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Powerline HDMI® analysis for very short range link HD and UHD applications

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Powerline Telecommunications (PLT).

Modal verbs terminology

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Introduction

This Technical Report investigates how to transmit over the powerline medium HD and UHD contents that typically are exchanged through the HDMI® cable between transmitter video sources like Blu-ray™ players or set-top boxes and receiver video sinks like video displays. The report also presents earlier findings. The scope of the Technical Report is providing the technical elements needed to establish a PHDMI specification. The report is structured as follows: in clause 4, the requirements in terms of target bit rate to be fulfilled by a PHDMI technology are presented for different HD and UHD formats together with a set of PLT links used for testing purposes. It has to be underlined that the initial target for phase 1 was only HD. It was however estimated that the market is rapidly moving towards UHD and it was hence decided to enlarge the scope to also cover UHD. In clause 5, some target use cases are described: these scenarios highlight the potential fields of application of a PHDMI technology. Clause 6 presents the schemes that have been scrutinized as potential PHDMI technologies. Two of them are tandem schemes, i.e. systems that separate the channel encoding part from the source encoding part, they are based upon the serial concatenation of a compression encoder (based upon JPEG 2000 or Dirac) specifications and a OFDM power line modem operating in the 2 MHz to 100 MHz band that is able to provide SISO-based or MIMO-based communication. Besides tandem scheme, a joint scheme relying on the SoftCast paradigm has been also considered: it accommodates joint source and channel encoding. These communication schemes have been tested on HD and UHD videos both on flat channel with AWGN and on realistic PLT links (both SISO, MIMO 2×2 and MIMO 2×3): results are reported in terms of video quality metrics in clause 7 and clause 8. In particular, it is worth noticing that a realistic long video sequence was furnished by France Télévision for this analysis. Clause 9 shows how to optimize the source encoder parameters for the tandem schemes: an interesting point that it is also evaluated in this clause is the resiliency to errors at the PLT level, i.e. the investigation to see if it is possible to tolerate some errors at the PLT level without requiring retransmission of wrong packets. Clause 10 presents a scheme of a rate controller: it is the PHDMI component that manages the compression encoder rate as a function of eventual changes of the PLT rate during the video transmission. Transmit and receive buffer requirements are also put in evidence. Conclusion and final recommendations are reported in clause 11 of the present document.

NOTE: Blu-ray™ is an example of a suitable product available commercially. This information is given for the convenience of users of the present document and does not constitute an endorsement by ETSI of this product.

1 Scope

The present document addresses Short Range Powerline modems for Very High Bit Rate links for both HDMI® 1.x and HDMI® 2.0 interfaces.

2 References

2.1 Normative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found at http://docbox.etsi.org/Reference.

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NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

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3 Symbols and abbreviations

3.2 Symbols

For the purposes of the present document, the following symbols apply:

b	bit
dB	decibel
G	Giga
Hz	Hertz
M	Mega
s	second
2D	Bi-dimensional
3D	Three-dimensional
64K	65536

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

AVC	Advanced Video Coding
AWGN	Additive White Gaussian Noise
BBC	British Broadcasting Corporation
BCJR	Bahl Cocke Jelinek and Raviv
BER	Bit Error Rate
CE	Consumer Electronics
CEA	Consumer Electronics Association®
CR	Compression Ratio
DC	Direct Current
DCT	Discrete Cosine Transform
DWT	Discrete Wavelet Transform
EBCOT	Embedded Block Coding with Optimized Truncation
EMI	Electro Magnetic Interference
EZBC	Embedded Zero-Block Coding
EZW	Embedded Zero-Tree Wavelet coding
FEC	Forward Error Correction
GoP	Group of Pictures
HD	High Definition
HDMI®	HD Multimedia Interface
HDTV	High Definition TeleVision
HEVC	High Efficiency Video Coding
ICT	Irreversible Component Transformation
ITU	International Telecommunication Union
L1	Level 1
L2	Level 2
LCD	Liquid Crystal Display
LLSE	Linear Least Square Error
LS	Lifting Schemes
MAC	Medium Access Control
MC	Motion Compensation
MCTF	Motion Compensated Temporal Filtering
MIMO	Multiple Input Multiple Output
MPEG	Moving Picture Experts Group
MSE	Mean Square Error
MV	Motion Vector
NAL	Network Abstraction Layer
OFDM	Orthogonal Frequency Division Multiplexing
PE	Protective Earth
PHDMI	Powerline HDMI
PHY	PHYsical

