management for long-term storage. In contrast, NRT events are sent to the media asset management first and after the post production made available for transmission before the on-air time. The conventional broadcast scheduling remains as before and the planned program schedule is sent to the decision logic. The related metadata of the content e. g. content identification and an indication when the material will be available for transmission are extracted and forwarded to the decision logic for the delivery scheduling.

After the scheduling, the playout automation composes videos and sound tracks with media content from the media asset management or directly from the live editing according to the delivery schedule. When the media content is to be broadcasted, it is then directed to a multiplexer, where it is encoded and multiplexed with other TV programs. The outputs of a multiplexer are e.g. MPEG-2 transport streams and can be transmitted as payload in the broadcast channels. When the media content is to be transmitted via the broadband network, it will be first transcoded and then sent to the broadband playout server. Signalling information enabling the user terminals to follow the delivery schedule is also generated and inserted at this stage. For pre-download content an appropriate data broadcasting approach is selected.

The flexible distribution of media content through the broadcast and broadband network requires the packetized content to be multiplexed dynamically. Since the popularity of the different TV programs in one transport stream changes continuously, re-multiplexing may take place online, which means some content being transmitted may be reallocated to other physical channels or still remain in the current channel but with new transmission parameters. Such changes have to be carried out in a way unnoticeable by the users. The cooperation of the user terminals is essential for this purpose.

1.1.2 Broadcast Network

In traditional digital broadcast systems the modulation of the transmitted signal and the code rate of Forward Error Correction (FEC) used are decided once and then stay stable. The transmitter power is selected according to the coverage requirements of the network. This static network planning leads to inefficient usage of the valuable spectrum, because strong time-variant factors like the size of the audience watching a programme have not been taken into consideration.

In Dynamic Broadcast, the transmission channels, transmission parameters and the transmitter powers are adapted online. Candidate parameter sets are planned for the broadcast network and each candidate parameter set is characterized by the coverage area, data rate, cost and the spectrum resource required. The candidate parameter sets are offered to the decision logic to choose from.

1.1.3 Broadband Network

The broadband network is the second delivery means for the TV program in Dynamic Broadcast. For the content delivery via the broadband network, the broadcaster is charged based on the data volume. This makes it preferable for the delivery of TV content with only a small audience size. Another important role the broadband network plays is that it provides a bidirectional point-to-point link for efficient information exchange between the Dynamic Broadcast system and the user terminals. This communication channel is essential to integrate the user terminals into the whole Dynamic Broadcast system.

To optimize the network operation, knowledge about the actual media content consumption is important. Information should hence be collected from user terminals and transmitted to the decision logic through the broadband connection. This popularity of the TV content can be estimated by monitoring the watching activities of some or all users, as done in today's IPTV networks. Knowing the accurate popularity and usage pattern of the media content can help the decision logic determining which content should be delivered via the broadband network or pre-downloaded.

The signalling to the user terminals will provide all required information for the reception of TV programs. It will include a program schedule and deliver information about the dynamically changed broadcast parameters. The signalling information can be transmitted via both networks and in both push and pull modes, so that the user terminals can get the current network information even if it is just switched on for the first time.

1.2. Playout Use Cases

From the perspective of the decision logic, the playout system generally performs four tasks: live content transmission, pre-download, switching between delivery networks and on-line adaptation of broadcast parameters, as shown in Fig. 2.

The live content transmission can be differentiated in live broadcasting and live streaming via the broadband network. However, the choice of the network used for the delivery must not cause difference in the quality-of-service. The pre-download use case as well as the live content transmission is an extension of the basic content delivery use case which is generically defined as *to deliver a TV event or a fragment of it at a pre-defined time with certain quality of service to the user terminals*. Switching between the delivery networks can be interpreted as two closely related content delivery processes. While the delivery of the first content fragment stops in one network, the delivery of the other content fragment is started but in a different network. Switching between the delivery networks is at the same time part of the use case on-line adaptation of broadcast parameters. Whenever the user terminal realizes that the content has been pre-downloaded before, it will stop the reception and switch the presentation to the content stored in its hard-disk.

An exemplary scenario comprising several use cases is depicted in Fig. 3. The first content fragment of a TV event is broadcast via the broadcast network. It was the only content being delivered on that broadcast channel. According to the delivery schedule defined by the decision logic, the transmission parameters of the broadcast channel will be changed. To achieve this, the second content fragment has to be moved to another delivery channel which may be either in the broadcast network or the broadband network. A network switching takes place between these two content delivery processes. After that, the broadcast channel is ready for changing its parameter setup. When the parameters have been modified, another network switching brings the delivery of the TV event back to the broadcast channel but with new transmission parameters. If the TV event is non-real-time and if there is free capacity in the broadcast channel, the second fragment can be pre-downloaded in the same broadcast channel parallel to the first fragment as shown in Fig. 4. In this case no further delivery channels are needed.

