Scalable Video Transmission in Home PLC networks

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Abstract

Nowadays, the maturity of Powerline Communication (PLC) technologies enables high-speed Audio/Video (AV) in-home services. However, PLC data networks can have permanent and transient quality reductions. Permanent reductions are a consequence of the signal attenuation due to the powerline extension or infrastructure deficiencies, whereas transient fluctuations are mainly due to temporal interferences with nearby powerlines and electrical devices connected to the powerline. This paper explores the advantages of using the H.264 Scalable Video Codec (SVC) to adapt the video transmission to the quality fluctuations of PLC networks, and describes the architecture defined in the SCALNET Celtic project [5].

1. PLC fundamentals

Powerline Communication (PLC) allows to create a reliable audiovisual domestic network to transmit between residential devices different video contents with an ensured quality level, difficult to achieve with other transmission systems. Applications like high-definition video streaming between Media Center computers, Set-Top-Boxes, Personal Video Recorders, etc. require performance levels that are currently only achievable with In-Home PLC technology. These devices share two key needs: very high speed requirements (20-40 Mbps) and no mobility advantage (TVs and STBs cannot move around the home). Because it is not attenuated by concrete/brick/metal walls, In-Home powerline technology is the only technology that provides whole-house coverage solution for High-speed AV (Audio/Video) Home Networking. The technology is described by the UPA (Universal Powerline Association), using a Layered Reference Model.

The Physical Layer is based on Orthogonal Frequency Division Multiplexing (OFDM). OFDM has been chosen as the modulation technique because of its inherent adaptability in the presence of frequency selective channels, its resilience to jammer signals, its robustness to impulsive noise and its capacity of achieving high spectral efficiencies. Concatenation of four-dimensional trellis Reed-Solomon forward error correction, specially tuned to cope with the very special powerline channel impairments, assures high performance in the worst case.

Most of the features that allow 200 Mbps data transmission reside in the Physical layer. The PHY features configurable frequency bands, with bandwidths of 20 or 30 MHz. In its 30 MHz mode, In Home PLC systems provide a maximum physical throughput of exactly 240 Mbps, with information rates up to 158 Mbps. Modulation parameters for each transmitter/receiver pair are adapted in real-time depending on channel quality parameters for each carrier. Figures 1 and 2 depict an example of this functionality. The Signal-to-Noise Ratio (Fig. 1) is measured for each carrier and the optimum modulation (Fig. 2) is chosen, with the objective of achieving the maximum transmission speed while maintaining the desired Bit Error Rate (BER).

In-Home PLC technology uses an Advanced Dynamic Time Division (ADTDM) MAC

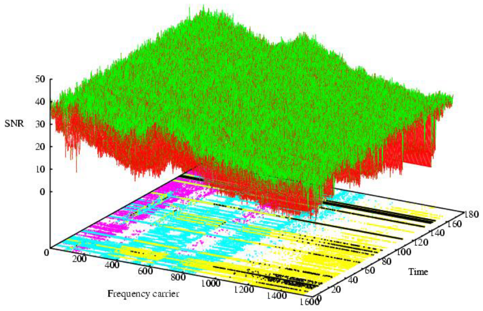

Figure 1: SNR Measurement

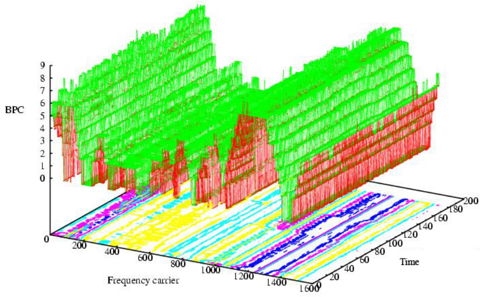

Figure 2: Bits-Per-Carrier (BPC) Assignment

that is optimized for Audio/Video distribution scenarios, where high performance, stringent bandwidth reservation, strict traffic prioritization and QoS are a must. The ADTDM MAC provides collision-free access for the channel to all the nodes in the power line network according to different service priorities. These can be adjusted to suit different types of applications, ranging from data, VoIP, Video on demand, etc.

The arbitration of the channel access is controlled by a centralized entity in the network in a way that adapts to the different topology possibilities, ensuring that all transmissions are compliant with the defined QoS profile. All nodes in the network are considered in the sharing mechanism, including hidden nodes, ensuring that any node in the network could have access to the channel if required.