PLT	PowerLine Telecommunications
PSD	Power Spectral Density
PSNR	Peak SNR
QAM	Quadrature Amplitude Modulation
QF	Quality Factor
QoS	Quality of Service
RCT	Reversible Component Transformation
RDO	Rate Distortion Optimization
SD	Standard Definition
SISO	Single Input Single Output
SNR	Signal to Noise Ratio
SPHIT	Set Partitioning in HIerarchical Trees
SSIM	Structural SIMilarity
SVC	Scalable Video Coding
TDMA	Time Division Multiple Access
UHD	Ultra HD
UHDTV	Ultra High Definition TeleVision
VLC	Variable Length Code
VS	Video Source
WSVC	Wavelet-based Scalable Video Coding
WT	Wavelet Transform

4 PLT HDMI® bit rate targets

4.1 Introduction

The recent increase in HD video contents has brought the need to develop communication standards capable of multi-gigabit per second throughput, like HDMI® and Display Port. Consumer electronics (CE) users also want the flexibility provided by wireless connections to set up and reconfigure multimedia systems, and to eliminate wired connections required by HD multimedia systems, like home theatres.

Driven by these needs, the CE industry is developing formats capable of delivering uncompressed video, at the necessary data rates, via wireless and wireline connections.

Simultaneously, PLT devices have become widespread and, in the latest specifications, are capable of data rates at the physical (PHY) layer up to 1 Gbit/s for single input single output (SISO) implementations and up to 2 Gbit/s for multiple input multiple output (MIMO) implementations.

These data rates are obtained for optimum channel conditions : taking into account PHY and medium access (MAC) layer PLT overheads, it is clear that they are insufficient for streaming uncompressed HD video or for transferring HD contents, like a HD film, as fast as would be desirable.

Uncompressed HD video transmission requires very high bit rates, up to 2 to 4 Gbit/s for Full HD video.

Uncompressed HD video transmission avoids compression at the transmitter and decompression at the receiver, therefore providing:

a) lower latency which permits timing sensitive applications like multimedia applications and gaming;

b) higher interoperability between devices because, unlike compressed video transmission, the receiver device just displays the video content and does not need to be able to decode the video codec;

c) no degradation in picture quality due to compression losses in the transmission.

The technologies specifically designed for video transmission organize the source devices (transmitters) and the sink devices (receivers) into a short range powerline video network, that allows for example:

- Point to point uncompressed video transmission ;
- Point to multi point uncompressed video transmission.

The video network has three type of devices: video sink (HD display), video sources (set top box, Blu-ray™ player) and devices that can perform both tasks (desktop).

The characterization of digital video and audio signals is important to assess the network data rate requirements. A digital video signal data rate is defined by: resolution, i.e. the total number of pixels of each image, normally referred as number of horizontal pixels by vertical pixels on the screen; colour depth, i.e. the number of bits used to represent each of the three colours of a pixel; refresh rate, i.e. number of times per second the image is completely reconstructed on the screen; progressive or interlaced formats, i.e. the way lines of an image are displayed in the refreshing cycles, progressive formats display all the lines on all the refresh cycles, while interlaced ones display even and the odd lines in alternated refresh cycles.

Currently available HD video formats are referred as "720p", "1080i", and "1080p". These terms indicate the number of lines and the display method used. Images used in HD video formats have a 16:9 aspect ratio, resulting in wider images than the conventional 4:3 aspect ratio used in Standard Definition (SD) video. The number of pixels, np, in each HD image can be calculated by:

$$np = (16/9) \times nl \qquad (1)$$

where nl is the number of lines, indicated by the video format designation. From this equation, it is possible to calculate that 720p images are formed by 1280 × 720 pixels; 1080i and 1080p images are formed by 1920 × 1080 pixels.

