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Foreword

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

Modal verbs terminology

In the present document "**shall**", "**shall not**", "**should**", "**should not**", "**may**", "**may not**", "**need**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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Introduction

Already back in 2012, the ETSI STF410 studied the feasibility to increase the transmission capacity of the PLT modems by using the existing ground wiring in houses, in addition to the Phase and Neutral wiring being used by the SISO-PLT modems. The PLT industry today takes benefit of this technology to launch MIMO-PLT modems on the market. These new generation MIMO-PLT modems offer a throughput above 1Gbits allowing Gigabit Home Networking for high internet services developments as UHD/4K video services distribution in a house.

The present document addresses the transportation of very high bitrate services like UHD/4K in phase over MIMO-PLT. The present analysis carried out by the ETSI STF468 is taking place at the crossroad of three major technologies for video distribution in a house using existing electrical grids:

- MIMO-PLT offering a throughput up to the double compared to SISO-PLT;
- HEVC/H.265 reducing the bit-rate by a factor of 2 compared to existing AVC/H.264; and
- emergence of UHD/4K increasing the number of pixels by four compared to the HD (High Definition) video.

Therefore the actual phase 1 of the present study, explore the benefits of each component of the emerging technologies. The STF establishes performances of video transportation over powerline by validation of the combination of MIMO-PLT and UHD/4K video based on visual criteria. For this purpose a visual quality criteria recognized by e.g. ITU and MPEG groups video experts is used in this study for evaluation of video after transmission on electrical grids as well as throughput and robustness of the PLT links is measured.

For UHD/4K and HD video sequences used in this work, definitions given by EBU [i.2], [i.3] and specifications published by DVB group in an ETSI standard [i.1] were referred to.

The present document, first, present the phase 1 of UHD specifications [i.1] from DVB is now published as a technical standard from ITU, EBU and DVB to avoid confusion with 4K from Digital Cinema as 4K is referring to quad HD resolutions encoded in AVC/H.265.

The specification includes an HEVC Profile for DVB broadcasting services that draws, from the options available with HEVC, those that will match the requirements for delivery of UHDTV Phase 1 and other formats [i.1].

The present document studies the video transportation of HD and UHD video sequences encoded in H.264/AVC and HEVC/H.265 over Powerline technologies based on SISO and MIMO in referring to measurements based on PSNR and SSIM as described by figure 1.

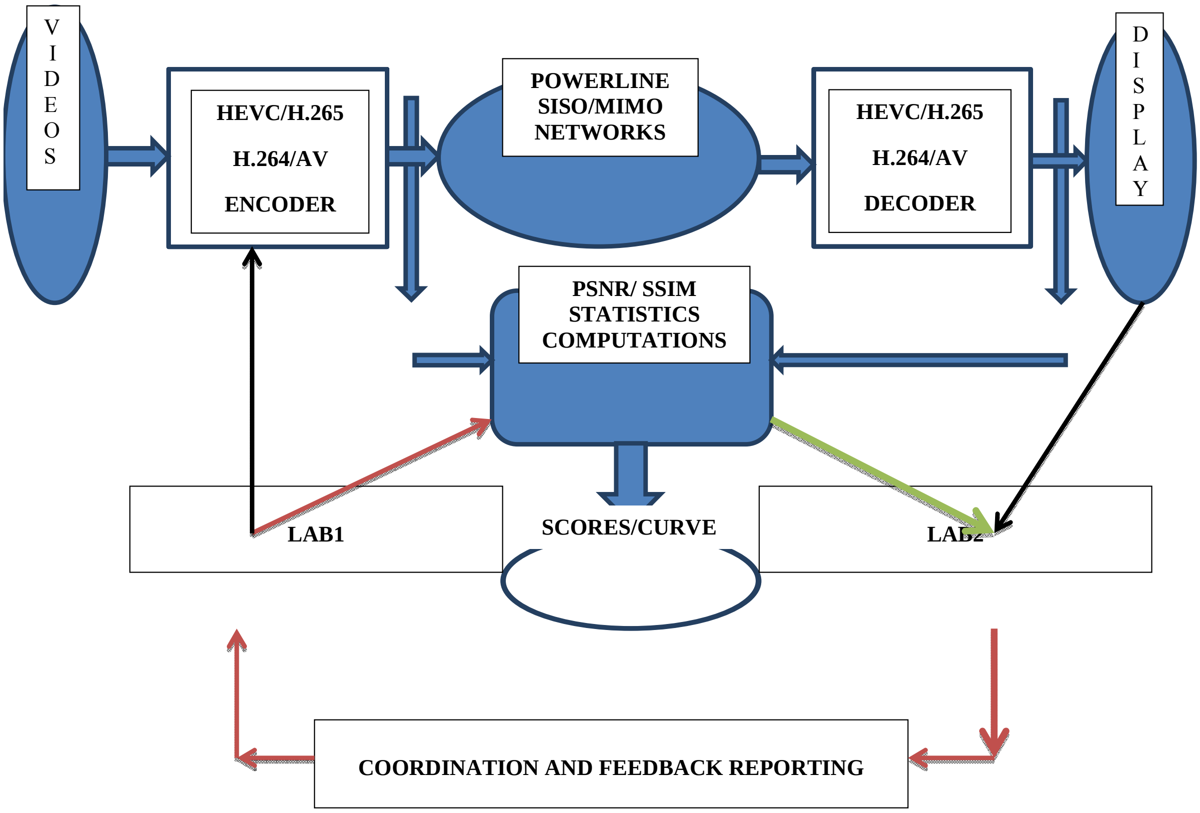


Figure 1: General Principles of tests and video quality measurements

1 Scope

The scope of the present document is to investigate the increased capacity of MIMO-PLT for Gigabit Home Networking based on forthcoming UHD/4K SVOD and streaming services distribution from Residential Home Gateway (VDSL2/G.Fast) to Set-Top-Box & Network-Top-Box, Media Servers for Tablets & Smart Phones.

The present phase 1 of the work is focusing on validation of the performances of MIMO versus SISO PLT channels in laboratory tests and in real houses using video sequences.

These video sequences consist of reference sequences of HD and UHD/UHD (used by experts from ITU, EBU and MPEG experts) and from real world sequences encoded by H.265/AVC and H.265/HEVC codecs are used for comparison of performances SISO-PLT versus MIMO-PLT.

2 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 referenced 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.

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

2.1 Normative references

The following referenced documents are necessary for the application of the present document.

Not applicable.

2.2 Informative references

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.

[i.1] ETSI TS 101 154: "Digital Video Broadcasting (DVB); Specification for the use of Video and Audio Coding in Broadcasting Applications based on the MPEG-2 Transport Stream".

[i.2] EBU: "Beyond HD update" (H.HOFFMAN).

[i.3] MPEG: "HEVC: Targeting streaming and mobile applications and higher resolution".

[i.4] Recommendation ITU-R BT.2020: "Parameter values for ultra-high definition television systems for production and international programme exchange".

[i.5] IEEE Consumer Electronics Magazine July 2012: "The new gold standard for video compression".

[i.6] RWTH Aachen University, March 2014, J.R. Ohm: "Overview of High Efficiency Video Coding (HEVC)".

[i.7] DVB: "CM- UHDTV and DVB TM-AVC is looking into HEVC".

[i.8] CEA: "4K" Working Group, define 4K technology, discuss 4K content options, and educate consumers about the newest era in high-definition television (HDTV). Nomenclature: "Ultra HD".

[i.9] EBU: "Ultra High Definition Television in Europe".

[i.10] Recommendation ITU-R BT.709: " Parameter values for the HDTV standards for production and international programme exchange".

[i.11] ITU-T SG16-Q6: "Mutlimedia".

[i.12] ISO/IEC JTC 1/SC 29/WG 11: "Coding of moving pictures and audio".

3 Abbreviations

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

AC	Alternating Current
AV	Audio and Video
AVC	Advanced Video Coding (H.265)
AWGN	Additive White Gaussian Noise
BPSK	Binary Phase Shift Keying
CEA	Consumer Electronic Association
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
DCT	Discrete Cosine Transform
DSSIM	structural dissimilarity derived from SSIM
DVB	Digital Video Broadcasting
EBU	European Broadcasting Union
EMC	Electromagnetic Compatibility
FEC	Forward Error Correction
GB	Giga Byte
GOP	Group Of Pictures
HD	High Definition
HD	High Definition (720p, 1080i/p)
HDR	High Dynamic Range
HEVC	High Efficient Video Coding (H.265)
HFR	High Frame Rate
HM	HEVC test Model
HPAV	HomePlug AV
IBBB	Sequence of a Intra frame (I) followed by Interpolated frames (B)
IP	Internet Protocol
IPPP	Sequence of a Intra frame (I) followed by Predicted frames (P)
IPTV	Internet Protocol TeleVision
ITU	International Telecommunication Union
JM	Joint Model
KTA	Key Technical Area
LISN	Line Impedance Stabilizing Network
MAC	Media Access Control
MB	Mega Byte
MIMO	Multiple Input Multiple Output
MKV	Matroska Video container
MPEG	Motion Picture Expert Group
MSE	Mean Square Error
MTU	Maximum Transfer Unit
NAL	Network Adaptation Layer
OFDM	Orthogonal Frequency Division Multiplex
OSI	Open System Interconnection
PC	Personal Computer
PHY	PHYsical
PLC	Powerline Communication
PLT	Power Line Telecommunications
PSNR	Peak Signal to Noise Ratio
QAM	Quadrature Amplitude Modulation
QoE	Quality of Experience
RTP	Real Time Protocol
RTSP	Real Time Streaming Protocol

SC	Sub Committee
SISO	Single Input Single Output
SNR	Signal to Noise Ratio
SSIM	Structural SIMilarity
SSIM	Structural Similarity Index Measurement
TCC	Turbo Convolutional Code
TCP	Transmission Control Protocol
UDP	User Defined Protocol
UHD	Ultra High Definition
UHD	Ultra High Definition (UHD1 for UHD and UHD2 for 8K)
UHDTV	Ultra High Definition TeleVision
VCEG	Video Coding Experts Group
VLC	VLC media Player
WG	Working Group
YUV	A colour space format

4 HD and UHD video specifications

With more than eight million pixels of resolution UHD (Ultra High Definition) video, also called 4K or Quad HD in the past, is the next generation of video technology and contents to distribute in the whole home using PLT modems, connecting Home Gateway to Set-top-Box and Media Servers.

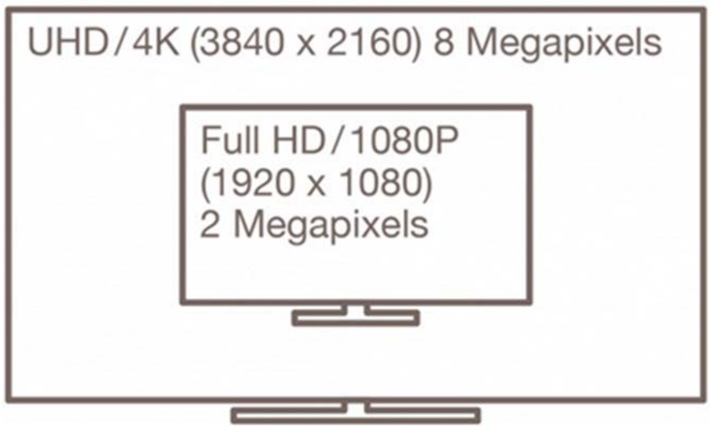


Figure 2: Number of Pixels of UHDTV [i.4] versus HDTV

In 2012, the usage of 4K introduce consumers confusion on devices on the market as TV sets and contents as UHD is not only more pixels but better pixels as defined by EBU experts.

During the year 2013, the industry has developed a common understanding with respect to a two-stage introduction of Ultra HD based on EBU, DVB and CEA standards.

Phase 1 is intended to provide a short-term market entry (2014/2015) based on the current available Ultra HD displays and limited compared to Full HD (1 920 x 1 080) mainly due to a four times the number of pixels (3 840 x 2 160).

The DVB specification for UHD Phase 1 was published in July 2014 adopted by the DVB Steering Board. DVB-UHDTV contains a HEVC profile for DVB Broadcasting Services and renewed ETSI TS 101 154 [i.1].

In addition to the four times the resolution of the system allows frame rates up to 50/60 Hz and also sets bit at a bit depth of 10. For 2160p content level of 5.1 HEVC Main is 10 profile provided HD services with up to 1080p are supported by Level 4.1.

As UHD video specifications are still evolving in standardization processes by ITU, EBU DVB, CEA, the same definitions and parameters as described by DVB were used:

The main elements of UHD are:

- HEVC Main 10 profile encoding

- 4:2:0 video at resolutions up to 3 840 x 2 160
- Frame rates up to 50/60fps, including 100/120 variants of the 50/60 fps family
- Inclusion of hooks for forward compatibility with UHD Phase 2 signals at higher frame rates
- Bit depth of 8 and 10 bits
- Signalling of BT.709 [i.10] and BT.2020 [i.4] (non-constant luminance) colour space.

In the following, the definitions and specifications for HD and UHD video streams were adopted to be used for the tests and measurements performed by Lab1 for video encoding simulations and Lab2 for PLT technologies testing.

5 MPEG4-AVC VERSUS HEVC for Video Compression

5.1 Introduction to video codecs MPEG4-AVC and HEVC

Significant compression gain, compared to former video coding standards, has been achieved by the ITU-T SG16- Q6 [i.11] H.264 standard of the Video Coding Experts Group (VCEG), also known as ISO/IEC JTC 1/SC 29/WG 11 MPEG- 4 [i.12] AVC of the Moving Picture Experts Group (MPEG) (for technical details: see annex D).

This gain results from the improvement of existing tools and the inclusion of new ones. These improvements concern the motion estimation and the information coding with Context Adaptive Binary Arithmetic Coding (CABAC), and above all the addition of several Intra and Inter modes with many encoding methods, which need the transmission of competition signalization indices.

The goal was to reach a video coding standard that provides a bit-rate reduction of 50 % at the same subjective quality, with a complexity increased by a factor 2 or 3 at most. Several improvements are already known and gathered in the JM KTA software (Key Technical Area) or in the HEVC (High Efficiency Video Coding) Test Model.

5.2 Description of the main coding profiles

Profiles (and levels) are a compact method to describe a bunch of codec parameters, which leads to an estimation of the complexity in coding or decoding.

The AVC /H.265 and HEVC/ H.265 profiles are different.

5.2.1 The H.265 (MPEG4-AVC) profiles

The present document defines several profiles, most of them dealing with the 4:2:0 colour format. Below are listed those profiles which were considered the most relevant:

- **Baseline**: the simplest (= constrained baseline). For low-cost applications that require additional data loss robustness, this profile is used in some videoconferencing and mobile applications.
- **Main Profile** declined in favor of High Profile. Standard-definition digital TV broadcasts that use the MPEG-4 format.
- **High Profile** (Constrained High Profile = High Profile without B frame). High-definition television applications (broadcast and disc storage applications).
- **High 10 or High 4:2:2** (High Profile adding support for up to 10 bits per sample of decoded picture precision).
- **High Intra** (profile constrained to all-Intra use) or Scalable, but seem out of the scope of the present document.

5.2.2 The H.265 (HEVC) profiles

The HEVC standard defines three profiles **Main**, **Main 10** and **Main still picture**.

The August 2013 draft of the range extensions amendment defines five additional profiles:

- Main 12, Main 4:2:2 10, Main 4:2:2 12, Main 4:4:4 10, and Main 4:4:4 12:
  - **Main profile** allows for a bit depth of 8-bits per sample with 4:2:0 chroma sampling, which is the most common type of video used with consumer devices.
  - **Main 10** allows for a bit depth of 8-bits to 10-bits per sample with 4:2:0 chroma sampling.
  - **Main Still Picture** allows for a single still picture to be encoded with the same constraints as the Main profile.
  - **Different bits precision** (8 bits, 10 bits, 12 bits).
  - **Different colour spaces** (4:2:0, 4:2:2, 4:4:4).
  - **Parameters of coding pass.**
  - **B frames numbers.**
  - **Intra prediction.**

5.3 Critical coding parameters for the study

5.3.1 Choice of the codecs

The goal of the study is to compare the video coding standards H.265/MPEG4 AVC (Advanced Video Coding), and its successor, H.265 (HEVC), for the direct transmission of compressed video without buffer over PLT channels.

The objective is to estimate the gain in bit-rate versus the robustness of the network flow. Since PLC is statistically not error free, and since RTP over UDP cannot recall a packet lost, then the quality of the video after transmission cannot be guaranteed for real time transmission and for a large amount of data (case of the UHD/4K-video).

The final drafting work on the first version of the standard H.265 was completed in May 2003 and since this time several codecs have been developed. Today, some of these optimized codecs are freely available.

The x264 implementation was chosen (http://www.videolan.org/developers/x264.html).

On the contrary, only few optimized free versions of the H.265 codec were available since the standard was published at the beginning of 2013.

One of them is the x265 implementation (http://x265.org/) which offers a limited number of parameters to tune when compared to the HM implementation jointly developed by the ISO/IEC Moving Picture Experts Group (MPEG) and ITU-T Video Coding Experts Group (VCEG).

In that context, the verification model HM13 of the standard was finally preferred in some cases, which unfortunately remained very costly in term of computation time and slows down the experiments.

5.3.2 Choice of the global parameters

Two compression standards H.265 and H.265 in the context of direct video transmission over the Power Line were compared.

The goal was to estimate the gain in bit-rate versus the robustness of the network flow without buffer.

Both H.265 and H.265 use prediction modes and are composed by three types of frames:

- I frames are standalone Intra frames coded without prediction;

- P frames are predicted from before-displayed I or P frames; and
- B frames can be predicted in both directions and from any frame.

Thus, to be able to analyze the necessity of flow refreshing in case of packet lost, the present study will work on every type of frame and different length of I period. The **High-profile** in case of H.265 (not the constraint version) and the **Main-profile** for H.265 is selected.

Note that the HM13 does not support every kind of pixel representation. It needs 8 bits and a colour sampling 4:2:0. In order to manage a fair comparison with H.265, this representation is kept for all the codecs.

5.4 Performance study

5.4.1 Quality criteria

In order to evaluate the quality of a decoded video two cases are considered; the quality of the coded/decoded video without considering transmission (general case) and considering Power Line transmission. In the first case, the quality depends only on the efficiency of the codec (namely H.265 or H.265) while in the second case it depends also on the noise introduced by the transmission channel.

5.4.1.1 General case (without transmission)

This study used as quality criteria the Signal-to-Noise ratio (PSNR) based on the Mean Squared Error (MSE) and the Structural Similarity (SSIM) which is generally utilized for characterizing the visual perception. Indeed, SSIM has been designed to improve on the PSNR metric, which has proven to be inconsistent with human eye perception.

The PSNR and the SSIM are full reference metrics recognized by video experts from ITU, MPEG, DVB.

These two criteria are computed between the original video (called x in the following) and the decoded one:

- The PSNR (expressed in dB) is given by (for image pixels coded in 8 bits):

$$PSNR_{dB}(x,y) = 10log_{10}\frac{255^2}{MSE(x,y)}$$

where MSE corresponds to the mean square error between the two images x (original) and y(transformed)

- The SSIM (comprised between 0 and 1) is given by:

$$SSIM(x,y) = \frac{(2\mu_x\mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)}$$

where μ_x is the average of x, μ_y the average of y, σ_x the standard deviation of x, σ_y the standard deviation of y and σ_{xy} the covariance of x and y. C_1 and C_2 are two variables to stabilize the division with weak denominator.

In the rest of the document the common expression of the SSIM expressed in decibels (dB) is used:

$$SSIM_{dB} = -10log_{10}(1 - SSIM)$$

These criteria are evaluated with the tool QPSNR that calculates both PSNR and SSIM on all the video sequences that the libav library.

The experiments (see clause 5.5) provide the curves PSNR in function of bit rates or SSIM in function of bit rates, for several profiles, several test sequences with format full HD and 4K, and for the two different codecs MPEG4 AVC and HEVC.