From our analysis above it is shown that the requirements on the playout system can be summarized as to support a flexible content delivery, so that other complex use cases can be built upon it.

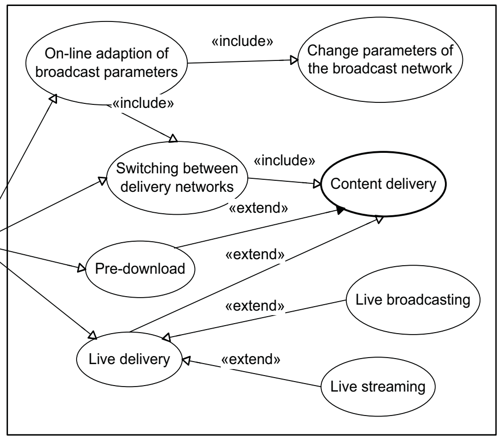

Figure 2 Use case diagram

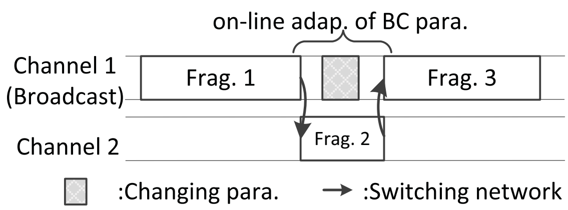

Figure 3 On-line adaptation of broadcast parameters in the presence of a second delivery channel

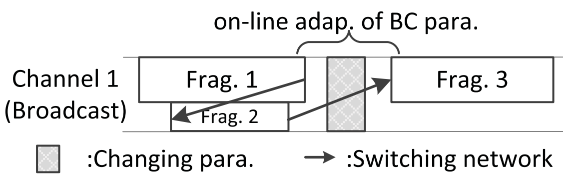

Figure 4 On-line adaptation of broadcast parameters in the presence of pre-download content

2. Current Playout Systems

While the migration to a file-based production is happening, the required functions in the playout systems are increasingly realized by software solutions. To simplify the integration of these system components, industry standards have been developed. The flexibilities and extensibilities created by these developments facilitate the realization of a dynamic playout system. In this section, central components and relevant standards in current playout systems are briefly described.

2.1 Ingest and Media Asset Management

The workflow of media broadcast begins with the ingest of media content. The key features of the media ingest system are transcoding and quality control. The media asset management (MAM) is the central subsystem in a file-based media broadcast workflow and can be seen as the interface between ingest, playout automation and the central content storage device. After the material has entered the broadcast facility, the ingest assigns it with a unique identifier. Together with the virtual memory address inside the storage system this identifier has to be stored in the MAM-database, in order to make the content and the metadata accessible for later processing by editors and cutters. The Media Exchange Format (MXF, [4]) is one of the non-proprietary standards used in file-based broadcast workflows. It is intended for exchanging metadata within the broadcast workflow as a file. The Edit Decision Lists are supported in MXF through the definition of the SourceClips sequence in the Material Package track.

2.2 Playout Automation

In the modern file-based environment, frame accurate and fully automatic playout automation systems have been widely adopted. The playout automation (PA) manages the transfer of media files from video streaming devices to the associated multiplexers according to a program schedule provided by program planning. In current systems, the Broadcast Exchange Format (BXF, [5]) can be used to set up and exchange among others the schedule information and the associated content metadata between systems in a broadcast facility.

In view of our application, the BXF messages identify the content in the central storage system, assign this content to the output channels and define the exact time at which the content file has to be distributed. One important element in the BXF message is the *Schedule* type. Its main elements are *Channel*, lists of *ScheduledEvent* and *AsRun*. The settings of a channel which is identified with a *channelNumber* are described by the *Channel* element. This includes the packet identifiers for the PCR and PMTs. In traditional broadcasting, a playout output channel corresponds to exactly one physical broadcast channel, therefore this information usually stays constant. Both *ScheduledEvent* and *AsRun* carry schedule messages. The *ScheduledEvent* describes the events to be broadcasted, while the events that have been broadcasted are listed in the *AsRun*. The schedule can be modified flexibly through schedule messages, which includes four different types as *read, add, update,* and *remove*. The content of an event is uniquely identified through a *ContentID*.