The bit rate required to transmit "Full HD" video, vbr, with progressive display can be calculated from:

$$vbr = np \times ncchannels \times cdepth \times rfreq \qquad (2)$$

where np is the number of pixels, ncchannels is the number of colour channels, cdepth is the number of bits used to represent each colour and rfreq is the display refresh frequency. Video signals also contain audio information and digital audio data is defined by: number of audio channels (nac), sampling rate(srate) and number of bits used to quantify each audio sample (sdepth). The audio bit rate, abr, can be calculated from these three quantities :

$$abr = nac \times srate \times sdepth \qquad (3)$$

Using these relations, it is possible to calculate the required bit rate to transmit an uncompressed video and audio signal. The net bit rate for Full HD video and audio is shown.

$$vbrFullHD = 1920 \times 1080 \times 3 \times 8 \times 60 = 2{,}99 \text{ Gbit/s} \qquad (4)$$

$$abrFullHD = 8 \times 192 \text{ k} \times 24 = 36{,}8 \text{ Mbit/s} \qquad (5)$$

NOTE: Blu-ray™ is an example of a suitable product available commercially. This information is given for the convenience of users of the present document and does not constitute an endorsement by ETSI of this product.

4.2 Targets for HD support

In table 1 essential Powerline High-Definition Multimedia Interface (PHDMI) video formats for HD video delivery are reported (information video bit rates 1,1 Gbit/s to 3 Gbit/s). They have been chosen after investigating both the HDMI® specification [i.1] and available datasheets of HD sources like Blu-ray™ players or set top boxes. In table 2 other formats that are typically also supported by the aforementioned applications or similar are reported (information video bit rates 0,4 Gbit/s to 0,5 Gbit/s). Clearly, there are also many other video formats that an HD capable PHDMI technology could support, the scope of table 1 and table 2 only being indicating the most important ones.

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Table 1: Essential video formats for HD support

Video format @60 Hz	720p	1080i	1080p
Video format @50Hz	720p	1080i	
Video format @24 Hz			1080p

Table 2: Important video formats for HD support

Video format @60 Hz	720x480p	640x480p
Video format @50Hz		720x576p

Table 3 reports the target information video bit rate for the video formats reported in table 1 and table 2 considering chrominance subsampling of 4 :4 :4 and 24 bits per pixel. Table 3 also reports, as a reference, the bit rate that HDMI® needs to transport video, audio and control information. The difference among the two bit rates is mainly due to two features :

- HDMI® introduces an 8/10 channel encoding module; and
- HDMI® uses the video blanking zone to transport audio and control data.

For instance, in accordance with CEA-861-D standard [i.2], in the case of 1080p (1920×1080) at 60 fps, HDMI® transmits a 2200×1125 format using the extended 280 45 matrix for audio and control data. Considering that the audio information bit rate that is needed amounts to about 37 Mbit/s, hence it is negligible compared to the video, it results that the total informative content has a required bit rate which is quite similar to the information video bit rate reported in table 3.

Table 3: Target bit rates for HD support

Video format	Frame rate (fps)	≈ Information video bit rate (Gbps)	≈ HDMI® bit rate (Gbps)
1080p	60	2,99	4,46
1080i	60	1,49	2,23
720p	60	1,33	2,23
1080i	50	1,24	2,16
1080p	24	1,19	2,23
720p	50	1,11	2,23
720×480p	60	0,50	0,81
720×576p	50	0,50	0,81
640×480p	60	0,44	0,76

Accordingly, a PHDMI technology has at least two possibilities:

1) The PHDMI video source module passes the audio, video and control informative content to the source power line PHDMI module which includes its signal processing before transmitting it to the power line. At the receiver, the power line PHDMI sink module processes the received information and furnishes it to the PHDMI video sink module (information content approach).

2) The PHDMI video source module passes the HDMI® content (including all the HDMI® overhead) to the power line PHDMI source module which includes its signal processing before transmitting it to the power line. At the receiver, the power line PHDMI module processes the content and furnishes it to the PHDMI video sink which applies HDMI® signal processing to recover video and audio information (*HDMI® content approach*);

Both approaches have advantages and drawbacks.