The experiments were done by the laboratory (LAB1) without channel noise (no PLT transmission) to generate reference coded/decoded sequences. The coded sequences and tools for decoding and computing the PSNR and the SSIM were provided to LAB2 for measuring the quality on the decoded sequences after PLT transmission.

Mostly shown result is the PSNR. For SSIM calculation the window size to evaluate the local mean and standard deviation was adjusted. The default value of 8 by 8 pixels was chosen. Then the behaviour of these two quality measurements on 4K-sequences were compared.

Figure 3 shows PSNR against SSIM. Firstly it can be noted that it forms straight lines, and then an optimization by SSIM will lead to the same result than by PSNR. Secondly for the same SSIM, x265 leads to a better PSNR compared to x264 or equivalently for the same PSNR x265 gives a much better SSIM than x264. Three conclusions can be drawn; a trial with both SSIM and PSNR is not necessary, x265 will probably give better sequence in terms of visual quality and the results do not depend on the Gop size.

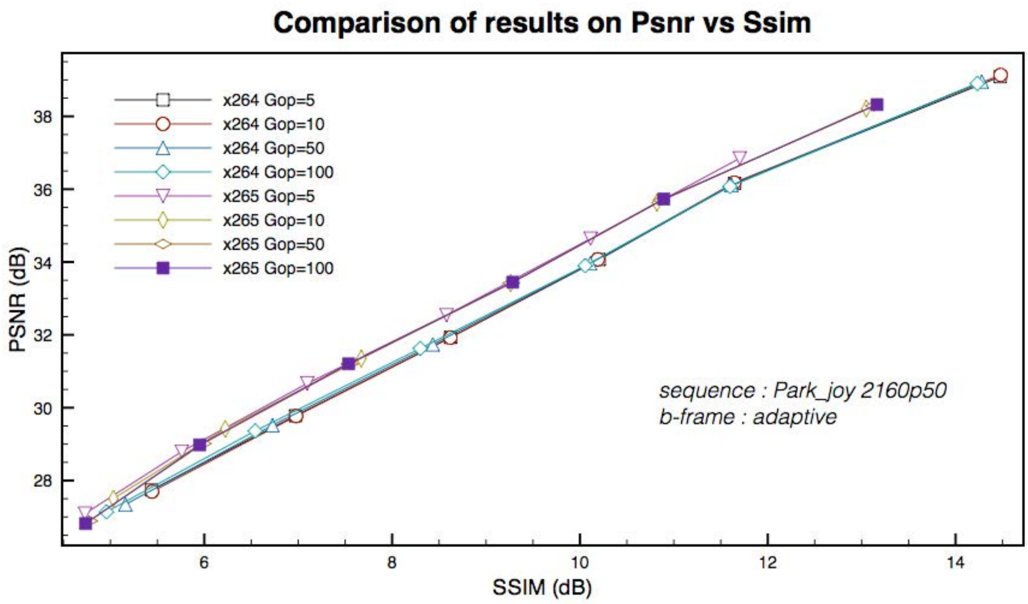


Figure 3: Comparison between PSNR and SSIM

5.4.1.2 Case with transmissions

During the transmission on PLT, as for other unreliable networks, packets can be lost. It may de-synchronize the video flow and then the criteria proposed in the previous clause are not able to compare the correct frames (due to the de-synchronization).

Then, the difference of quality between the input sequence (coded before transmission) and the output sequence (decoded after transmission) and measured by the proposed criteria can be huge, even if the visual quality of the two sequences remains correct.

NOTE: The use of the previous criteria for estimating the quality when a Power Line transmission is considered is meaningful only for experiments with a few lost packets. In case of a heavy loss of packets, it seems better to use network-oriented criteria like packet lost rate, jitter.

Effects of lost packets during transmission: A packet loss during the transmission leads to a blocking effect on the decoded video as showed on figure 4.

Figure 4: Effect of block loss

Video quality can be worse when the lost packets are used for prediction, and this case can occur frequently.

Indeed, current hybrid video codecs use temporal prediction to reduce the temporal redundancy.

The artifacts introduced by the loss of a packet used for prediction can be observed on the following pictures of figure 5.

(a) bad prediction *(b) missing object* *(c) original*

Figure 5: Effects of packets loss

5.4.2 Test sequences

5.4.2.1 Comparison strategy

The following comparison strategy based on the following 3 points was adopted:

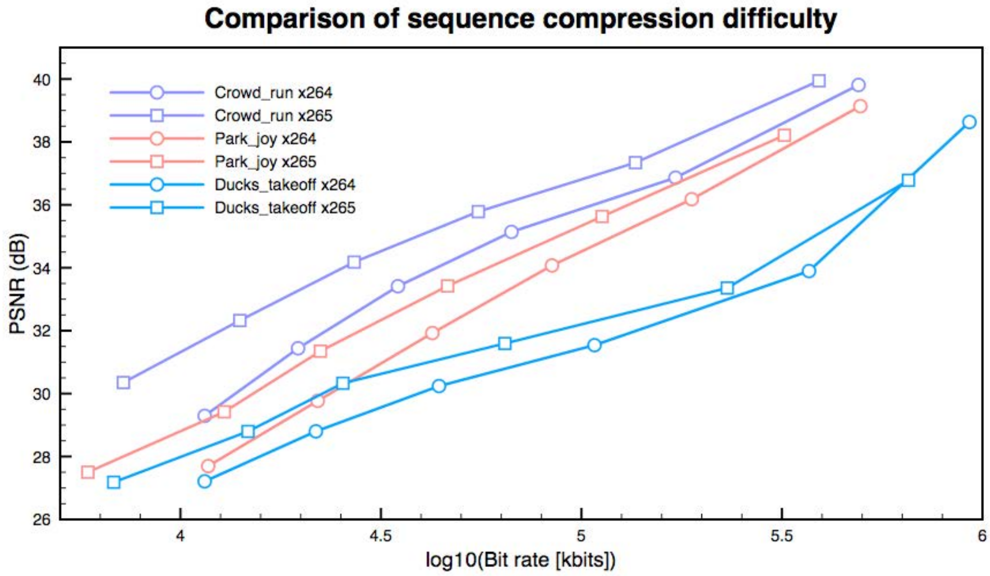
1) Comparison of the coding results on:
   - full HD(1080p) and UHD (2160p) video sequences.
2) Classic sequences from MPEG group.
3) "Real life" sequences.

5.4.2.2 Choice of the test video sequences

Simulations of transmission on a large number of video sequences, HD, full-HD and UHD/4K were conducted and the parameters of the different softwares were tuned to obtain fairly comparable results.

Actually, the difficulty was to tune the parameters of the different software in a fair way.

Figure 6 present the quality in as a PSNR in function of the bit-rate for three coded/decoded sequences obtained by both codecs x264 and x265.



NOTE: The considered Gop size is equal to 10.

Figure 6: Choice of a relevant 4K-sequence for the tests

The sequence "Ducks_takeoff" was very difficult due to the small movements on the water, which are not easily predicted. Both codecs present poor results on this sequence.

The sequence "Crowd_run" presents many small movements because each runner has his own rhythm, but the camera has global movements. Thanks to a better movement refinement, x265 gives then very good results at low bit-rate and thus doesn't allow to give a fair comparison with x264. Results for sequences like "Old_town" are not shown because it presents only a global movement which both codecs are able to predict.

For the LAB2 experiments, a video, named "Park Joy" (see figure 7) was chosen. The video presents some coding difficulties, but which leads to good compression ratio at a correct visual quality. Since easy comparisons and easy video displaying was desired, the tests were conducted with the 1080p and 2106p resolution at 50 frames per second. This sequence presents global movements at different distances, small movements of people and occlusions. In figure 6, the "Park_joy" sequence shows more regular results than the others.

Figure 7: Frame extracted from "Park Joy" video

5.4.3 Coding at fixed bit-rate or fixed Quality

The codecs used were able to handle two coding strategies: optimizing the compression result given a *target bit-rate* or given a *quality target*.

In the case of a target bit-rate, the example presented in figure 8 shows that the quality, given in terms of PSNR, improves during the coding process but never return to the initial level. Indeed, the I-frames cost is so high that limiting the bit-rate prevents using a sufficient bit-rate for the other frames (non I-frames). This case is then not interesting for the study.

On the contrary, figure 9 shows a more interesting result: imposing a quality target allows obtaining a decoded sequence with constant quality. In that case it is not possible to control the output bit-rate (see figure 10 which shows the behaviour of the bit-rate in function of the frame). For all of the tests provided in this study, it was then chosen to constrain the quality.

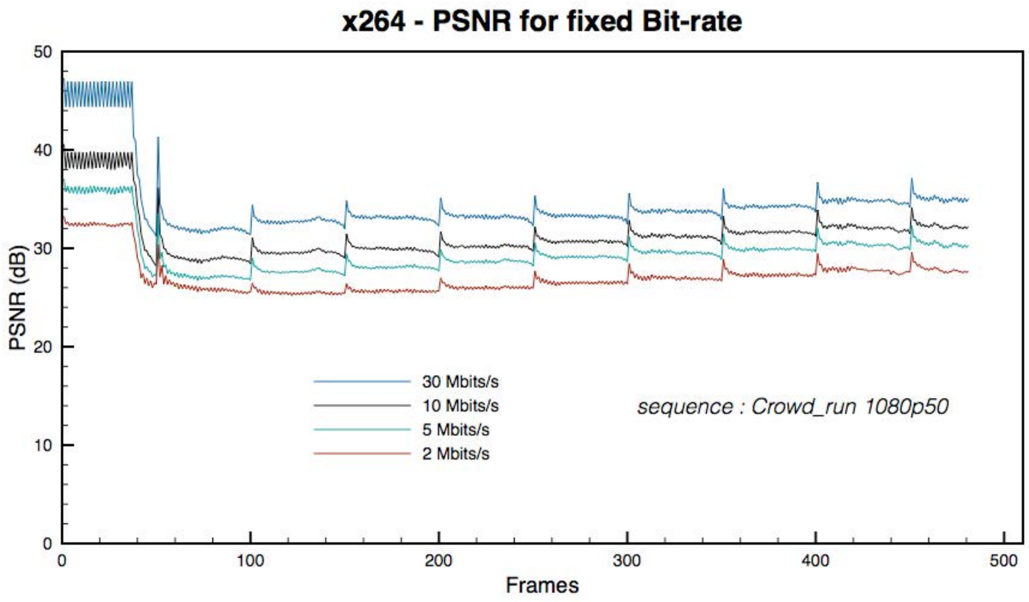


Figure 8: PSNR in function of the frame for a constant bit-rate constraint

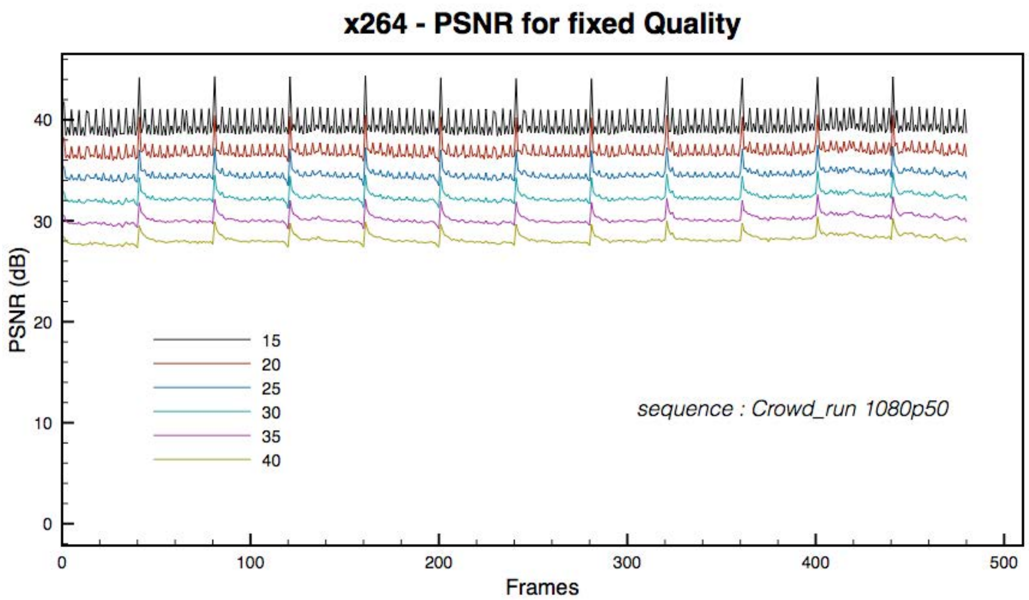


Figure 9: PSNR in function of the frame for a constant quality constraint

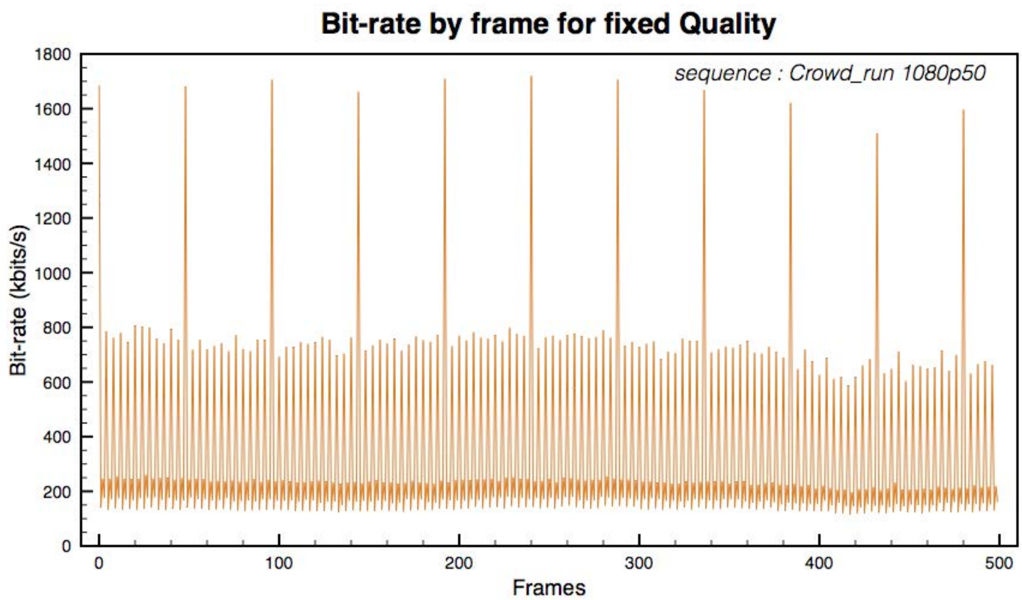


Figure 10: Bit-rate in function of the frame for a constant quality constraint

5.5 Tuning of the parameters

5.5.1 Parameterization of the codecs

Different parameterization on different sequences were experimented and an answer to the following questions is given:

- *Is the B-frame exclusion a good choice?* Definitely no. Both codecs give almost the same results. The gain of using H.265 without B-frames is few for small GOP and leads to a waste of bits for large GOP (see figure 11).
- *Is the low-delay a good strategy?* For H.265 the low-delay gives a IPPP... scheme and for H.265 it leads to a IBBB... There is no significant gain with H.265 but it gives almost the same results at each GOP and is less dependent of the I-period size. The same result with the HM and the x265 codec and for other sequences were obtained (see figure 12).
- *Is the strategy of letting both codecs x264 and x265 optimizing their behaviour is a good one?* Definitely yes. The big deal with the GOP-size if the possibility of quick refreshing the sequence stream by having more I-frames. However, it is well known that in this case the bit-rate becomes heavier: that was really a problem with H.265 it does not seem to be so with H.265. Comparing the graphics from figures 13 to 20, one can see see that the GOP-size is a parameter less sensitive for x265 than for x264. Here the results for two sequences and two sizes are presented, but also other sequences were experimented and obtained the same results. In our opinion, this is a very important observation for the conclusion. If the GOP can be shorter for the same bit-rate then the refreshment time during the transmission could be faster.