In order to create a PLC transmission, incoming Ethernet frames are encapsulated in PLC bursts. A burst is composed of a Burst Header delimiter followed by a data payload including one or several fragmented and/or completed packets. A Burst Header delimiter without any following data payload is used to send ACK when there are no data to be sent. The Ethernet frame is encapsulated into a powerline packet, which is basically formed from the original Ethernet frame plus a powerline header that includes information such as powerline-level priority, OVLAN (an extension of VLAN), broadcast control information, etc.

2. SVC fundamentals

H.264/SVC was standardized as an extension to H.264/AVC, in a common effort of the Joint Video Team of the ITU-T VCEG and the ISO/IEC MPEG. The term scalable refers to the possibility to adapt the video bit stream to user preferences, terminal capabilities or network conditions by simply removing certain parts, called enhancement layers from the video bit stream. Such enhancement layers define a representation of the same video sequence that improves either the temporal resolution (frame rate), the spatial resolution (video dimensions) or the quality (signal-to-noise ratio) of the video bit stream. Quality layers can be of two modes: Coarse Grain Scalability (CGS) and Medium Grain Scalability (MGS). CGS uses a compression procedure similar to the spatial scalability using inter-layer prediction between layers with the same resolution. On the other hand, MGS improves picture fidelity using more quantization steps, and thus gives more flexibility than CGS to select the fidelity level.

Enhancement layers can be removed to fit the video bit rate to the available network throughput or to adjust the temporal or spatial resolution of the bit stream to the end device characteristics. Dynamic switching between enhancement layers is possible during the streaming session. However, it is only possible at certain access units of the video bit stream. These Instantaneous Decoding Refresh (IDR) access units signal that all following access

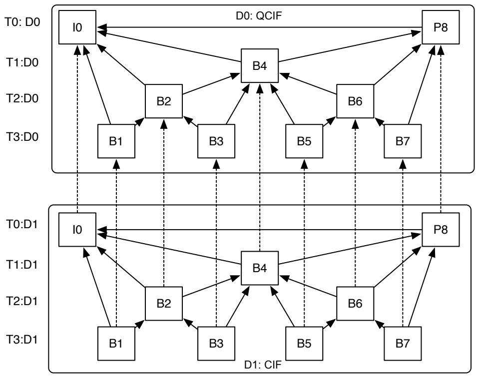

Figure 3: SVC combined scalability

units (until the next IDR access unit) may be decoded without decoding any previous pictures of the bit stream and can therefore be disregarded without causing decoder drift.

Figure 3 shows an example of temporal and spatial scalability. Two spatial dimensions are used in the example, QCIF and CIF, identified with D0 and D1, and four temporal dimensions, identified with T0-T3. The base layer of the video (D0) is backwards compatible to AVC. This base layer, which the enhancement layer D1 predicts from, is thus playable by existing AVC players, which would simply disregard all information dealing with enhancement layers. In addition to intra layer prediction (based on AVC mechanisms), each enhancement layer either predicts from the base layer (if it is the lowest enhancement layer) or from its lower enhancement layer(s) of the same scalability dimension. For additional information on the coding fundamentals of SVC the reader is referred to [8].

In order to transmit an SVC bit stream over a packet-switched network, such as the Internet, the SVC bit stream needs to be divided into packets. The Network Abstraction Layer (NAL) organizes coded media bits into NAL units (NALUs). Each NALU includes a number of macroblocks of a given picture and a given layer of the SVC bit stream. There are also NALUs which include meta information, i.e., Parameter Set (PS) NALUs and Supplemental Enhancement Information (SEI) NALUs. PS NALUs contain header information which is needed for decoding, such as the dimensions of the video. SEI NALUs are not required for the decoding of output pictures. They contain supplemental information such as, for example, the bit rate of the current layer which may be used to decide whether to keep or disregard the layer in case of network constraints. Each NALU includes a NALU header which provides information about the NALU payload, such as the scalability hierarchy, i.e., the layer which it belongs to. Each scalability layer is identified by the dependency id, quality id and temporal id, or (D,Q,T) triple. The dependency id indicates the CGS or spatial scalability layer, the quality id indicates the MGS layer and the temporal id indicates the temporal layer. For additional information on the NAL, the reader is referred to [10].