The information content approach has the following advantages :

1) It allows targeting lower bit rates on the powerline.

2) PHDMI source and sink have only PLT signal processing on the information content. The information content approach has the following drawback:

   - The control part at the sink PHDMI PLT module should be able to present to the PHDMI video sink module the information content in a proper way in order to enable synchronizing the received audio and video content with the sink characteristics.

The HDMI® content approach has the following advantages :

1) Control information is already furnished by HDMI® processing. The HDMI content approach has the following drawbacks : 1) The bit rate to target on the powerline is higher (up to 100 % higher).

2) PHDMI source and sink have both HDMI and PLT processing.

The analysis presented in clause 7 will follow the information content approach, also because the available testing video sequences are in a video format that does not include blanking. Note however that it is evident from table 3 that a PHDMI technology HD capable and able to sustain information video bit rates ≤ 3 Gbit/s will automatically be able to sustain most (all but one) of the HDMI® bit rates. Note also that if the PHDMI technology is UHD capable (see clause 4.3), it can deal with both approaches for HD.

4.3 Targets for UHD support

On 12th of November 2014, CEA® announced that it sets licensing agreement for UHD logos to be used by manufacturers, a sign that the UHD era has started. For the scopes of the present document, the definition reported in table 4 is used:

Table 4: UHD video format

UHD video format	3840×2160p

With UHD it is expected that a variety of combinations of parameter will be adopted in the future, which are more difficult to predict than the more consolidated ones for HD. In table 5 target bit rates for some selected combination parameters are presented for UHD. As in clause 4.2, both the information video bit rate and the HDMI® bit rate needed to transmit video, audio and control data are reported. The HDMI® bit rate is computed taking into account HDMI blanking transmission (4400×2250 extended matrix) and HDMI® 8/10 channel encoding and it is about 50 % higher than the information video bit rate for UHD. As in clause 4.2, a PHDMI technology UHD capable could follow the information content approach or the HDMI® content approach. The advantages and the drawbacks are the same as highlighted in clause 4.2 and they will be not repeated here. Results presented in clause 8 will follow the information content approach. This theoretically will allow also complying with the target of the HDMI® content approach for several combinations of the parameters.

Table 5: UHD target bit rate for different parameter combinations

Video format	Frame rate (fps)	Chrominance subsampling	Bits per pixel	≈Information video bit rate (Gbps)	≈Bit rate HDMI® (Gbps)
UHD	60	4:4:4	24	11,94	17,82
UHD	60	4:2:2	36	11,94	17,82
UHD	60	4:2:2	30	9,95	14,85
UHD	50	4:4:4	24	9,95	14,85
UHD	50	4:2:2	36	9,95	14,85
UHD	60	4:2:0	36	8,96	13,37
UHD	50	4:2:2	30	8,29	12,38
UHD	60	4:2:2	24	7,96	11,88
UHD	60	4:2:0	30	7,46	11,14
UHD	50	4:2:0	36	7,46	11,14
UHD	24	4:4:4	36	7,17	10,69
UHD	50	4:2:0	30	6,22	9,28
UHD	24	4:4:4	30	5,97	8,91
UHD	50	4:2:0	24	4,98	7,43
UHD	24	4:4:4	24	4,78	7,13
UHD	24	4:2:2	24	3,18	4,75

4.4 500 test links and bit rate

Earlier projects have made extensive characterization of in home MIMO PLT links [i.3]. MIMO has been adopted by different standardization organization as a basis for new technologies (HomePlug® AV2 [i.4] by HomePlug® and G.hn MIMO by ITU-T). As demonstrated in clause 4.3, the lowest target PHDMI throughput for UHD is greater than 3 Gbps: current MIMO technologies furnish a maximum throughput lower than 2 Gbit/s. Moreover, it has to be noticed that this maximum throughput is achieved at the PHY layer and in ideal SNR conditions.