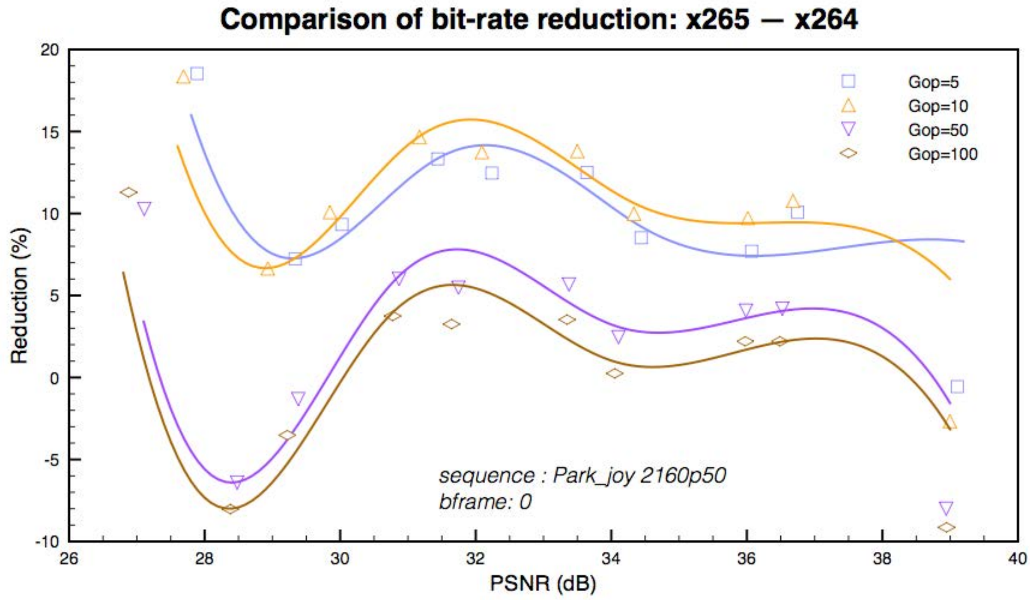


Figure 11: Reduction of bit-rate between x265 and x264

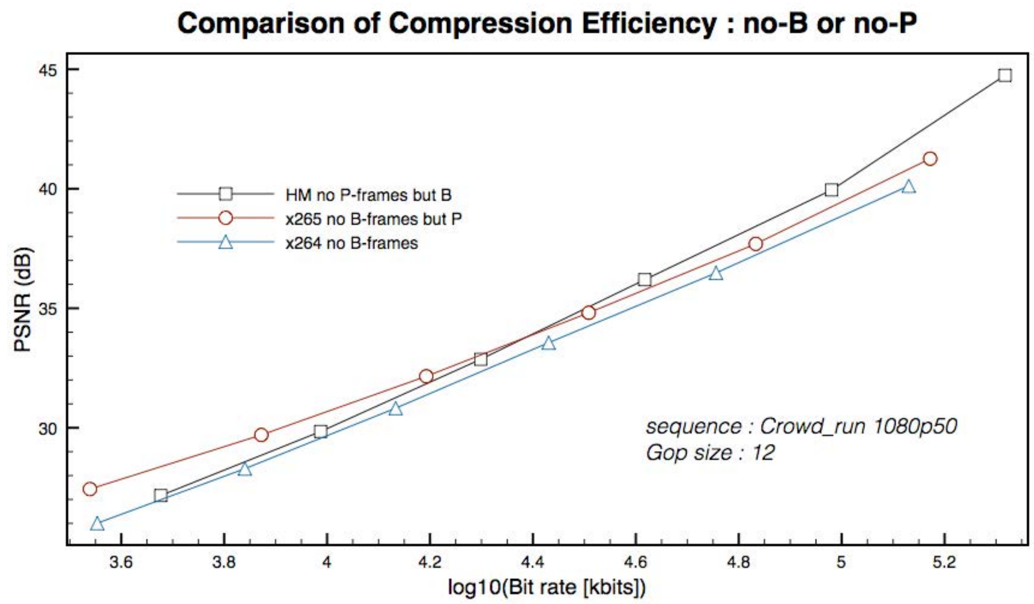


Figure 12: Comparison of IPPP… and IBBB…

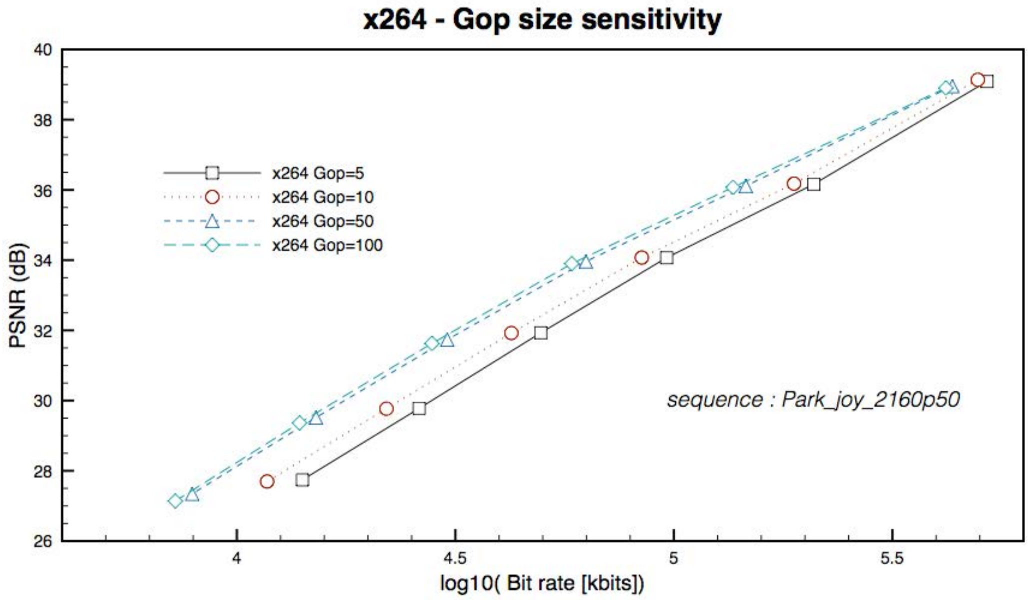


Figure 13: Comparison of the sensitivity on the GOP size for x264

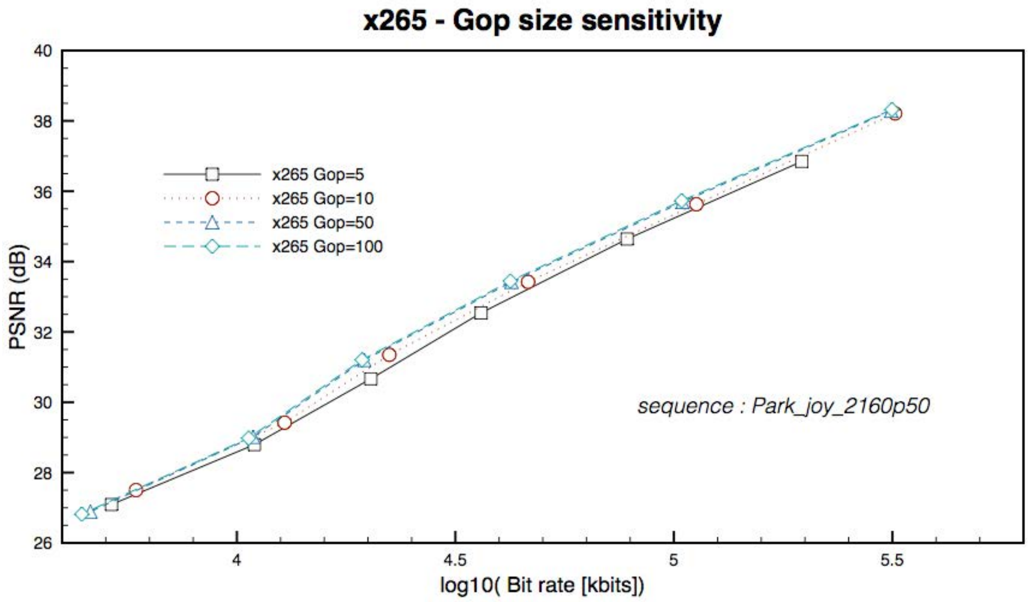


Figure 14: Comparison of the sensitivity on the GOP size for x265

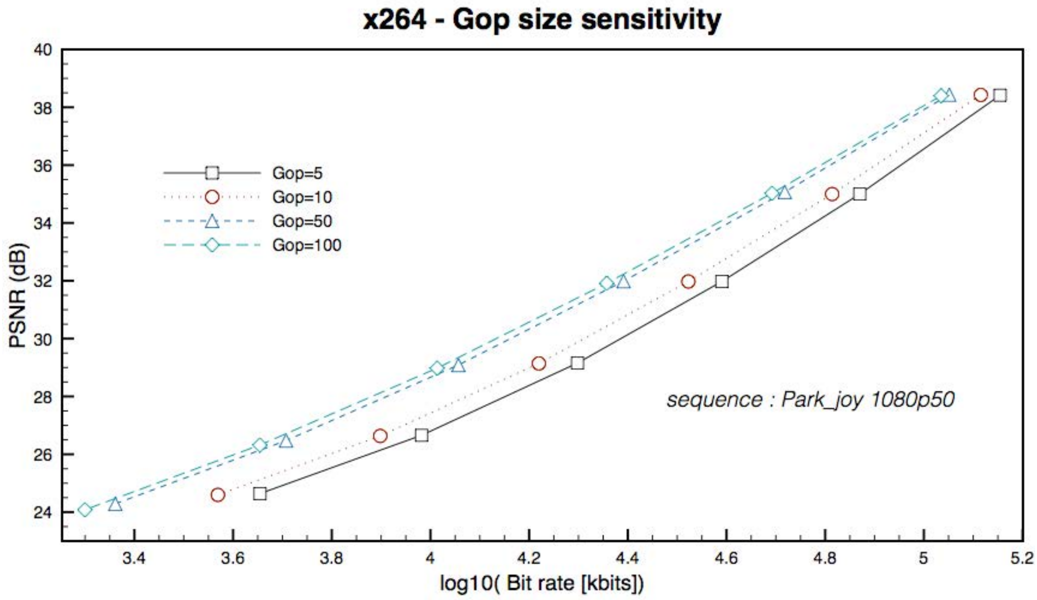


Figure 15: Comparison of the sensitivity on the GOP size for x264

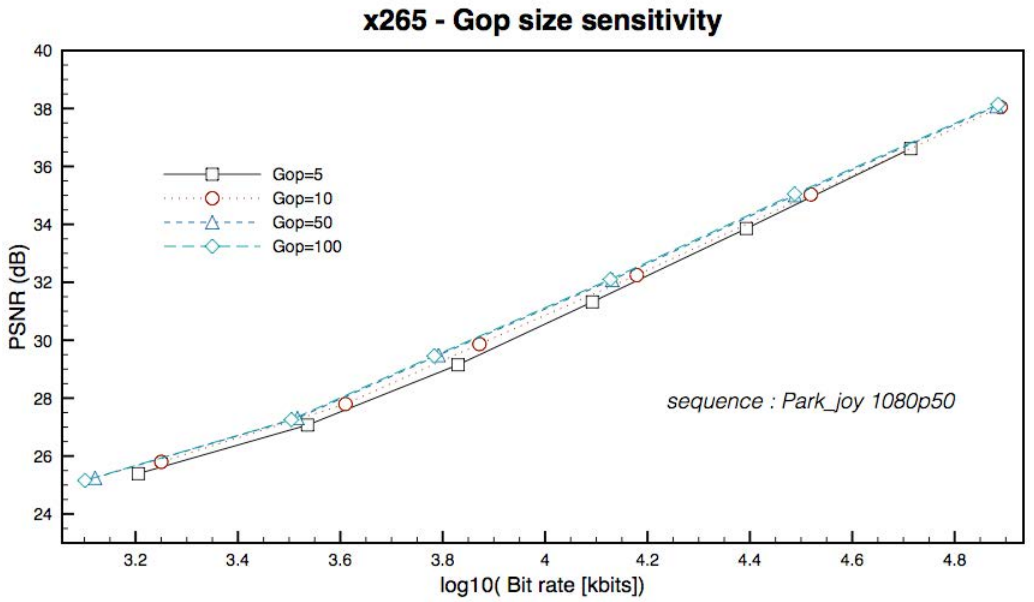


Figure 16: Comparison of the sensitivity on the GOP size for x265

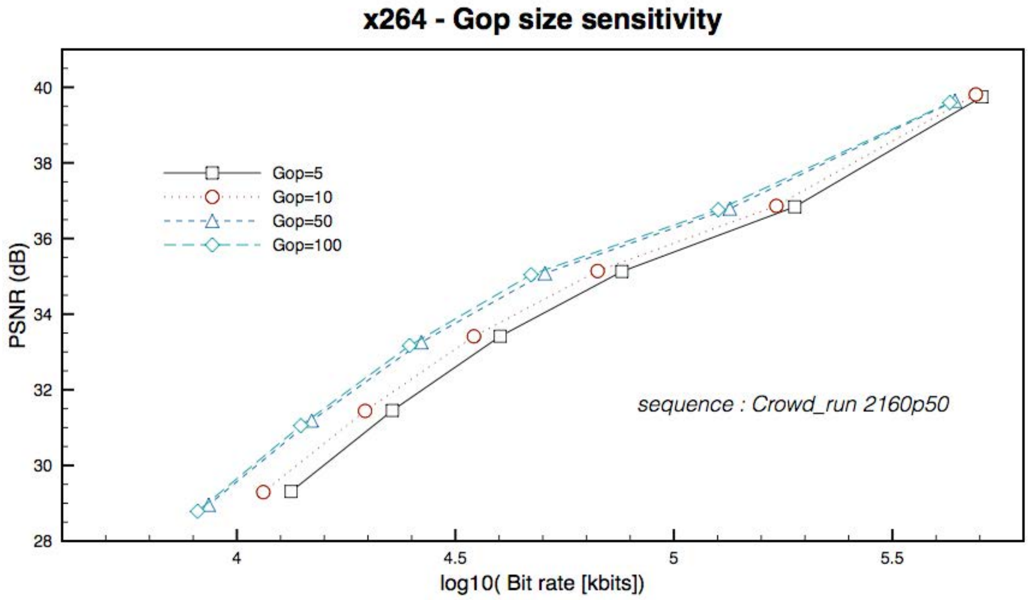


Figure 17: Comparison of the sensitivity on the GOP size for x264

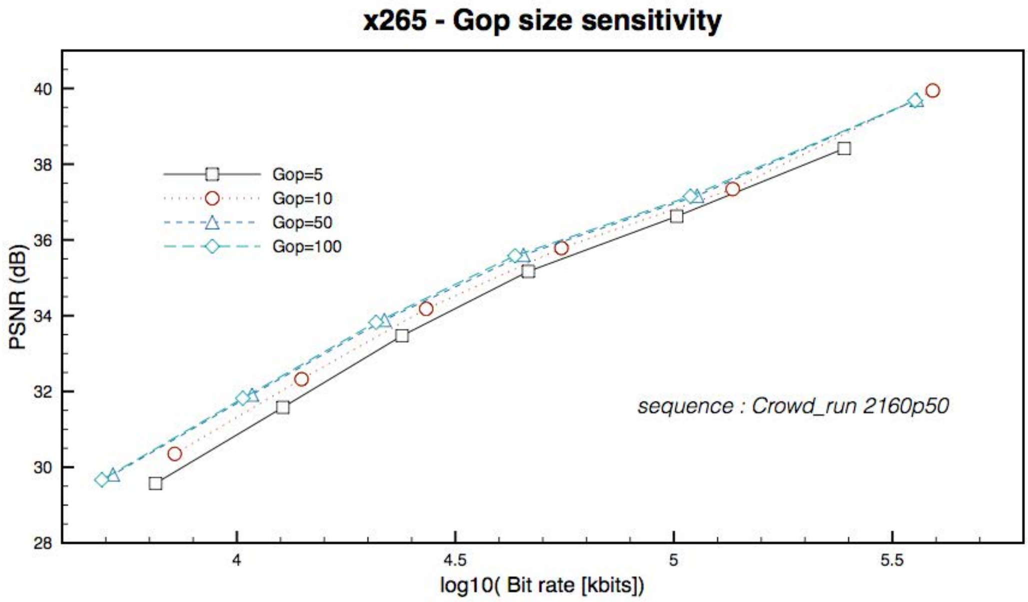


Figure 18: Comparison of the sensitivity on the GOP size for x265

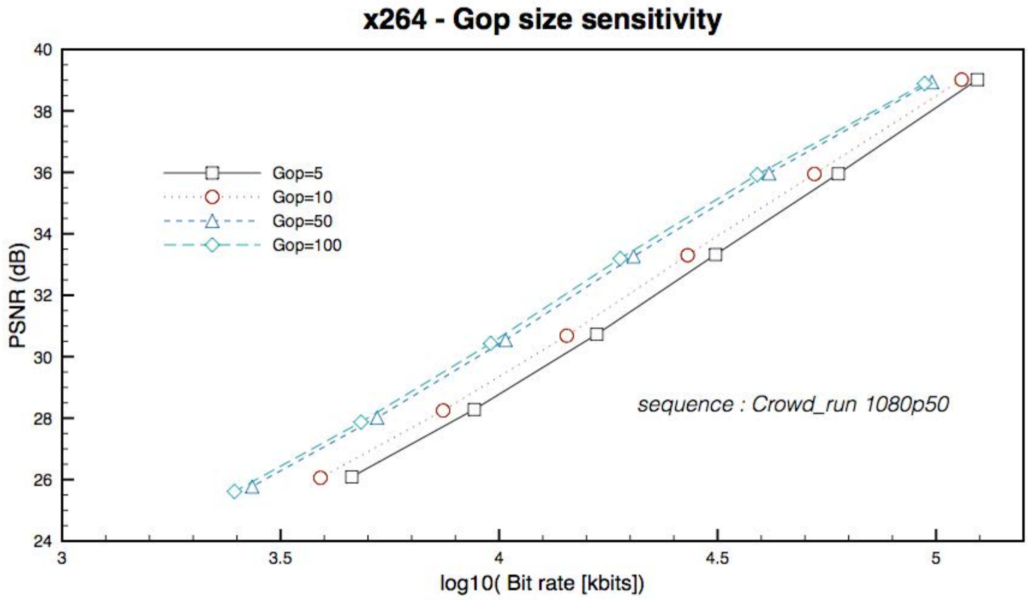


Figure 19: Comparison of the sensitivity on the GOP size for x264

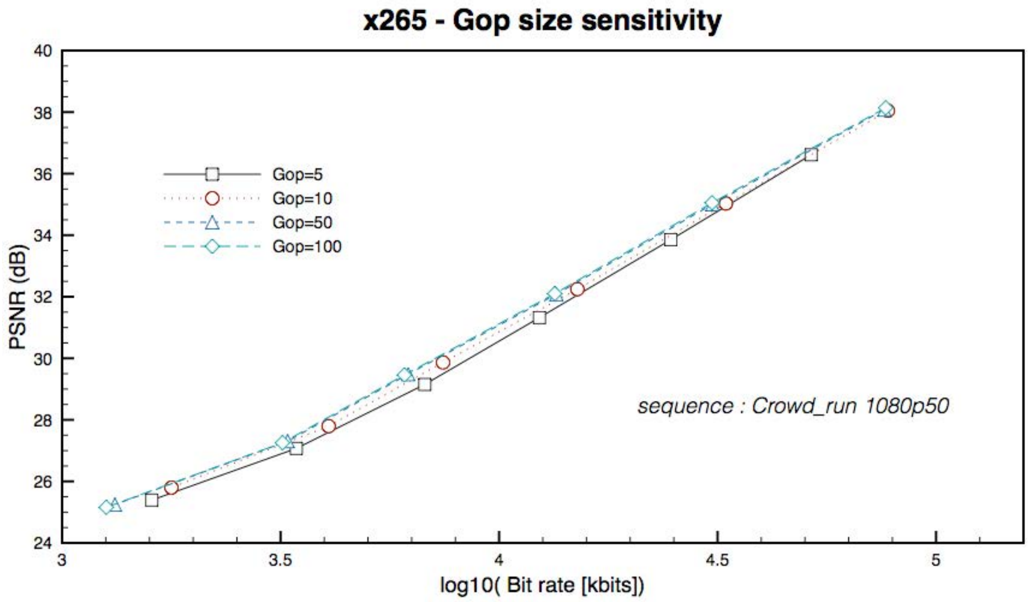


Figure 20: Comparison of the sensitivity on the GOP size for x265

5.5.2 Limiting the size of the slices

The deliveries of UHD/4K-sequences allow LAB2 to test large size images at a rate of 50 fps.

It was demonstrated that a "constant quality" constraint leads to a much better visual quality but involves huge bit-rate for the I-frame and thus transmission issues.

The streaming process needs to limit the NAL (Network Abstraction Layer) size, because it tries to send packets with an entire NAL inside without fragmentation.

The Real time Transport Protocol (RTP) can handle NAL fragments but at a costly time lost on the receiver. Between the emitter and the receiver, an assumed PLT connection with a MTU (Maximum Transfer Unit) near 65 000 bytes, but both extremities use the Ethernet protocol with a MTU of size near 1 500 bytes. Then, in any case there is a huge fragmentation of the IP-packets and thus of the NAL. Then, in case of packet-loss the whole NAL will be unusable, and the most probable lost is on I-frames. Then the whole GOP (Group Of Pictures) will be of poor quality, because P-frames and B-frames are predicted from the I-frame.

Is the NAL size limiting a cause of overload? On an UHD/4k-sequence it seems to be very limited (see figure 21).

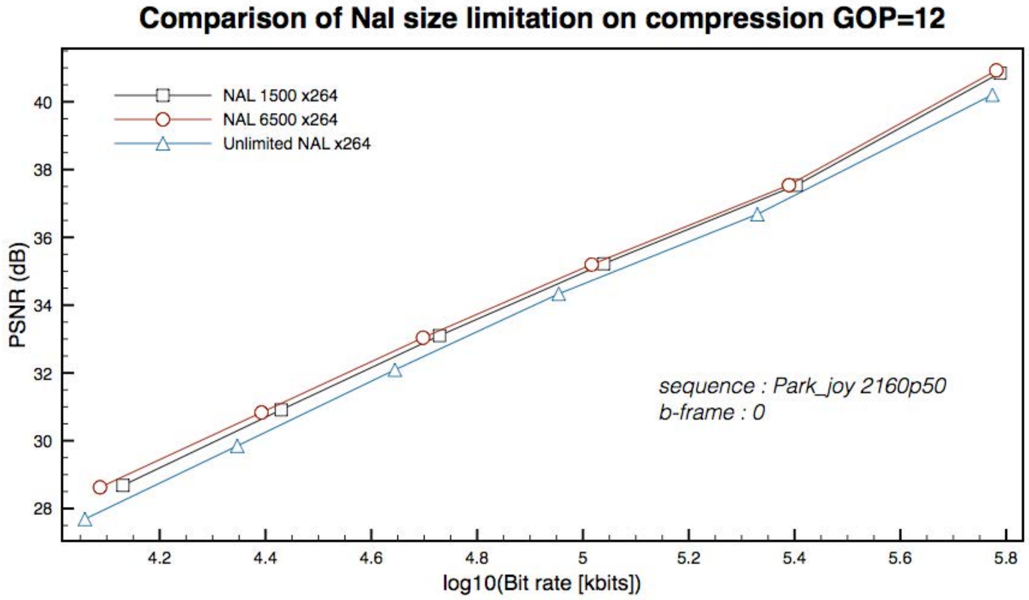


Figure 21: Overload due to limiting the size of the slice

5.6 Coding of a "real life" video

A "real life" sequence of more than 8 minutes at 50 fps containing a mixture of scenes of sport, opera and meetings etc. was run. The sequence was processed with both the codecs x264 and x265. The other codecs cannot be used because of the processing time. For better comparison sequence was converted to YUV 4:2:0 at a depth of 8 bits.

The H.265 codec bit-rate reduction is in this case between 60 % and 80 % compared to H.264 (see figure 20)!