2.3 Encoding, Multiplexing and Modulation

The output channels of the PA contain media streams, which have to be MPEG-transcoded by the central encoding unit. For broadband transmission, the transcoded streams are sent to the broadband playout server for distribution. For broadcast, the packetized elementary streams (PES) are generated and the PESs from multiple TV Programs are multiplexed together in one transport stream. Data needed for generating the DVB Service Information (DVB – SI, [8]) tables are provided by the broadcasters/network operator and inserted into the transport stream. After multiplexing, the transport streams are transmitted through the distribution network to the transmitter sites. The modulator at the transmitter site processes the incoming transport streams according to parameters defined by the network operator. The datarate of the multiplexed transport streams must be identical to the datarate supported by the broadcast network settings. Stuffing packets and advanced approaches such as statistical multiplexing are used to adjust the datarate of the transport streams. Online-adaptation of the transmission parameters is basically allowed in DVB-T2 by introducing a gateway block at the modulator interface [6].

3. Proposed Extensions

In order to realize the flexible content delivery the workflow in conventional playout systems explained in Section 2 has to be modified. In this Section, the proposed extended workflow will be explained first. After that the new data structures and processing steps will be explained.

3.1. Modified Workflow

As shown in Fig. 5, the decision logic schedules the content delivery and requires the media asset management (MAM) to prepare the related TV content. The MAM checks the request and adds or updates the respective metadata associated to the TV content. Newly assigned identifiers or changed storage addresses of the content have to be sent back to the decision logic. The decision logic creates a complete delivery schedule and uses it to control the actions in the playout system. Having received this delivery schedule, the playout automation (PA) will generate signaling information for the user terminals and will load the content to local caches. At the transmission time the media content together with metadata, such as identifiers, will be transcoded and transmitted to the multiplexer or the broadband playout server (MUX/SERVER) for packetizing. In the following, we will describe how these functions can be supported with minimal extensions to current systems.

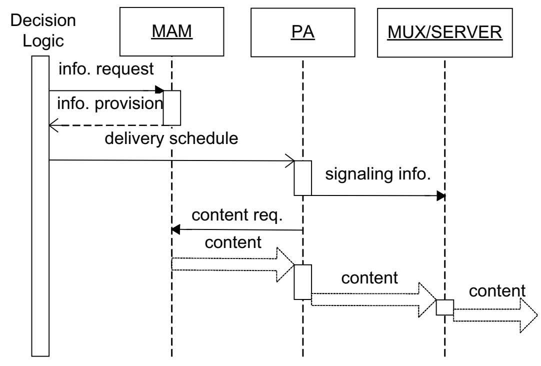

Figure 5 Sequence diagram of modified playout workflow

3.2 Delivery Schedule

In contrast to a traditional program schedule, which is merely a time plan for TV events in fixed channels, a delivery schedule contains additional information about:

1. the fragmentation of TV events,
2. the chosen transmission parameters for each separated time period,
3. the cross-mapping between the content fragments and the transmission source allocations.

We propose to extend BXF messages to express and exchange the delivery schedules. The information about the content fragmentation is reflected in the content identifier, which was assigned uniquely by the MAM. The commonly used transmission parameter sets can be internally defined as virtual channels in the playout system. The virtual channels which have the same broadcast central frequency should be distinguished by transmission parameters, in order to satisfy different needs, such as different data rates. Among them only one can be selected for a certain time period. The virtual channels and their transmission parameters are stored in a look-up table for all relevant components in the playout system. For the broadband network, a service discovery entry point as defined in [10] will be used. One example of such a look-up table is shown in Table 1. The cross-mapping can be understood as allocating a content fragment to a virtual channel for a specific time period.

Table 1 Look-up Table for Virtual Channels

Delivery Network	Virtual Channel ID	central frequency and parameters
Broadcast	1 2	594 MHz,16QAM,3/4, etc. 594 MHz, 64QAM,2/3,etc.
Broadband	3	Service discovery entry point

```
<BxfMessage messageType= "Information">
<BxfData action="add">
<Schedule type='delviery schedule'>
<Channel channelNumber="1"  type="broadcast"
        pcrPID="501" pmtID="500"> </Channel>
    <ScheduledEvent isLive='yes'>
        <EventData>
        <EventID> Frag 1 </EventId>
        <StartDateTime bxfDate="2013-01-21">
        <SmpteTimeCode> 20:15:00:00 </SmpteTimeCode>
        </StartDateTime>
        <LengthOption>
        <EndDateTime>
        <SmpteTimeCode> 20:29:30</SmpteTimeCode>
    ...
```

Figure 6 A abbreviated BXF message example for delivery schedule

An abbreviated BXF message for the delivery schedule of the first content fragment in Fig. 3 is presented in Fig. 6. In contrast to the case of current program schedules, the *channelNumber* indicates the ID of the virtual channel. The delivery schedule is accompanied by a conventional program schedule. The delivery schedule is not only considered as an action plan for the playout system, but is also required by the user terminals to allow a reception of the TV programs.