3. SVC-PLC testbed

This section describes an innovative synergy of PLC data transmission and monitoring, based on UPA standard specifications, SVC video structure and dynamic adaptation possibilities. Using a cross-layer feedback of the PLC performance, a controlled reduction of the video quality has been implemented. Additionally, QoS features of PLC networks can be used to segment the transportation of different SVC layers [2]. The source or a media aware network element (MANE) marks the stream accordingly to the video structure. The base layer, which is mandatory to decode any layer, should be transmitted with the maximum QoS, whereas the rest of layers could be prioritized having different policies.

As shown in figure 4, the PLC network infrastructure is made up of three types of nodes. Access points are unique in the network, it controls the access to the channel of the PLC nodes using Advanced Dynamic Time Division at the MAC layer. This technology permits to implement traffic prioritization according to IPv4 TOS field. Additionally, if this device has enough processing power, it can implement an SVC filter controlled from a MANE. The filter drops NALUs belonging to enhancement layers greater than a threshold identified with a maximum dependency, quality and temporal identifier. Repeater nodes receive packets addressed to another device and retransmits them. End points are end nodes of the PLC network, not being access point. Receivers are connected to end points.

The scenario for SVC-PLC transmission of the SCALNET project is completed with three software components: the SVC Streaming Server, the MANE and the SVC Player.

The SVC Streaming Server is outside the PLC in-home network (it is supposed to be in the content provider network). It is implemented as a modification of Darwin Streaming Server, an open source streaming server developed by Apple. The modifications permit the server to interact with files that conform to the SVC File Format [9]. These files are prepared with a modified version of the open source mp4creator tool [4]. The SVC File Format specification defines how SVC streams are stored in any file container based on the ISO Base Media file format (for instance, MP4 files). Although the specification is a specialization of the AVC File Format (back compliant with it) some new structures are defined to enable SVC specific features, including adaptation operations and erosion storage. SCALNET project is focused on adaptation operations, and to facilitate such operations, the MP4 SVC files define special video tracks that contain instructions on how to extract streams for concrete operating points (maximum enhanced layer). These are called extractor tracks. Usually, there are extractor tracks for those expected subsets of the scalable stream that will often be extracted.

MP4 SVC files are prepared off-line, so there is a static number of extractor tracks available. When a streaming client connects to the server, it sends its display resolution and the maximum access network throughput in a special header (X-Scalnet-ClientConfig) of the DESCRIBE RTSP command [7]. The streaming server employs an Adaptation Decision Taking Engine (ADTE) that uses this information to select the (D,Q,T) triple that best fits the specified configuration. If there is no extractor that matches exactly the client configuration, an SVC Filter is allocated to perform a fine grain adaptation. The server selects the hint track of the extractor immediately above the (D,Q,T) decision, and employs the SVC Filter to remove any NALU with dependency, quality or temporal identifiers grater that (D,Q,T). The adaptation performed by the server generates the stream with the maximum quality that the client can represent. Dynamic fluctuations in network quality are managed by the MANE.

The MANE is a device at the edge of the PLC in-home network that intercepts RTSP and RTP traffic between the server and the client. It can perform SVC filtering according to the dynamic network status information retrieved from PLC nodes, and the SVC stream scalability description. The description is represented as a special SEI NALU defined in the SVC standard, which is included in the SDP body[1] in the response of the DESCRIBE RTSP command. With this information, an Adaptation Decision Taking Engine (ADTE) can periodically decide to filter enhancement layers of the SVC stream coming from the server. The MANE can start the SVC Filter locally, but optionally it can delegate the filtering to the access point, to which it is connected. On the other hand, the MANE can mark video traffic with the IPv4 TOS field of the video packets to take profit of prioritization implemented by the access point. The communication between the MANE and the Access Point is implemented with a proprietary control protocol working at the link layer. When the MANE is started, it runs a procedure to discover the PLC nodes running in the network. Having identified the Access Point, the MANE periodically can retrieve the available bandwidth in the PLC network and configure a filtering rule. The filtering rule is made up of the data that identifies the RTP SVC flow (destination IP address and UDP port), and the data that defines the maximum layer with a triple (D,Q,T).