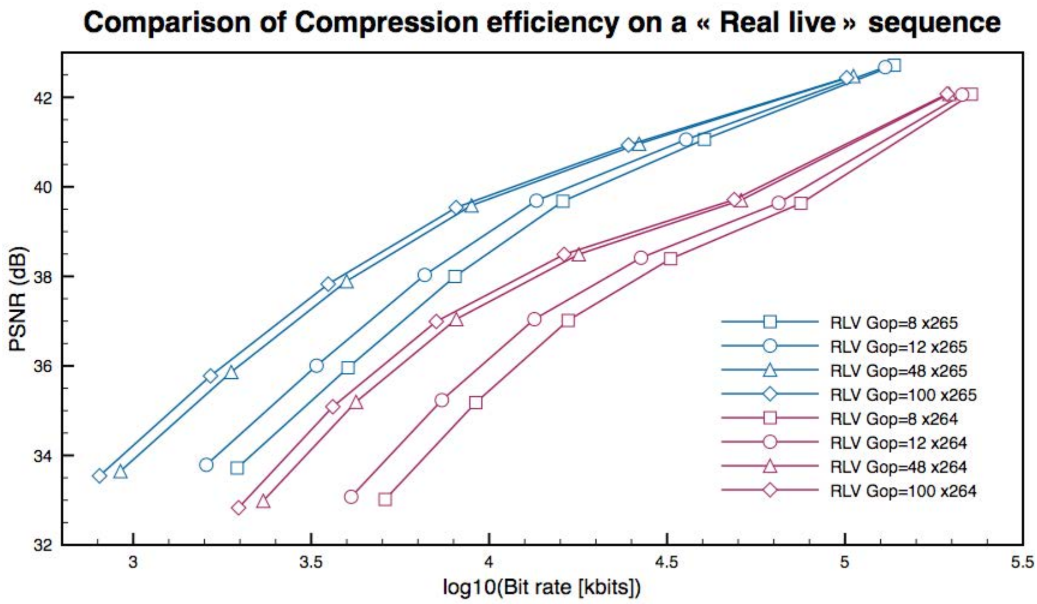


Figure 22: x264 vs x265: Quality comparison

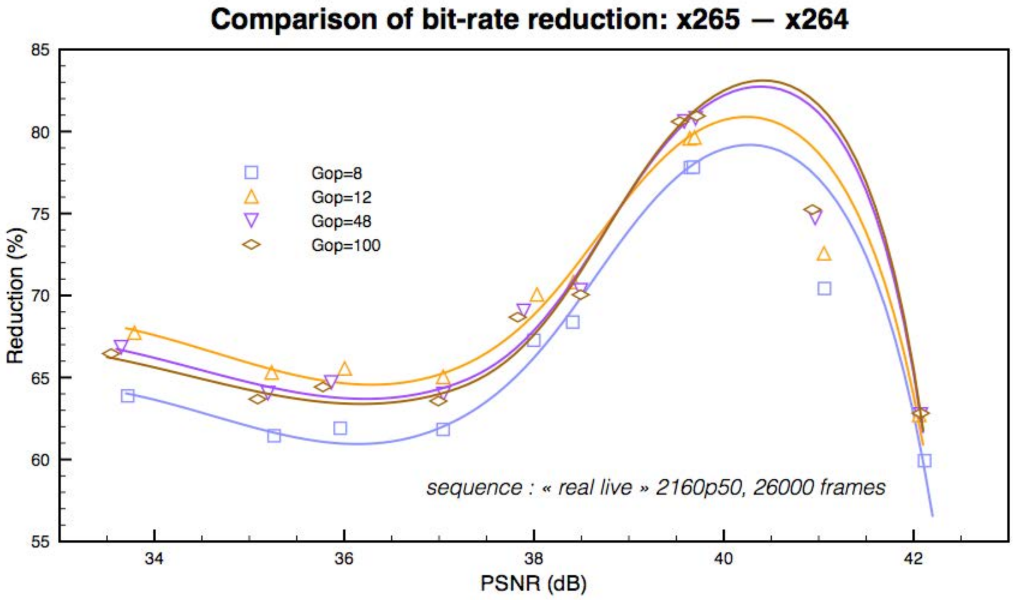


Figure 23: Bit-rate reduction from H.264 to H.265

5.7 Conclusion

The simulations of coding and transmission of HD and UHD video sequences over powerlines networks make assumptions on larger bandwidth instantaneously available as in burst transmission mode, this make easier estimation of each benefit in performance attached to new video codec.

The tests and simulations demonstrated that a good strategy for coding large images, like UHD/4K sequences, is to target a quality criterion rather than a fixed bit-rate when it is possible.

For these experiences, this choice allows us an instantaneous coding bit-rate of the I-frames is several times higher than the average bit-rate of the stream.

It is also shown that the H.265-codec presents a lower sensitivity to the GOP-size in terms of compression ratio.

The experiments show a very interesting usage of shorter GOP and thus obtain a quicker refreshment of the video-stream in case of packet loss over the network.

This is thus an advantage for the H.265 codec for which the performance is less sensitive to the GOP-size.

We observe that limiting the size of the slice and thus of the NAL-size allow a better matching of the network performances.

6 UHD video over Powerline Networks SISO versus MIMO

6.1 Selected Approach for the Test Campaign

6.1.1 Complexity Analysis

The purpose of this analysis is to make sure the complexity in terms of amount of testing of the test campaign does not harm its feasibility.

The complexity of the test campaign is a direct function of the number of parameters and variables that are used and that vary for the purpose of the study, among with:

- The number of types & formats of the video sources:
  - HD
  - UHD/4K
  - Different types of video content (sport, movie, tv show…)
- The number of compression techniques:
  - H.264
  - H.265
- The number of video compression profiles and their rates:
  - video compression profiles
  - compressed video sources rates 8/12/14/16/20 Mps
- The characteristics of the powerline technologies:
  - AV
  - AV2 (and used PLC devices)
- The number of powerline transmission setups: test locations selected for transmission and video quality measurements.

An execution index might also be added in the above list whenever a statistical approach would be followed in order to average results.

Example of complexity in terms of number of files

# of source format (HD/UHD-UHD)	3
# of source content (sport/cinema/slowmotion)	3
# of compression types (H.264/H.265)	2
# of sequence rates (8/12/14/16/20)	5
# of powerline technologies (AV/AV2SISO/AV2MIMO)	3
# of powerline fieldTest setups/locations	5

# of video source sequences	90
# of output sequences for analysis (after transmission)	**1 350**

Example of complexity in terms of file sizes (compressed case)

Compressed Sequence - Rate (Mb/s)	8		12		14		16		20	
Sequence Duration (s)	10	60	10	60	10	60	10	60	10	60
File size for one video sequence (MB)	10	60	15	90	17,5	105	20	120	25	150
TOTAL FILE SIZE (TB)	**3**	**17**	**4**	**26**	**5**	**30**	**6**	**35**	**7**	**43**

TOTAL FILE SIZE (TB) - aggregating all the rates	**25**	**151**

Example of complexity in terms of file sizes (uncompressed case)

	HD 1 920 x 1 080				UHD 4 096 x 2 160			
# of pixels	2 073 600	2 073 600	2 073 600	2 073 600	8 294 400	8 294 400	8 294 400	8 294 400
# of components	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
# of quantif bits	8	10	8	10	8	10	8	10
rate (images/s)	25	25	25	25	50	50	50	50
Sequence duration (s)	10	10	60	60	10	10	60	60
File size of one video sequence (GB)	**1**	**1**	**5**	**6**	**6**	**8**	**37**	**47**

Sequence Duration (s)	10	60
TOTAL FILE SIZE (TB) - *with q=10 bits*	**18**	**108**

6.1.2 Test Methodology

To face the above complexity, a reasonable balance was found between the following two constraints:

- On one hand, one has to deal with a limited power of real-time processing when evaluating the video quality criteria - the need for power of processing may be huge as video definitions & decompression complexity increase.
- On another hand, one has to deal with a limited capacity of files storage - files storage may indeed oversize quickly as many configurations are considered and as heavy/complex sequences are meant to be stored.

To deal with such a complexity, the following approaches are followed:

- Pre-encoded video streams are stored in a PC before use and ready for streaming:
  - details of the compression tools are given in clause B.1.4;
  - the definition of the set of pre-encoded sequences ready to transmit are given in annex A.
- A **PC-based streaming tool** is used in a single-stream only environment:
  - The streaming server software is: **live 555 Media Server** – LAB2 modified to handle NAL Units > 150 000 bytes and to transmit videos at 50 fps by default.
- Reception scheme:
  - On-the-fly (real time) decompression:
    - Real-time Display is used only for setup or demonstration purpose and also for preparation need (not for the field test campaign itself).
    - Set-top boxes are also used for this purpose.
  - Received uncompressed video files are stored:
    - With openRTSP software 2014-05-14.
    - For post-decompression with avlib library version 10.
    - For post-quality analysis with qPSNR version 0.2.5 – LAB2 modified for compatibility with libav version 10.
    - For post-visualization with VLC version 2.2.0-git Weathermax (revision 2.1.0-git-3463-g3054560).

6.1.3 Reference sequences

The video sequences used are different for the laboratory test campaign and the field test campaign.

The reason for such a difference is that the laboratory test campaign aims at finding the best parameters for the two codecs H.264 and H.265 as well as assessing video streaming performances over PLC, while field test campaign goal is to quantify the home coverage improvement for HD/UHD video thanks to H.265 and powerline MIMO over H.264 and powerline SISO.

In order to verify the impact of a single parameter, one need to generate as many compressed video sequences as parameter values. To avoid getting a huge and non-manageable set of compressed video sequences, a single source sequence was chosen to base all of the compressed sequences: ***park_joy***. See sequence characteristics in annex A.

For the field test campaign, a video sequence which is a concatenation of several "real-life" video sequences was chosen, in order to get something representative of the various video flux that travel through PLC on end-customers houses.

Table 1 gives the name of the various sequences used for laboratory and field tests campaigns.

Table 1: Reference Sequences

Test Campaign	Sequences names
Laboratory	Park_joy
Field	FTV

6.2 Introduction to Broadband Powerline Technologies

The powerline grid was originally designed to deliver electrical power at 50 ~ 60 Hz. It is also possible to transmit digital signals at high frequency with PLC technology. Since a lot of powerline outlets are available in houses, the access of PLC networks is much easier than other network solutions without new wiring.

In the present Technical Report SISO-PLT is referring to PLT technologies operating on a single channel using Phase and Neutral wiring of a home and MIMO-PLT are referring to PLT technologies that in addition to using the Phase and Neutral also exploits the existing ground wiring for additional channels.

Adapting MIMO transmission and reception techniques to a wired medium such as the home electrical networks requires to solving issues address in STF410 both regarding the physics of electromagnetic transmission and the channels and noises.

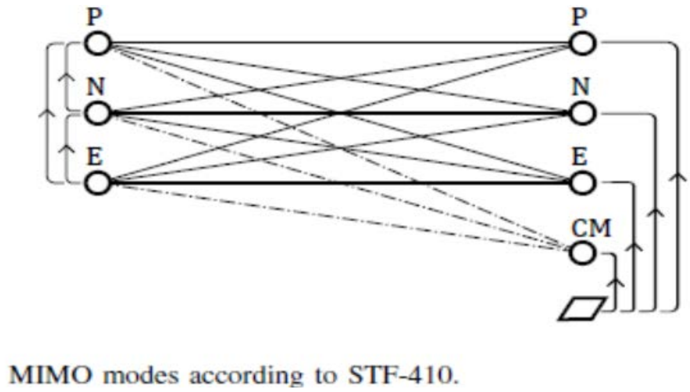


Figure 24: MIMO modes explored in STF410

As a result of STF410, MIMO PLC has been adopted in several broadband PLC specifications and products are reaching the market places.

MIMO PLC increased channel capacity adhering to the electromagnetic compatibility regulations currently in force.

Among MIMO techniques, it is found that beam forming is the best choice for MIMO PLC: the full spatial diversity gain is achieved for highly attenuated channels and maximum multiplexing gain is achieved for channels with low attenuation by utilizing all spatial streams.

In the following the PLT-AV1 is referring to PLT operating in frequency band of 1 MHz to 30 MHz and PLT-AV2 operating in frequency band of 1 MHz to 100 MHz with usual notched frequencies and according to CENELEC EMC requirements.

More precisely, the devices used for the tests were based on HomePlug® technologies, as described below.

6.2.1 HomePlug® AV (SISO only)

HomePlug® AV (HPAV) is a technology from the HomePlug® Alliance which provides high-quality, multi-stream, Layer 2 transport over existing AC wiring within the home. HPAV employs advanced PHY and MAC technologies providing up to a 200 Mbps powerline network capacity for the transport of video, audio and data content.

The Physical (PHY) Layer of HPAV uses a 200 Mbps channel rate to provide near a 100 Mbps information rate with robust, near-capacity communications over noisy powerline channels.

The PHY operates in the frequency range of 2 MHz - 28 MHz. It uses windowed OFDM and a powerful Turbo Convolutional Code (TCC), which provides robust performance within 0,5 dB of Shannon Capacity. OFDM symbols use 917 usable carriers (tones) in conjunction with a flexible guard interval. Different Modulation densities are also used going from BPSK to 1 024 QAM and are applied independently to each carrier based on the channel characteristics between the transmitter and the receiver.

Scrambling, Turbo FEC Encoding and Interleaving are also used to protect the data during their transmission.

6.2.2 HomePlug® AV2 (SISO & MIMO)

HomePlug® AV2 technology is an extension of the AV powerline technology, enabling gigabit-class speeds to almost every electrical outlet in the home, making it suited for Internet video, multi-room IPTV, online gaming, but also other high demand home networking uses, particularly the transport of multiple HD or 4k-UHD devices simultaneously.

The HomePlug® AV architecture has been extended upward to provide two to five times the performance of HomePlug® AV. This enables HomePlug® AV2 to provide both the throughput and coverage needed to support the escalating requirements of next-generation multimedia applications.

Key features enabled by HomePlug® AV2 include:

1) Gigabit-class PHY Rate
2) Support for MIMO (multiple-input and multiple-output) PHY
3) Whole home coverage with inherent repeater functionality
4) Streaming multiple high-definition video and audio programs
5) Interoperable with HomePlug® AV
6) HomePlug® Green PHY and IEEE 1901 devices
7) Power save with three modes of operation (Active, Standby and Idle)

In HomePlug® AV2 additional frequency spectrum are used beyond the frequency used for HomePlug® AV (30 to 85 MHz), significantly increasing HomePlug® AV2 throughput compared to AV. The additional spectrum also improves peak data rates and performance.

The HomePlug® AV2 specification also incorporates Multiple-Input Multiple-Output (MIMO) capabilities with beamforming. This offers the benefit of improved coverage throughout the home; particularly for hard-to-reach outlets. MIMO uses two independent transmitters and up to four receivers, with beamforming to improve the performance on independent streams. It enables HomePlug® AV2 devices to transmit on any two wire pairs within three-wire configurations.

Also, whereas HomePlug® AV always transmits on the Line-Neutral pair, HomePlug® AV2 can transmit on any two pairs formed by the Line, Neutral or Ground wires (i.e. Line-Neutral, Line-Ground or Neutral-Ground). This allows for significantly improved peak data rates and performance.

Note that some regions and some homes donot have the third wire required to implement MIMO however HomePlug® AV2 automatically switches to standard SISO operation whenever the third wire is not available.

HomePlug® AV2 also incorporates improved coding schemes in the PHY, which provide robust error correction and better peak data rates, while assisting with performance improvement on good paths at high data rates. The key improvements are higher order modulation (4 096-QAM), higher Rates (8/9 code rate) and smaller guard intervals Code.

Table 2: Comparison between HomePlug® AV, AV2 SISO & AV2 MIMO powerline technologies

	HPAV	HPAV2 SISO	HPAV2 MIMO
Frequency band	**2 MHz to 28 MHz**	**2 MHz to 28 MHz and 30 MHz to 85 MHz**	**2 MHz to 28 MHz and 30 MHz to 85 MHz**
SISO / MIMO	SISO	SISO	MIMO
Modulation	1 024-QAM	4 096-QAM	4 096-QAM
# of Carriers	917	Up to 3 455	Up to 3 455
Code rate	½ or 16/21	½ or 16/21 or 8/9	½ or 16/21 or 8/9

6.3 Laboratory Test Campaign

6.3.1 Introduction

6.3.1.1 Objectives and Goals

The Laboratory 2 performs tests campaign both in lab and real houses with three main objectives.

The first is to determine the best compression parameters for both H.264 and H.265 in order to get the best achievable video quality over a given PLC channel.

The second is to quantify the improvement of the performance in terms of achievable video quality and bitrate permitted by different evolutions of PLC technology.

The third goal consists in the quantification of the improvement given by H.265 versus H.264 for video streaming of HD and UHD sequences over a PLC channel.

6.3.1.2 Selected Approach

In order to achieve these goals, the selected approach is to transmit the different sequences, each encoded with different parameters in H.264 and H.265, over an AWGN PLC channel, with different Signal-to-Noise Ratio (SNR) values.

Each received sequence is then stored to post-compute all the desired quality metrics: PSNR, SSIM, Quality of Experience (QoE).

This approach allows to display the video quality metrics with respect to the tested powerline configuration (the SNR values), and to superimpose these graphs pointing out the impact of various parameters on the video quality.

Assessment of PLC technologies performance capabilities in terms of bitrate is also performed. This test consists in feeding the emitting modem using a traffic with a fixed bitrate and then to measure the bitrate of the traffic successfully received at the receiver modem using different powerline SNRs. This results in a graph representing the achieved powerline bitrate performance (in other words, the powerline capacity) as a function of the PLC channel quality for each powerline technology (PLT-AV, PLT AV2 SISO, PLT AV2 MIMO).

All the Laboratory Test Campaign methodology is described in annex B.

6.3.2 Results analysis

This part presents the quality assessment of video transmissions over different state (SNR) of the PLC channel. These assessments are used to compare the impact of the following parameters on the video quality:

- NAL unit size: see clause 6.3.2.1
- I frame period: see clause 6.3.2.2
- Coding strategy: see clause 6.3.2.3
- Codec used: see clauses 6.3.2.4 and 6.3.2.5
- PLC technology used: see clause 6.3.2.6

As stated in the test plan, the performances of each PLC technology in terms of maximum achievable bitrate in presence of AWGN noise (clause 6.3.3.1) was measured.

6.3.2.1 NAL Unit size impact

Referring to 6, a NAL unit is a chunk of compressed video, ready to be packetized (e.g. in an RTP packet). As stated in clause 6.3.2.3.2, there is different manners to encapsulate NAL units into RTP packets, depending of the size of the NAL units and the maximum payload size of the RTP datagrams:

- If the NAL unit size is greater than the RTP payload size, then it will be split into several RTP datagrams.
- If the NAL unit size and the RTP payload size are the same, then the NAL unit will be transmitted within one RTP datagram.
- If the RTP payload size is large enough to contain *n* NAL units, then these *n* NAL units will be transmitted within one RTP datagram.

This NAL unit size can have an impact on data loss and bitrate. More specifically, dealing with large NAL units (split over multiple RTP datagrams) reduce the overhead and thus the bitrate, but make the transmission more loss-sensitive as an error on one bit of the NAL unit leads it to be discarded. On the contrary, dealing with small NAL units make the transmission less loss sensitive, but induce more overhead and, as a consequence, a greater bitrate.

It has to be noted that using NAL units smaller than the maximum RTP payload has no interest given the fact that when an error is detected within an RTP datagram, all the datagram is discarded. So, in a context where multiple NAL units are present in a single RTP datagram, if an error is present on one of the NAL units, all the NAL units present in this datagram will be lost.

As this packetizer mechanism is identical in both H.264 and H.265, only measurements with H.264 compressed video sequences were conducted.

Two values of maximum NAL unit size was chosen:

- 1 500 bytes which is close to the maximum payload size of the RTP datagrams permitted by our test bench (1 436 bytes).
- 65 000 bytes which is largely greater than the maximum payload size of the RTP datagrams permitted by our test bench.