3.3 Content Fragmentation

Fragmentation has been adopted widely in IP-based data dissemination to increase the transmission flexibility. The recently developed MPEG-Dynamic Adaptive Streaming over HTTP (DASH, [7]) employs a hierarchical data structure and fragments the media content into presentation periods and segments. Alternative bitrates are provided for the A/V components of the media content. The DASH client needs to select the most appropriate bitrates according to the available data rate on the transport medium dynamically.
In Dynamic Broadcast, the fragmentation is carried out on the TV programs which have already been post-edited and are ready for distribution. The initial delivery schedule provides only the time boundaries of the desired content fragmentation. The MAM checks the viability and assigns each newly created content fragment a unique identifier. Metadata describing the fragments, such as to which TV event they belong and the time offset to the start of the TV event, is added or updated respectively. These changes can be registered directly in the MXF file. At the end the MAM completes the delivery schedule with the information about the content fragments and sends it back to the decision logic.

3.4 Signalling

The current signalling structure in DVB systems is channel-based and comparatively simple [8]. The TV channels are mapped to static network parameters, so that the user terminals only have to run the scan process once and can store a mapping for later tune-in. This approach is however inadequate for the application in Dynamic Broadcast. In addition to the normal program schedule, the flexible delivery schedule must be encoded as signalling information for the user terminals to discover and receive the TV programs. This requires separating the identifiers of the TV content and the locators clearly. This concept has been adopted in TV-Anytime [11].
The content fragmentation and identification can follow a hierarchical structure such as bouquet ID, service ID, event ID and fragment ID. In addition, a locator is specified at three levels for both transmission networks in Dynamic Broadcast. A basic locator indicates the necessary parameters for the reception at physical layer, such as the virtual channels in Table 1. An extended locator contains additional information required for the decoding at higher layers, such as a packet identifier in a transport stream. A complete locator should include the exact start time and duration of the transmission. The mapping between the identifiers and the locators could be dynamically changed. One content fragment can be allocated to multiple transmission locators, e.g. one for pre-download and one for the repeat via the broadband network. One transmission locator can also hold more than one content fragment as long as the transmission capacity is not ex-

ceeded. The current event information table (EIT) can be used to carry this information, where the TV event can be further fragmented and the location information can be presented as descriptors.

3.5 Packetizing

The content fragments have to be encoded and packetized before multiplexing. The conventional broadcasting system is stream-oriented; the metadata describing the TV events is intended for the usage by a digital video recorder and often contains uncertainties. For instance, no start/end indicator or identifier is embedded in the packetized elementary streams (PES) to allow an exact extraction of a TV event from the MPEG-2 transport stream (TS). One possible solution is to switch to a packet-oriented protocol, IP for instance. Thereafter advanced technologies such as DASH or the evolving MPEG media transport (MMT) [9] can be applied. Should the MPEG-TS be preserved, a new logical layer between the TV events and the PES has to be inserted. This can be implemented using customized private data fields in the header of the TS-Packet or the PES-Packet. Essential information for the user terminals are the identification and size of the content fragment. For the transmission of pre-download content, data broadcasting approaches specified by DVB [2] can be employed.

3.6 Broadcast Multiplexing and Transmitter Control

The basic functions of the multiplexer remain the same as explained in Section 2.3. A dynamic broadcast multiplexer is required to generate a transport stream whose data rate is controlled by the delivery schedule. We have implemented this function with the real-time multiplexer MuxXpert SDK from DekTec [12]. The playout automation controls the broadcast transmitter according to the delivery schedule as well. In case of a DVB-T2 system, the broadcast transmission parameters can be adjusted through a DVB T2-Gateway; otherwise, an additional communication link is required and device-specific control commands have to be implemented.

4. Conclusion

Dynamic Broadcast introduces different flexibilities for the delivery of TV content. With features such as pre-download, delivery network switching and online adaptation of broadcast transmission parameters, the efficiency of a broadcast system can be improved. However, these advantages pose challenging requirements on the playout system. After an analysis of the use cases for the playout system, we found out the complex use cases are built up upon the basic content delivery use case which is generically defined as *to deliver a TV event or a fragment of it at a pre-defined time with certain quality of service to the user terminals*. To support this basic use case, we modified the workflow in the playout system, while most of the current playout devices can be reused. A delivery schedule represented in a modified BXF message structure is used to control the actions of the components in the playout system. In the signalling information for the user terminals the content identifier is separated from the locator for reception, and has to be embedded into the transport stream or the IP stream to allow an easy and precise extraction of the content data by the user terminals. A controllable multiplexing module is used to create an output stream of the data rate that the momentarily used broadcast parameters support. The concepts of our proposal have been implemented in a demonstrator.

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