Figures 5 and 6 show an adaptation session using the City MPEG reference video sequen-

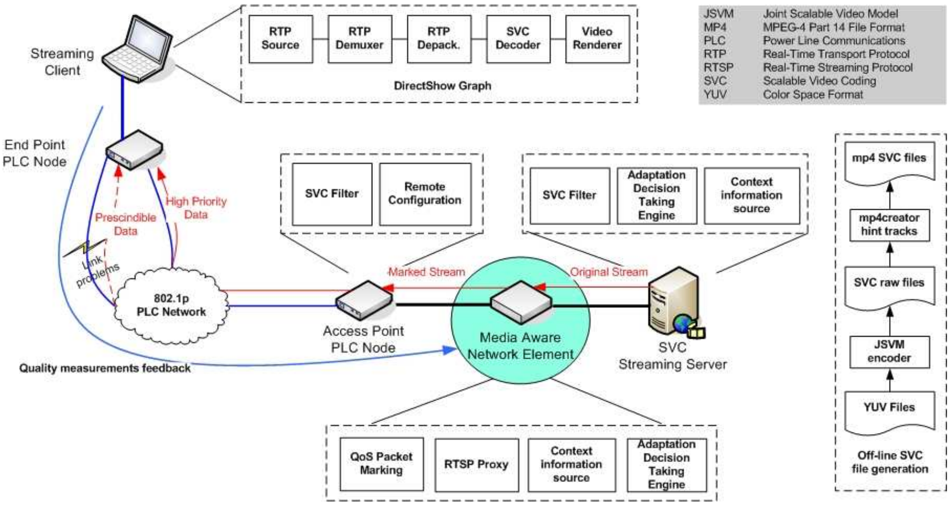

Figure 4: SVC-PLC testbed

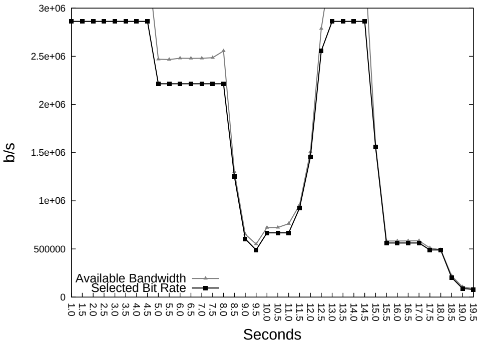

Figure 5: Bandwidth adjustment

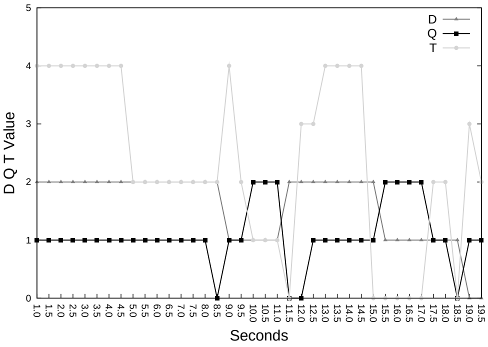

Figure 6: DQT selection

ce, encoded with three spatial, three quality and five temporal layers. The highest layer corresponds to 4CIF spatial resolution at 30 fps with just one quality enhancement. For both lower spatial resolutions (CIF and QCIF) a second quality enhancement was encoded. Figure 5 shows the evolution of the adaptation in terms of bandwidth. The ADTE selects the layer that best fits the available bandwidth in the PLC network using a simple preference in the video dimensions: spatial, quality and temporal. Figure 6 shows the adaptation in terms of DQT selection. We can observe that D line is more stable, whereas T line is very sharp, generating a poor QoE to the user. In order to avoid this behaviour, a smoothing algorithm must be developed to stabilize the video DTQ dimensions. Such an algorithm needs to take some decisions about the dropping order preference and may establish some quality minimums. The proposal followed in [3] allows the user to drive such parameters.

Finally, the SVC Player is able to decode and render SVC video content, and runs in a device connected to an end point PLC node. The player is implemented with Microsoft DirectShow technology, and makes use of the OpenSVC decoder [6].

4. Conclusions and Future Work

This paper shows the interesting synergy between SVC video transmission and in-home PLC networks. This type of networks include several mechanisms to enforce QoS for powerline applications, needed for the AV transmission: traffic classification and centralized bandwidth management. The Access Point device allocates channel access time to each device, having complete information about the network, including the bandwidth requirements of each application, and the available data rate between any pair of devices. Nevertheless, PLC networks are subject to bandwidth fluctuations due to powerline interferences. SVC video can be easily adapted to fit the available bandwidth in the PLC network. The adaptation can be done in the Access Point device, under the control of a MANE that monitors the streaming sessions and network throughput.

Future work needs to be done to smooth the video adaptation in the spatial, quality and temporal dimensions, in order to obtain a better user experience.

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