In figure 25, it can be seen that limiting NAL units to 1 500 bytes leads to a more robust transmission as a the percentage of video decoded is greater than with NAL units size limited to 65 000 bytes.

One can also see on the quality (SSIM and PSNR) curves figures 26 to 27 that the quality of the successfully decoded frames is better with NAL units size limited to 65 000 bytes.

However, for low PLC SNR (below 6 dB), the NAL units limit of 1 500 bytes allows the decoding of 30 % (see note) more video compared to NAL units limit of 65 000 while the quality loss is only of 18 % for SSIM and 15 % for PSNR.

NOTE: Here and below, percentages are relative differences of performances normalized by the quality/number of decoded frames of reference (calculated on the non-transmitted compressed sequences).

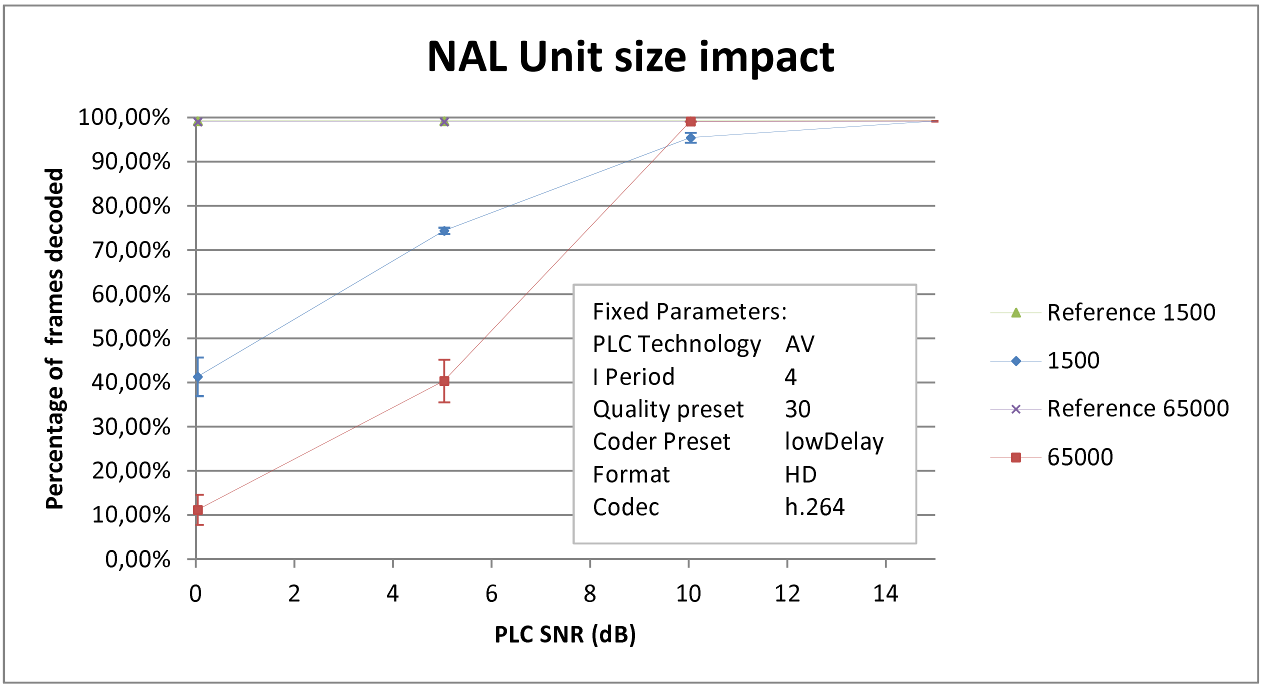


Figure 25: Impact of NAL unit size on decoding performances - % of frames decoded

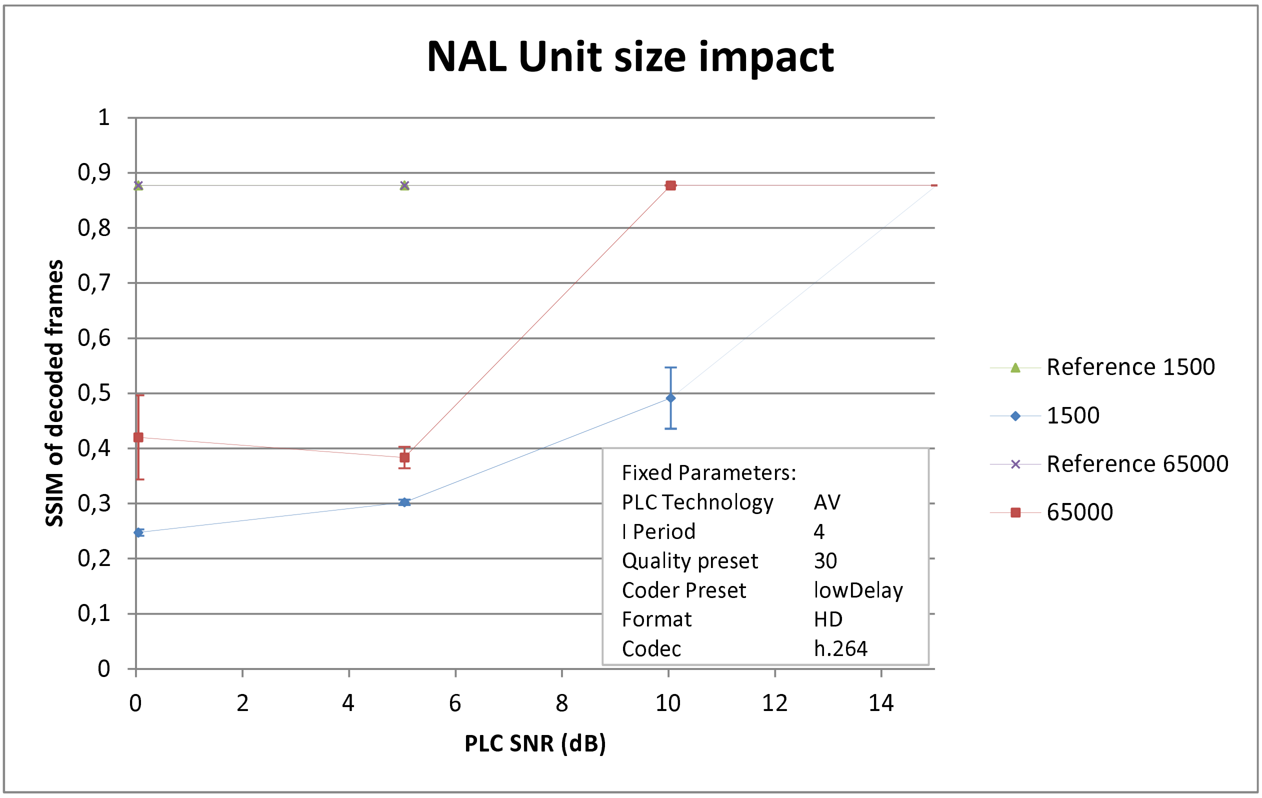


Figure 26: Impact of NAL unit size on decoding performances - SSIM

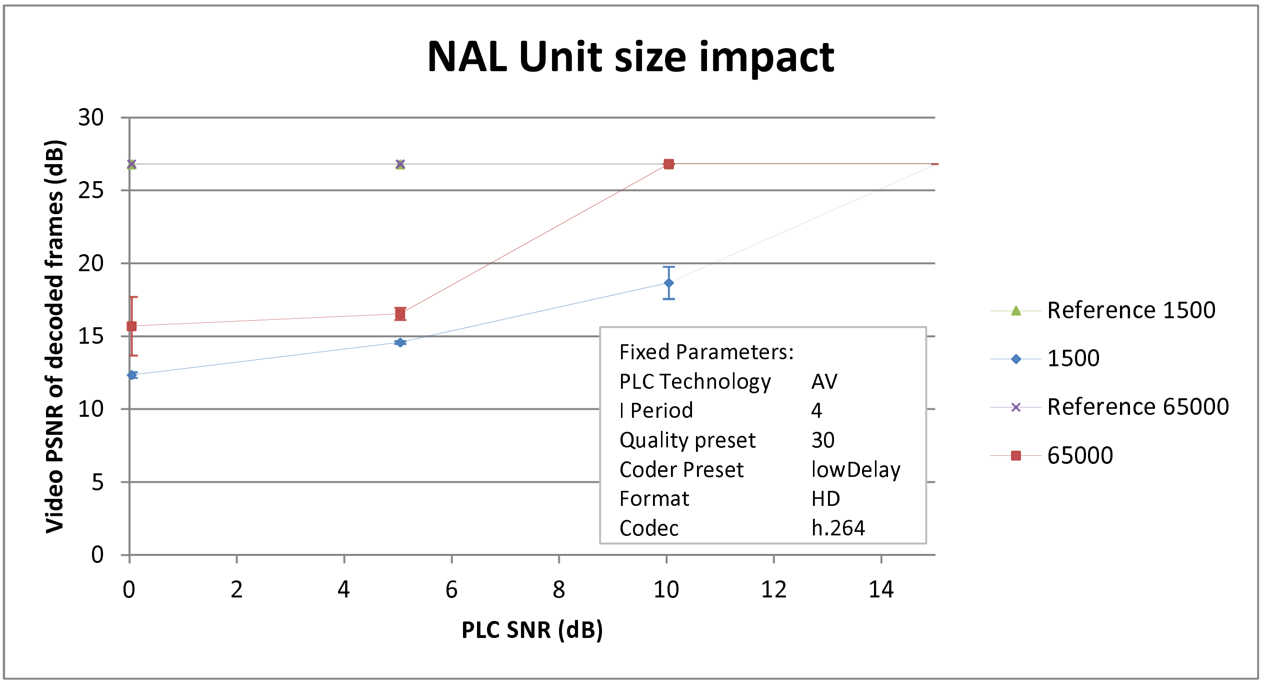


Figure 27: Impact of NAL unit size on decoding performances - PSNR

6.3.2.2 I frame period impact

The I frames are the reference frames which are derived (motion estimation, etc.) by the coder to produce the P and B frames. Reducing the I frame period has several advantages:

- The video quality is better, even without losses.
- If an isolated loss occurs (i.e. bitrate is below channel capacity), the original image quality will be retrieved faster (as soon as another I frame is received).
- The interactivity is better (decoders wait for an I frame to begin decoding).

But I frames needs more bitrate to be transmitted than P or B frames, so reducing I frame period also means consuming more bandwidth. Furthermore, each I frame transmission induce a huge bitrate peak (see figure 28, each peak is caused by the emission of an I frame) that has to be smoothed by using caches in order to avoid losses. This caching reduces the interactivity.

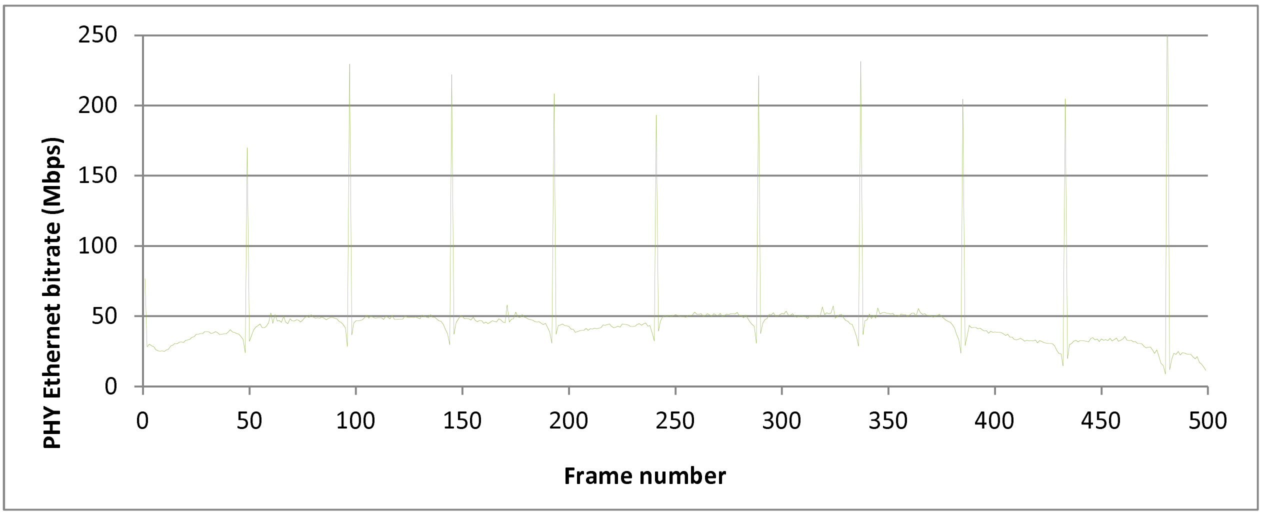


Figure 28: Video diffusion bitrate behaviour

Here the video quality with four I frame periods was measured:

- 1 I frame every 8 frames (I8)
- 1 I frame every 16 frames (I16)
- 1 I frame every 48 frames (I48)
- 1 I frame every 96 frames (I96)

It was observed for both H.264 and H.265 that the lower I frame period, the lower performances. The curves below also show that the quality gains are not significant for I frame period greater than 16. Given this, and the fact that too big I frame periods leads to loss of interactivity, it is recommended to use I frame period of 16.