According to the use cases (see clause 5), the present work has involved the creation of an internal SNR database on 500 links to be used for testing the different PHDMI techniques through this document. Each link relates to SISO, MIMO 2×2 and MIMO 2×3 on the 2 MHz to 100 MHz band. It should be noted that eigenbeamforming has been used for MIMO. Eigenbeamforming has been selected by the HomePlug® consortium as a basis for the HomePlug® AV2 technology. SNRs for an exemplary link are reported in figure 1.

Result that will be presented in clause 7 and clause 8 have been obtained with very long simulations: for instance the UHD video "FTV" (see clause 8) is more than 8 minutes long and targets an information video bit rate of 5 Gbit/s. It could take more than one week for a test on a single PLT link. Hence, the test links have been accurately chosen in order to provide some variety of performance. One can perceive this variety by looking at figure 2 that shows the throughput that can be obtained at the PLT application level in the case of a tandem scheme (see clause 6.2): it goes from 50 Mbit/s (the worst SISO case) to about 400 Mbit/s (the best MIMO 2×3 case). Note that it is expected that links associated to higher throughputs exist: a choice has been made in order to analyse power line conditions that can allow being confident in the definition of the PHDMI technology.

For tandem schemes (see clause 6.3), one has to properly use the compression capability of the source encoder to pass from the PLT rates shown in figure 1 (or higher) to the bit rate requirements shown in clauses 4.2 and 4.3. For the joint schemes (see clause 6.3), the bit rate requirements of clauses 4.2 and 4.3 are jointly achieved by the compression and channel encoding part. As it will be shown in clause 7 and clause 8, in the present context of video delivery, a comparison between tandem schemes and joint schemes can be done by analysing the displayed video quality.

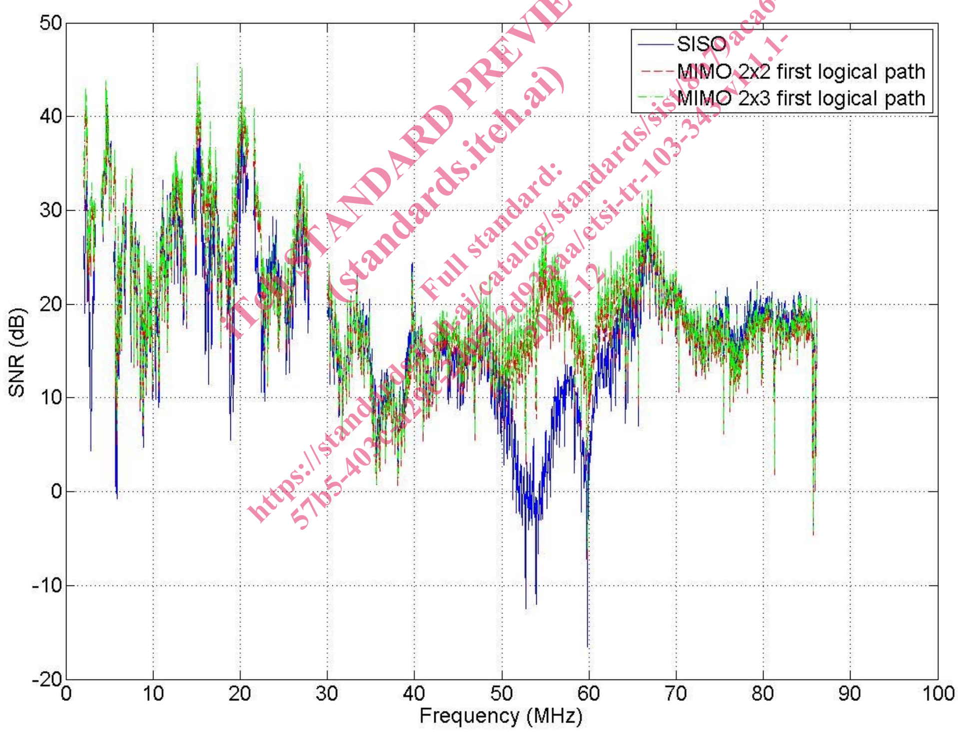

Figure 1: Example of a PLT link SNR extracted SNR database (MIMO reported only on the first logical path)