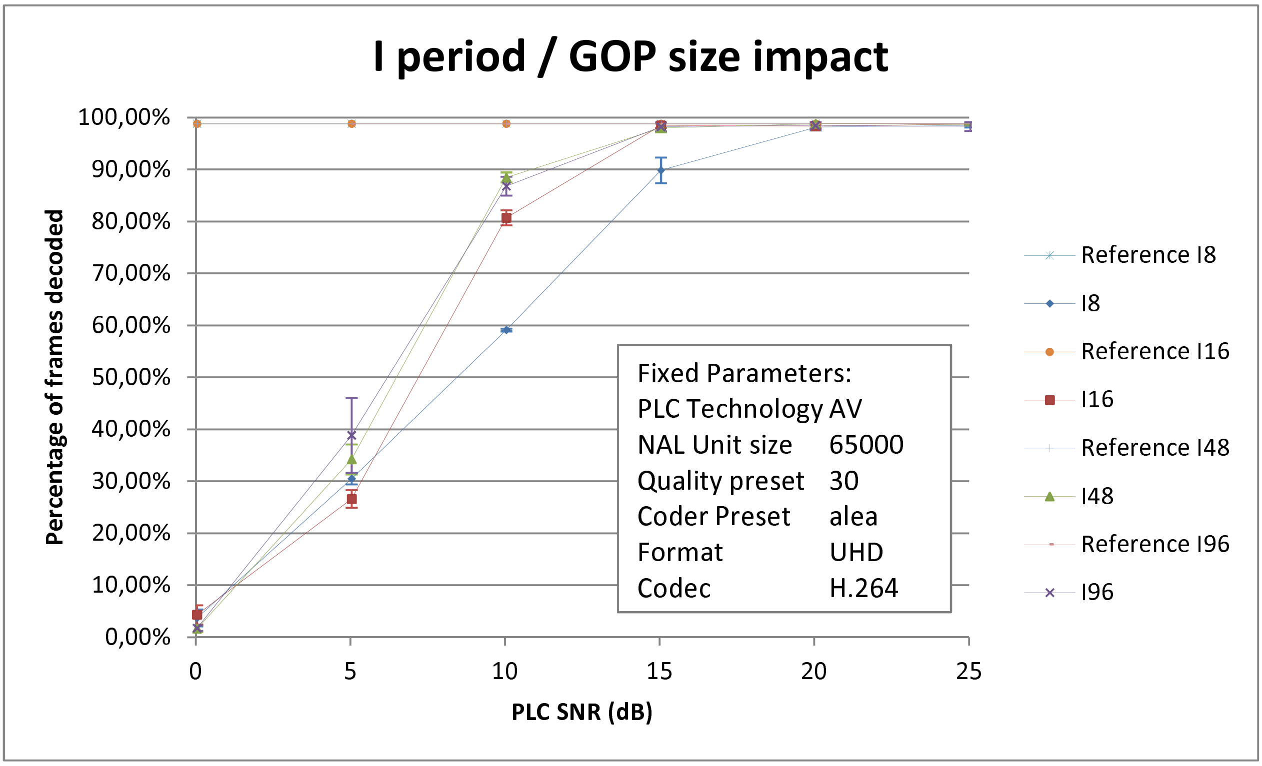


Figure 29: I period / GOP size impact - H.264 - % of frames decoded

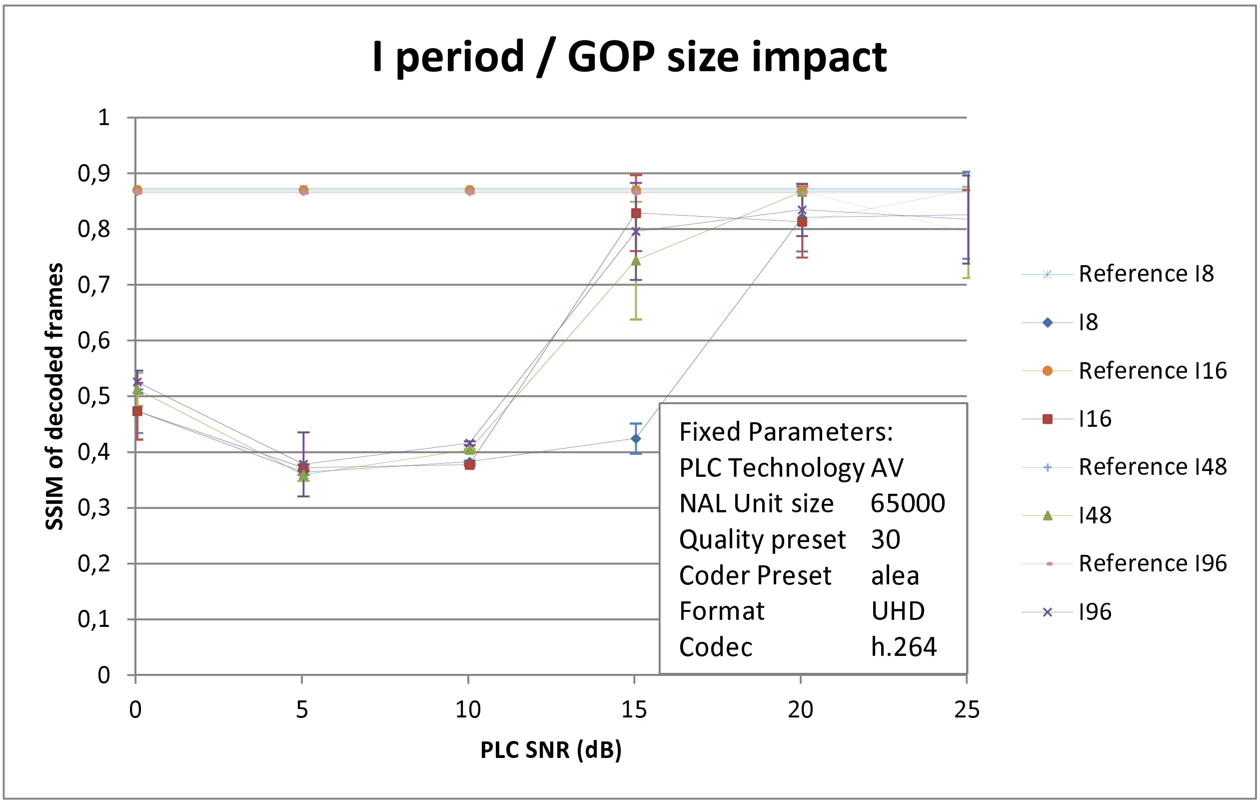


Figure 30: I period / GOP size impact - H.264 - SSIM

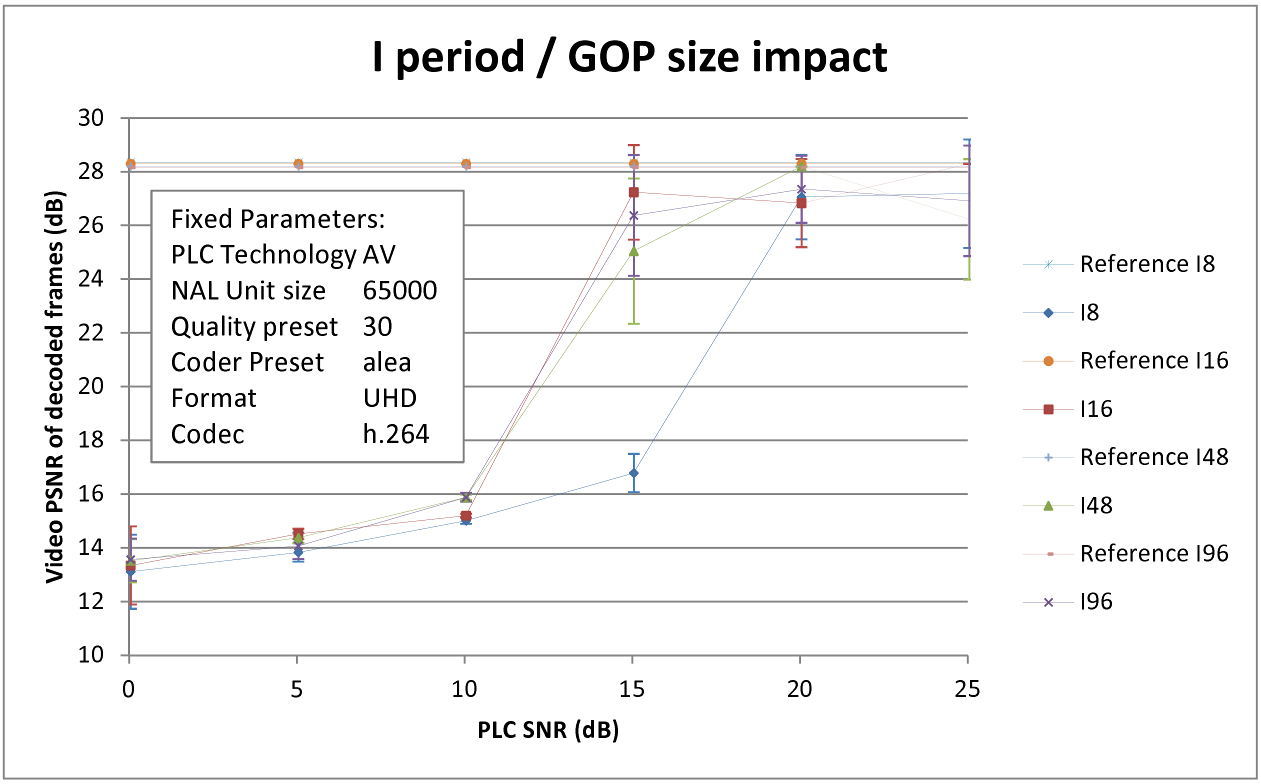


Figure 31: I period / GOP size impact - H.264 - PSNR

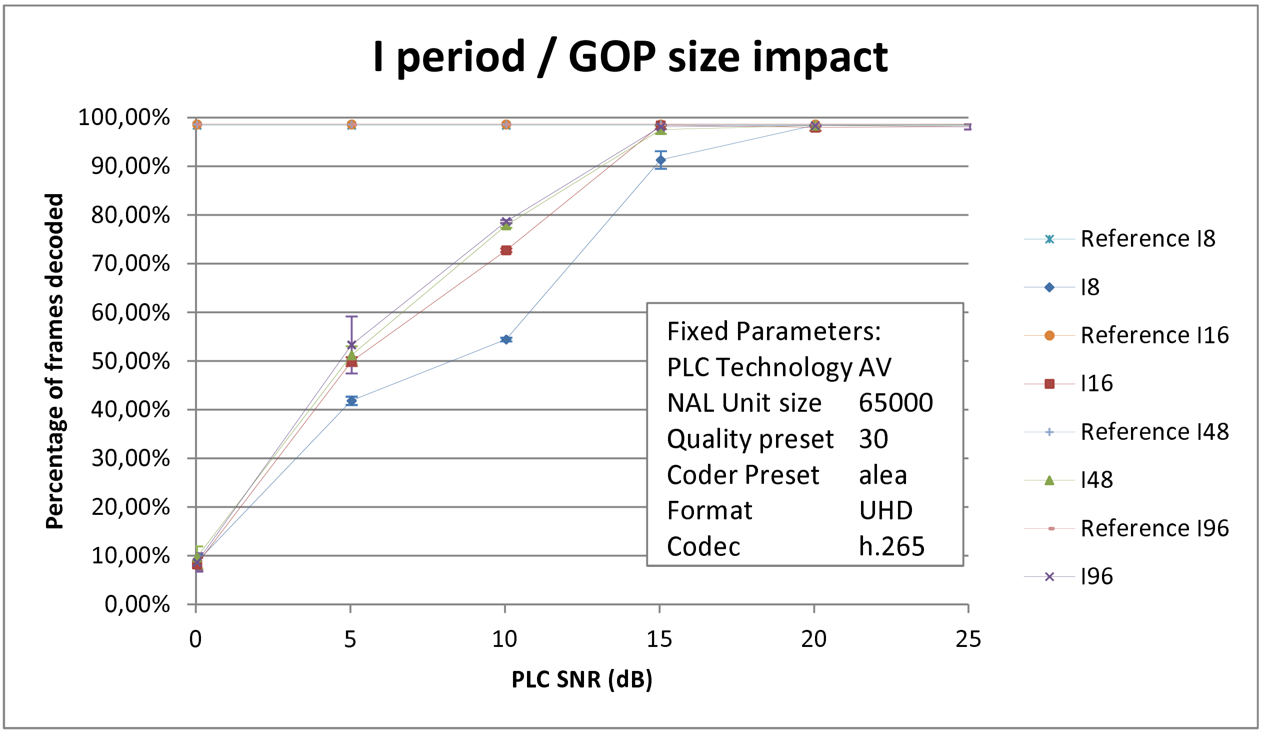


Figure 32: I period / GOP size impact - H.265 - % of frames decoded

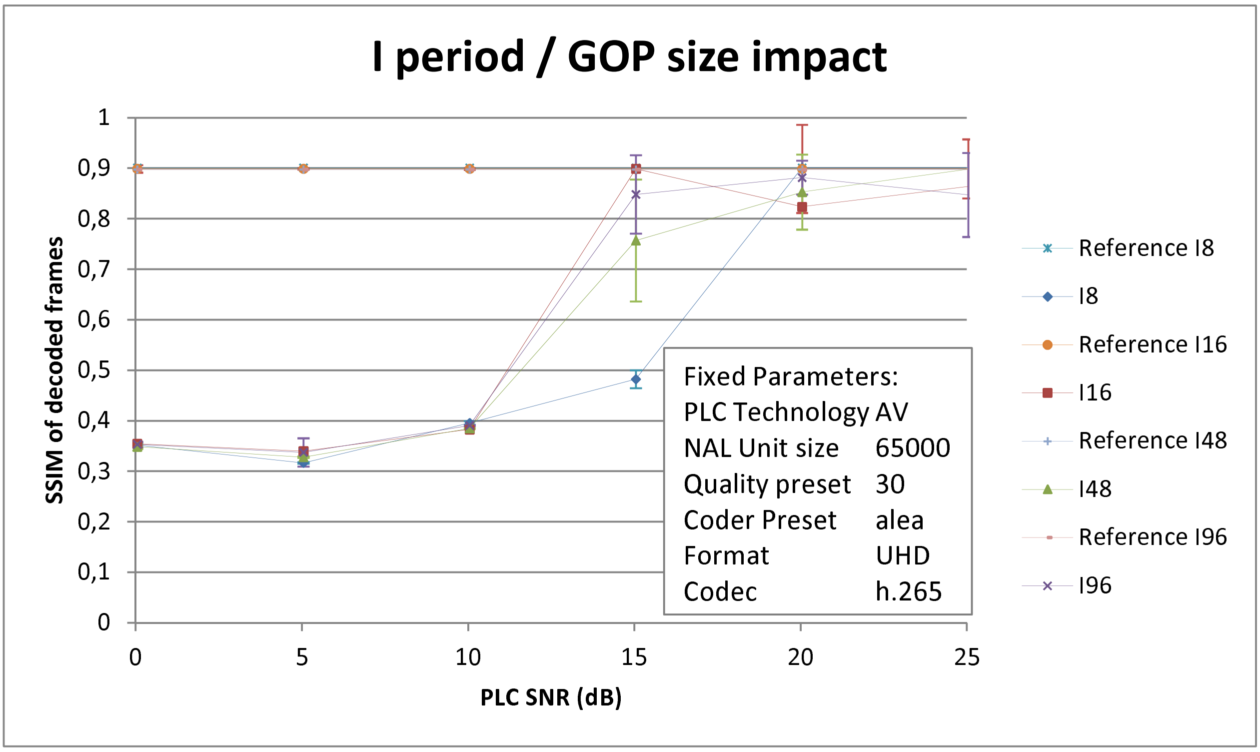


Figure 33: I period / GOP size impact - H.265 - SSIM

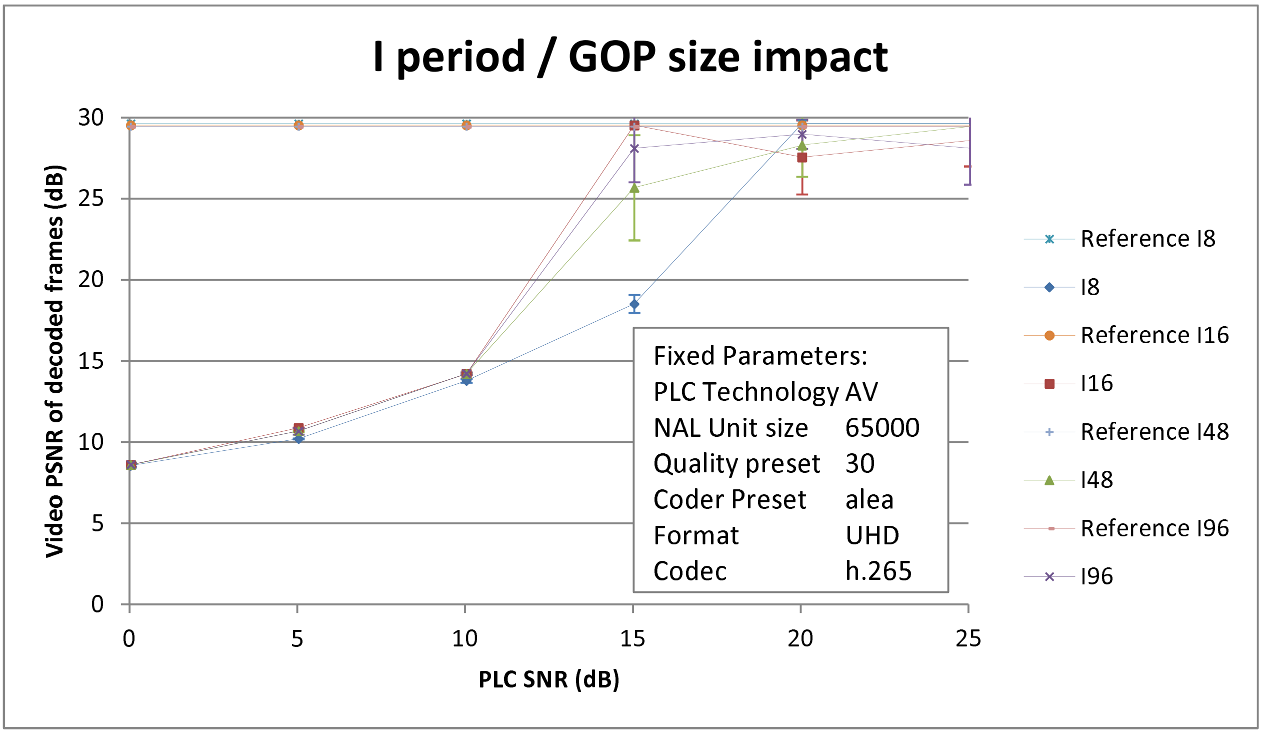


Figure 34: I period / GOP size impact - H.265 - PSNR

6.3.2.3 Coding strategy impact

Here the impact of two coding strategies which are two presets of the coders (H.264 and H.265) are studied. The first one "lowDelay" is designed to fit appliances which needs great interactivity like videoconference. The second one "alea" is a preset in which the coder will try to optimize his coding parameters in order to be the most efficient in terms of compression.

As seen in the below figures 35 to 40, one can observe a similar phenomenon as for the NAL unit size impact. The "alea" coding strategy leads to a greater number of frames decoded but, on the decoded frames, the average quality is lower than with the "lowDelay" preset. However, the gain in number of frames decoded (up to 60 % @ PLC SNR of 10 dB) is greater than the loss of video quality (up to 11 % SSIM and 11 % of PSNR). The behaviours are similar with both H.264 and H.265.

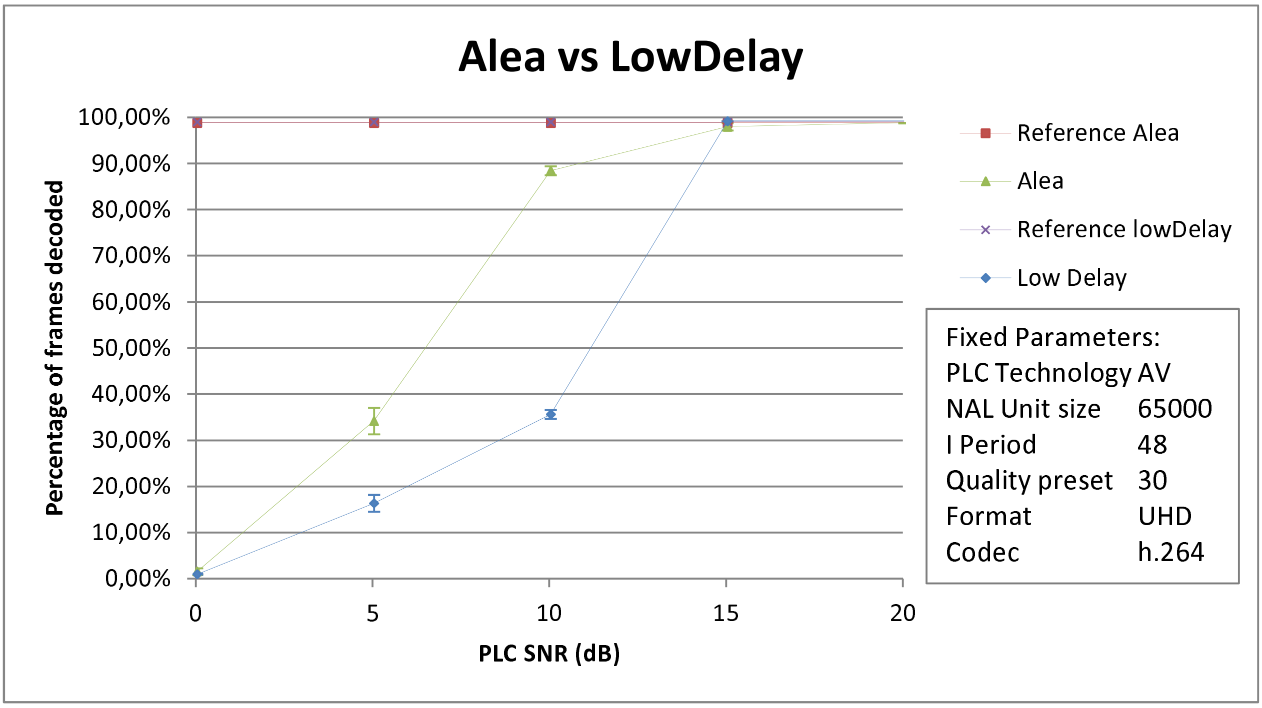


Figure 35: Alea vs LowDelay - H.264 - % of frames decoded

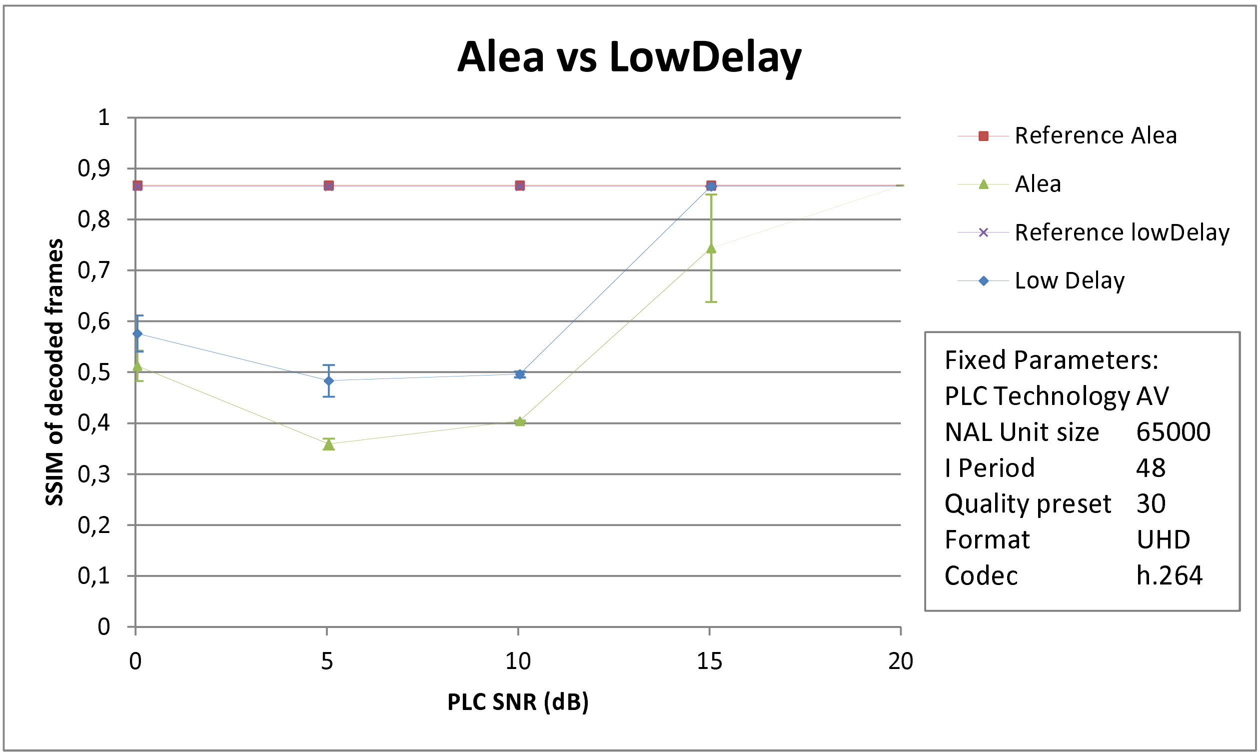


Figure 36: Alea vs LowDelay - H.264 - SSIM

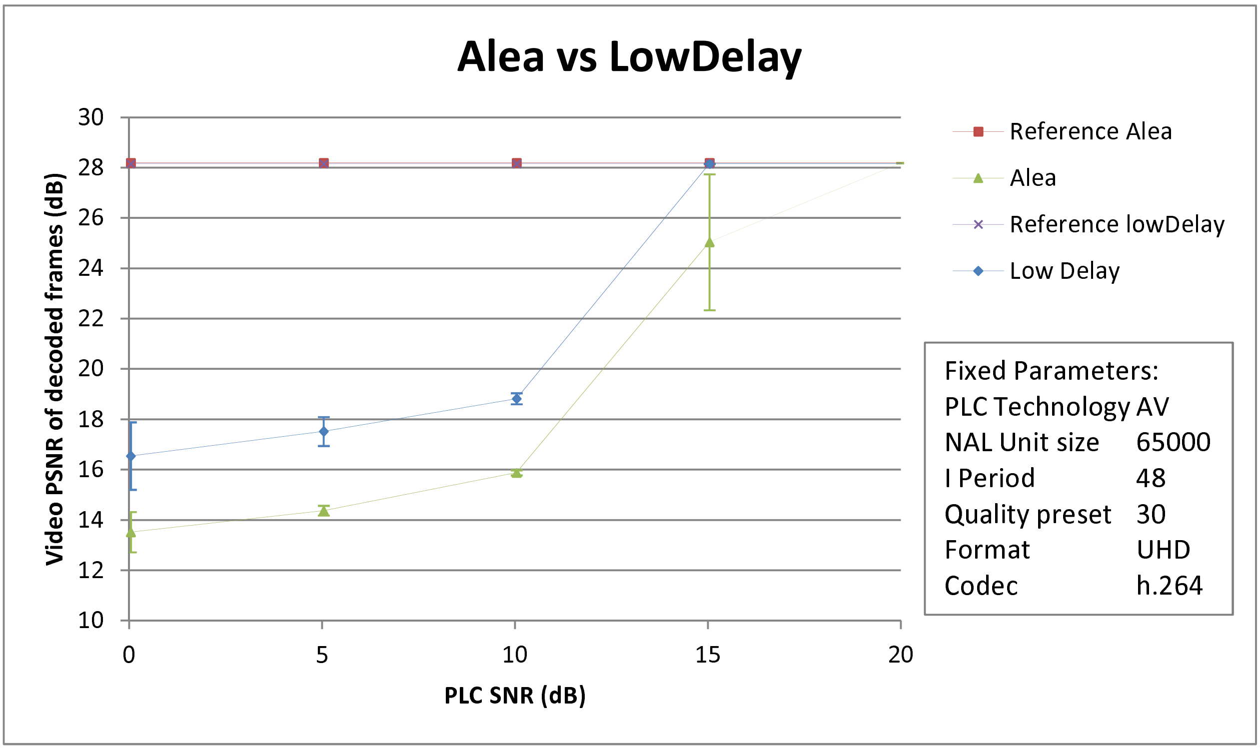


Figure 37: Alea vs LowDelay - H.264 - PSNR

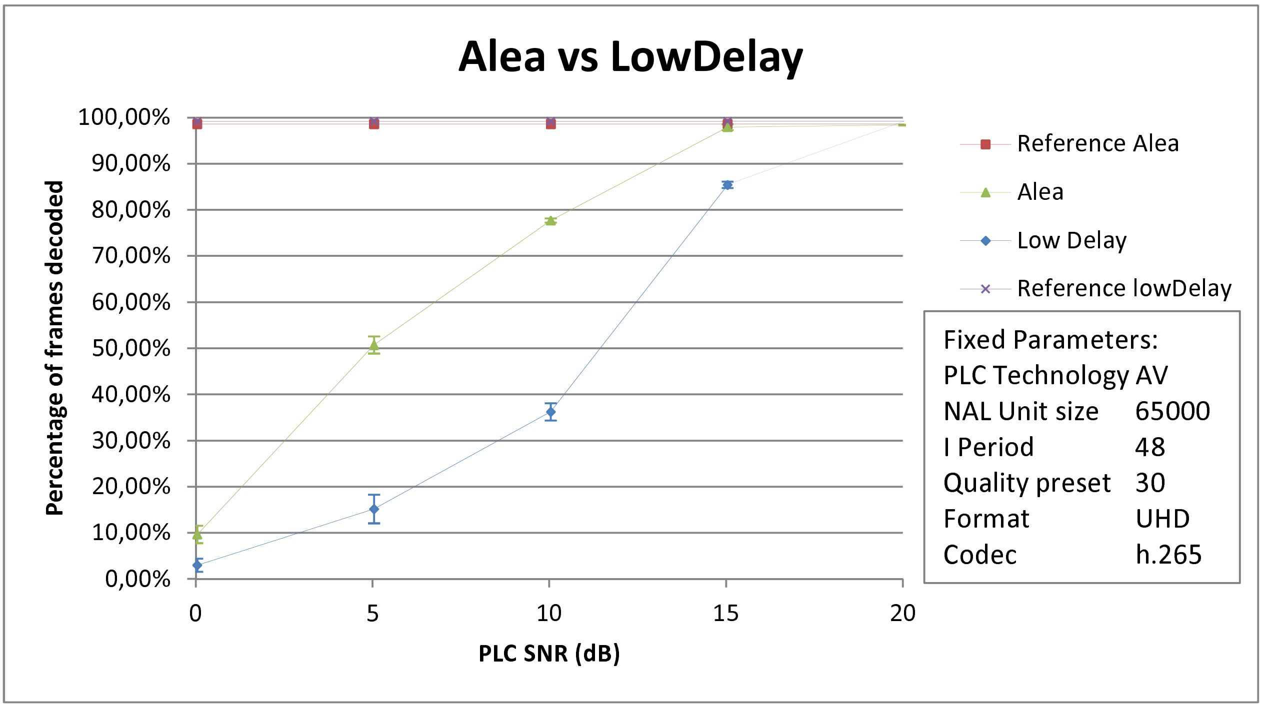


Figure 38: Alea vs LowDelay - H.265 - % of frames decoded

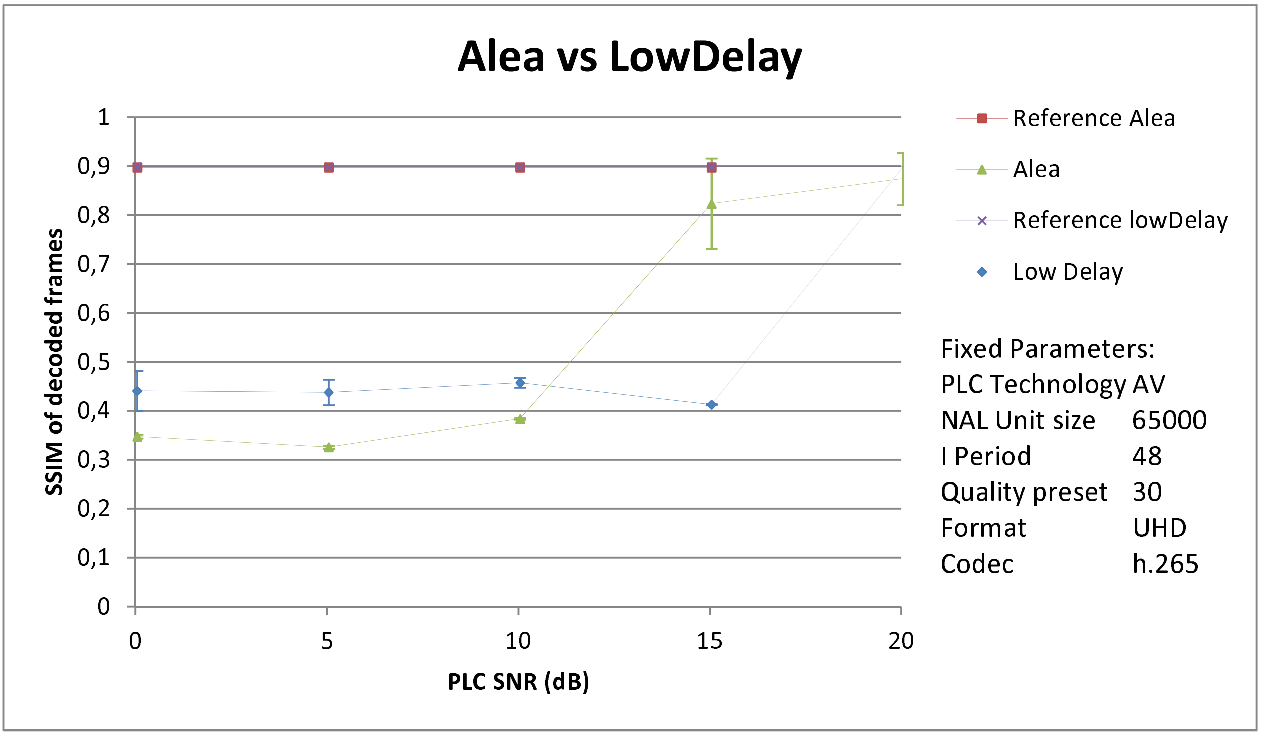


Figure 39: Alea vs LowDelay - H.265 - SSIM

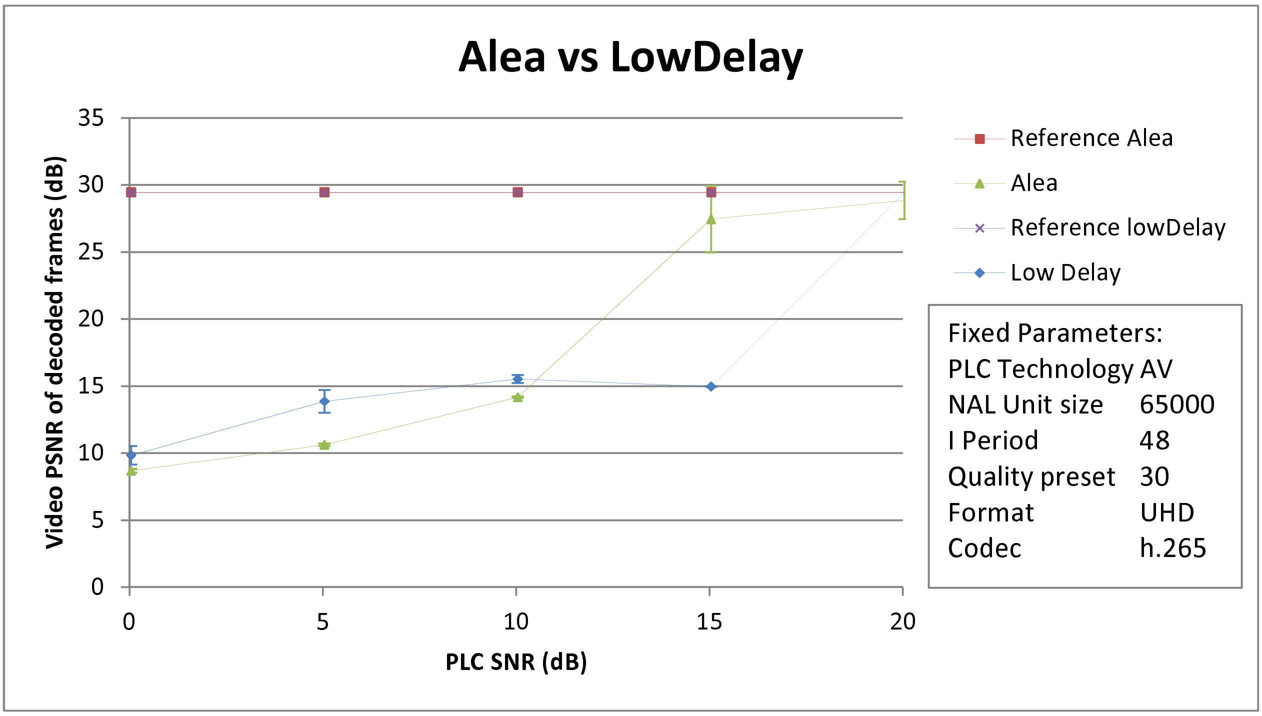


Figure 40: Alea vs LowDelay - H.265 - PSNR

6.3.2.4 H.264 vs H.265 with HD sequences

The comparison of the two codecs when used to transmit HD video sequences over PLC showed an improvement of 25 % of the number of framed decoded at 0 dB of PLC SNR, while the quality of the decoded frame loss is only of 16 % (SSIM) and 22 % (PSNR).

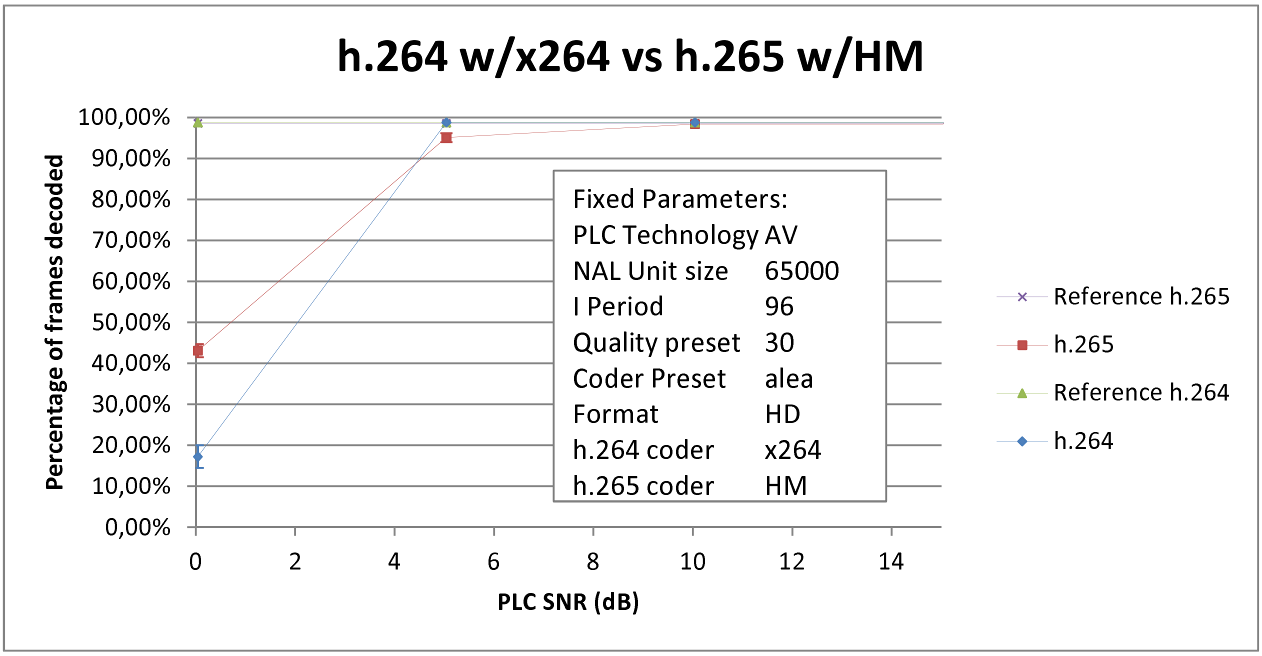


Figure 41: H.264 w/x264 vs H.265 w/HM - % of frames decoded

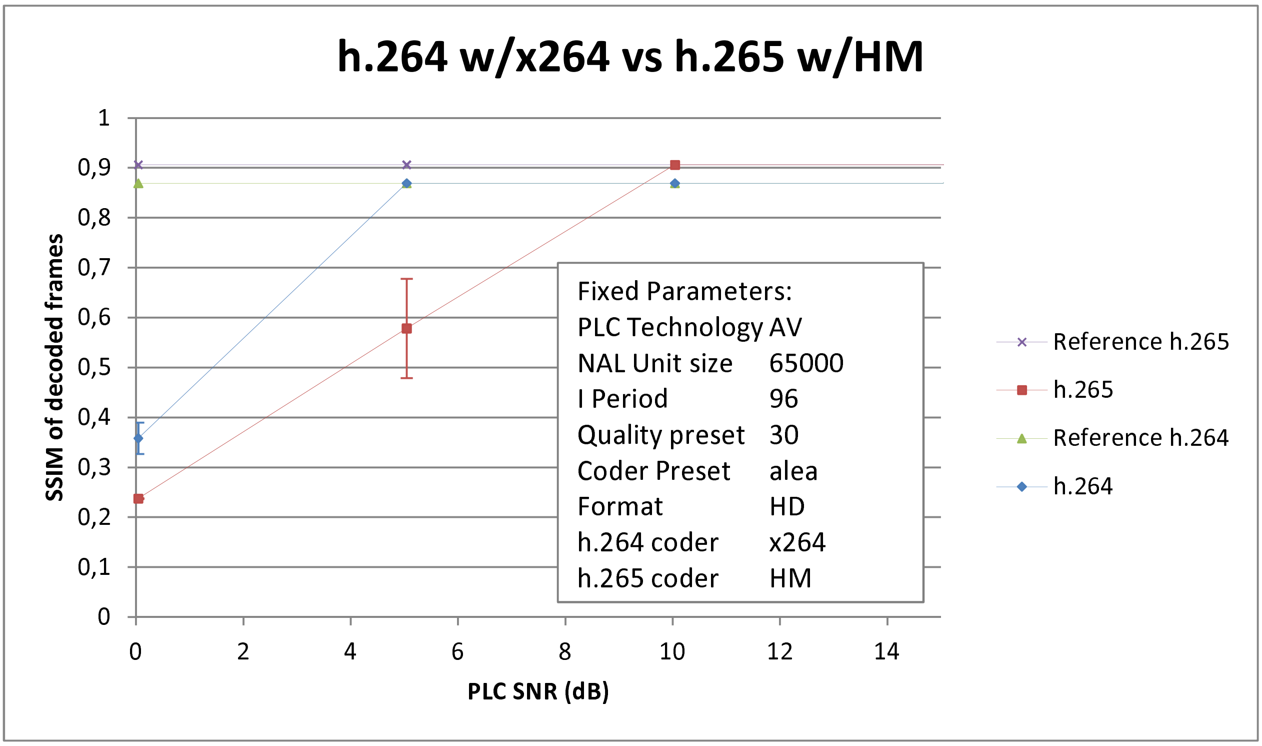


Figure 42: H.264 w/x264 vs H.265 w/HM - SSIM

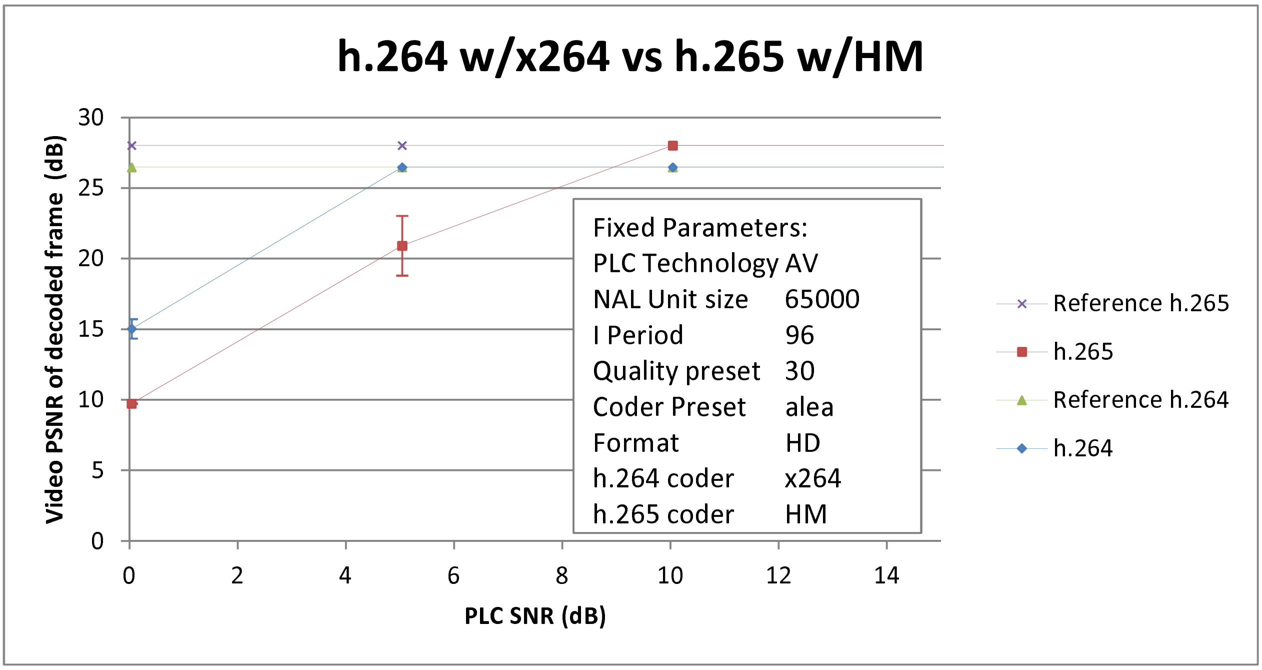


Figure 43: H.264 w/x264 vs H.265 w/HM - PSNR

6.3.2.5 H.264 vs H.265 with UHD sequences

The comparison of the two codecs when used to transmit UHD video sequences over PLC showed very similar performances between the two codecs. Nevertheless, one should keep in mind that the H.264 coder used (x264) is a very optimized implementation of H.264, while the H.265 coder used (HM) is the reference implementation, which is not optimized. The fact that the reference implementation of H.265 and an optimized implementation of H.264 are close in terms of performance tends to show that future implementations of H.265 will permit performances improvement over H.264.

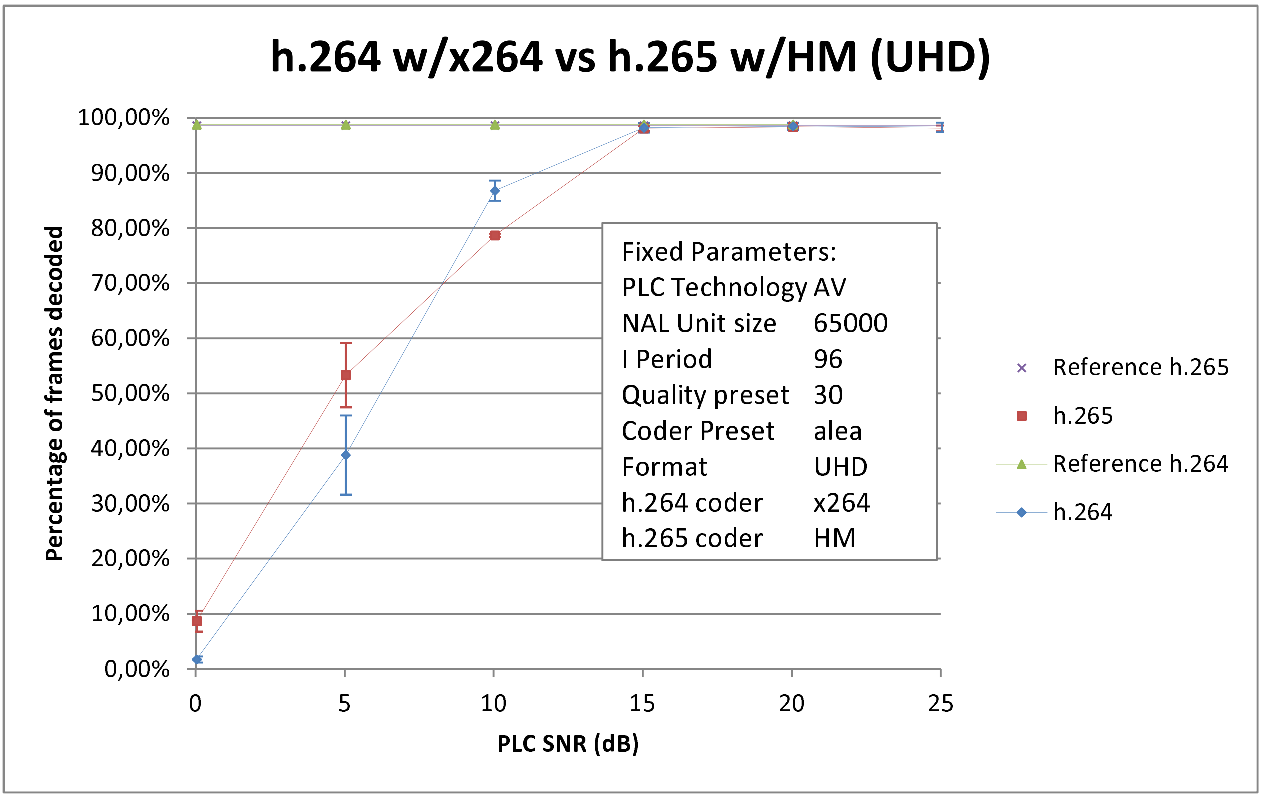


Figure 44: H.264 w/x264 vs H.265 w/HM (UHD) - % of frames decoded

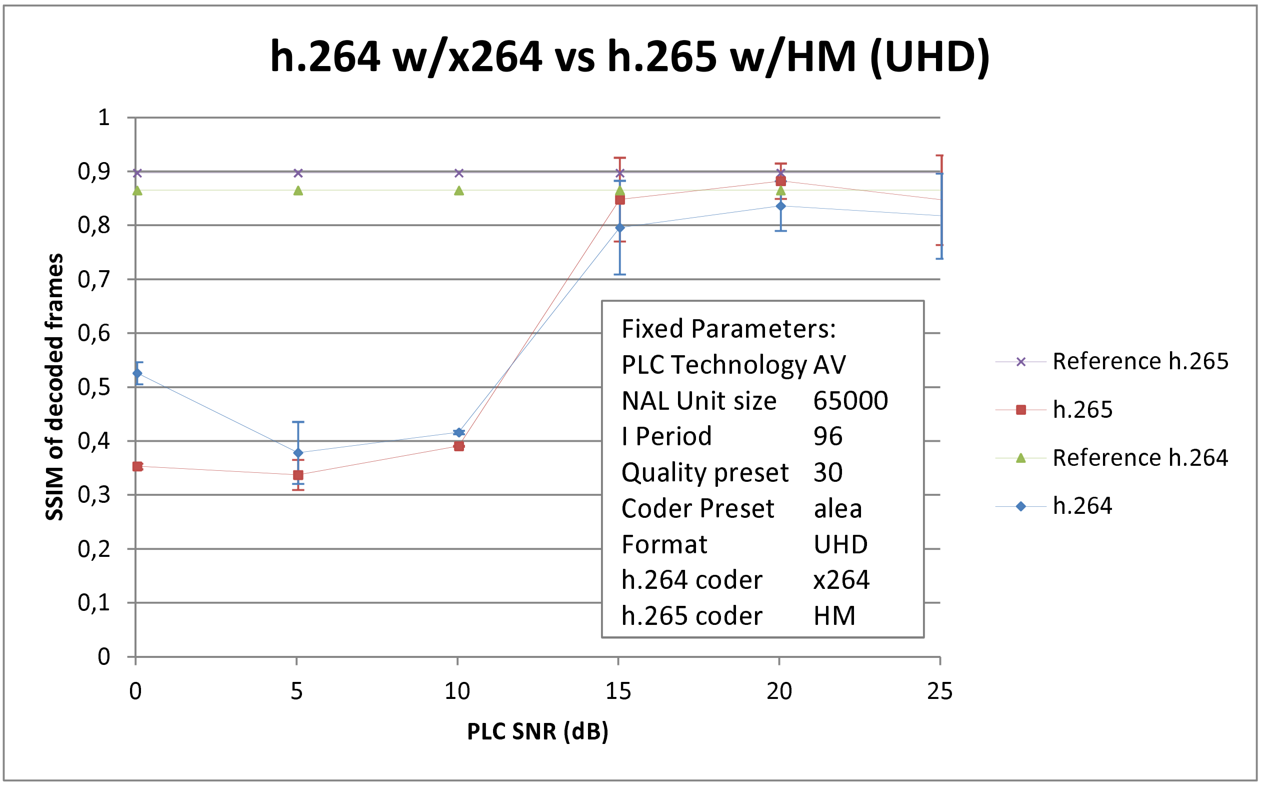


Figure 45: H.264 w/x264 vs H.265 w/HM (UHD) - SSIM

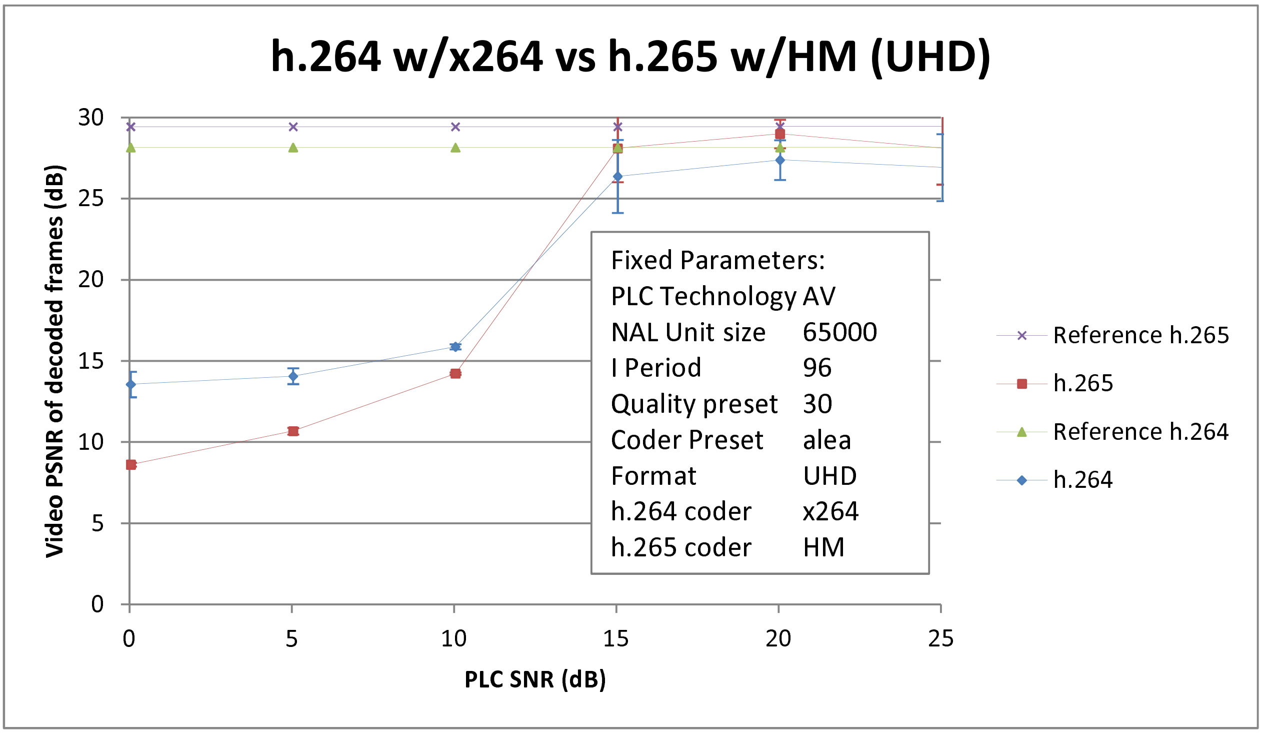


Figure 46: H.264 w/x264 vs H.265 w/HM (UHD) - PSNR

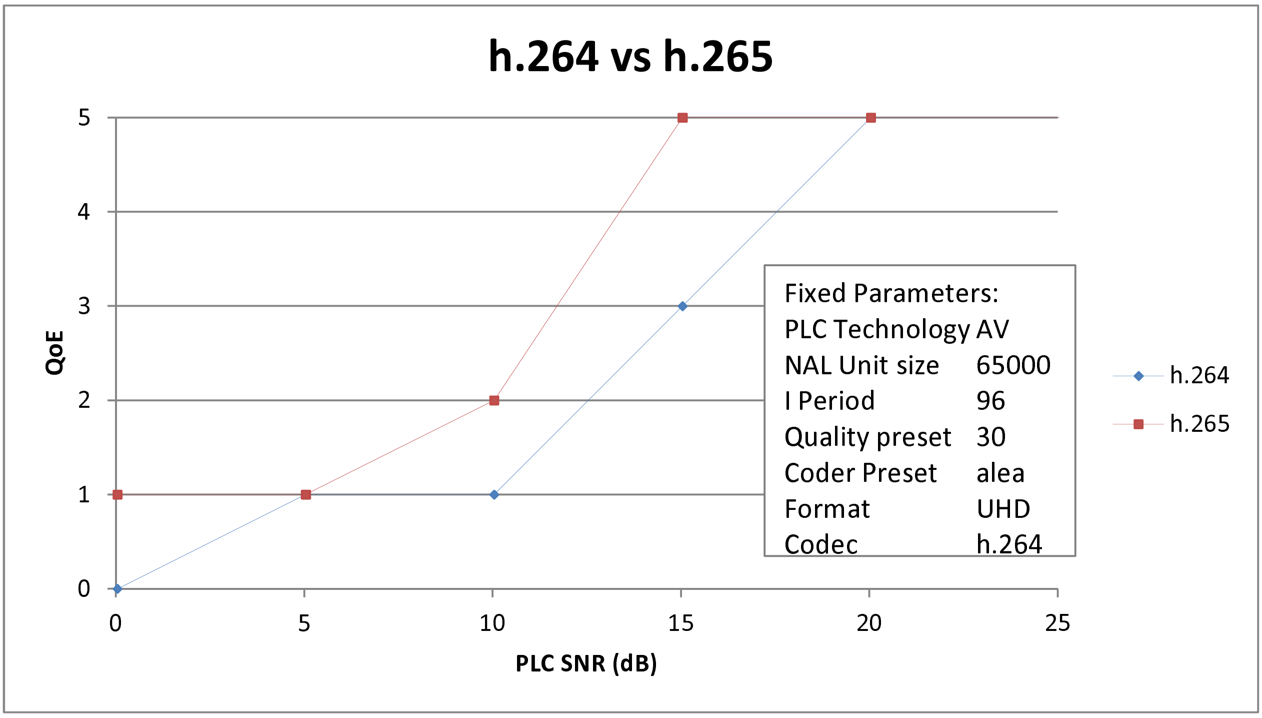


Figure 47: H.264 w/x264 vs H.265 w/HM (UHD) - QoE

6.3.2.6 AV vs AV2 SISO vs AV2 MIMO Raw PLC performance

The comparison between PLT- AV, PLT- AV2 SISO and PLT- AV2 MIMO show a great improvement permitted by MIMO technologies.

The following curves show, for low bitrates (close to 10 Mbps), the SNR gain permitted by PLT- AV2 MIMO over PLT- AV is 5 dB, while PLT- AV2 SISO allows a gain of 3 dB.

This gain is more significant for greater bitrates. At 50 Mbps, the SNR gain permitted by PLT- AV2 MIMO over PLT- AV is 13 dB, while PLT- AV2 SISO allows a gain of 8 dB.

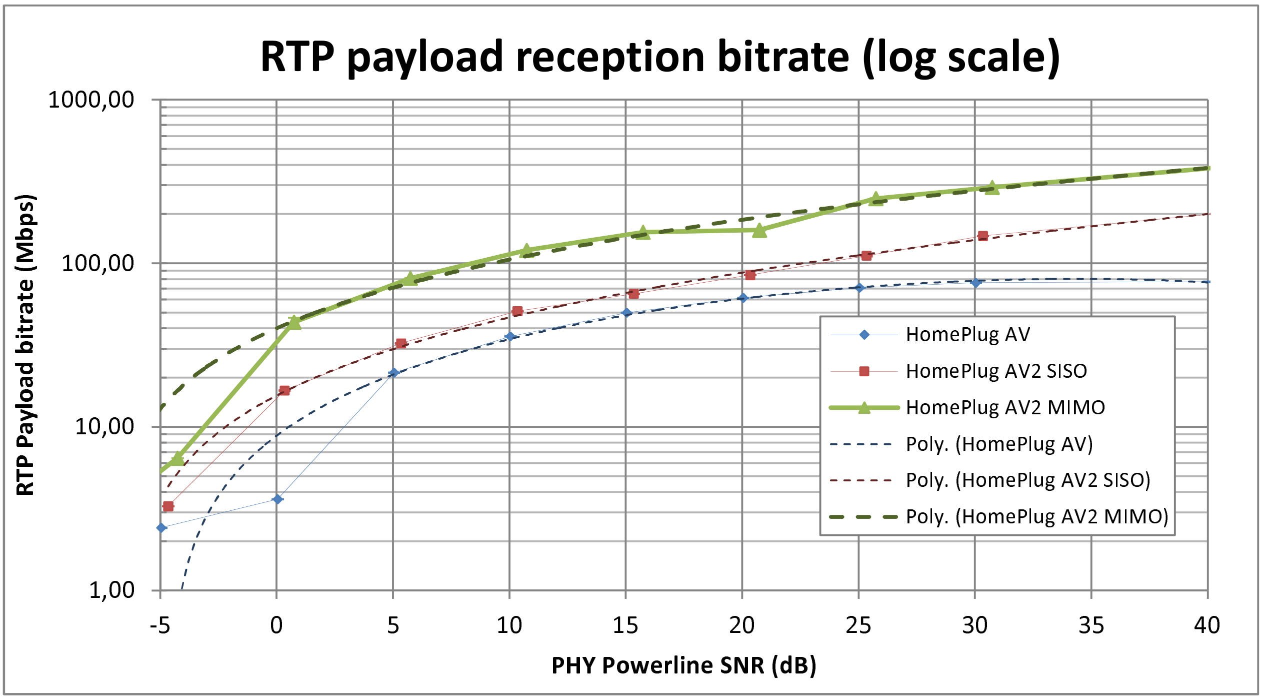


Figure 48: HPAV vs AV2 SISO vs AV2 MIMO Raw PLC performance

6.3.2.7 Video Streaming over AV vs AV2 SISO vs AV2 MIMO performance

The measurements showed that, as for raw PLC performances comparison, the gain permitted by PLT- AV2 MIMO over PLT- AV is 13 dB and the gain permitted by PLT- AV2 SISO over PLT- AV is 8 dB. This means that it can be expected that PLC MIMO technologies significantly improve in-home video coverage.

In terms of video quality at constant PLC SNR of 0 dB, one can observe that the improvement of percentage of video decoded permitted by PLT- AV2 MIMO is up to 95 % comparing to PLT- AV. One can also note that the video quality is perfect at 5 dB of PLC SNR with PLT- AV2 MIMO, while PLT- AV2 SISO shows a lot of artifacts, and PLT- AV is clearly not able to convey such a video with a decent quality.

This great improvement offered by MIMO technologies is confirmed by the QoE measurements.

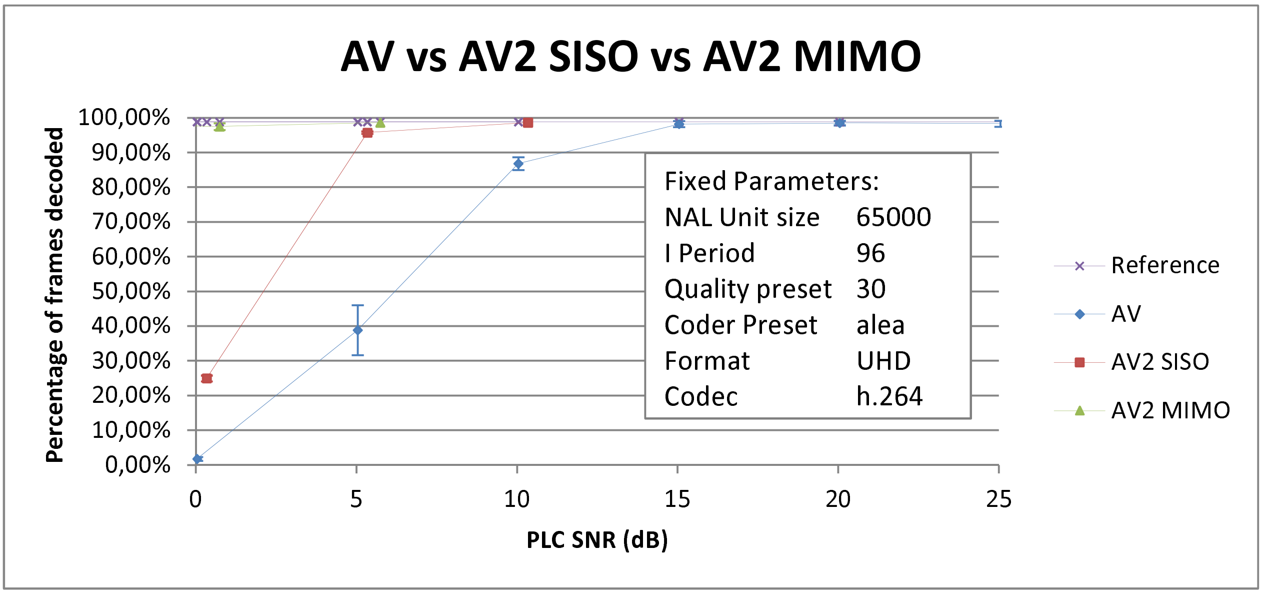


Figure 49: HP AV vs AV2 SISO vs AV2 MIMO - % of frames decoded

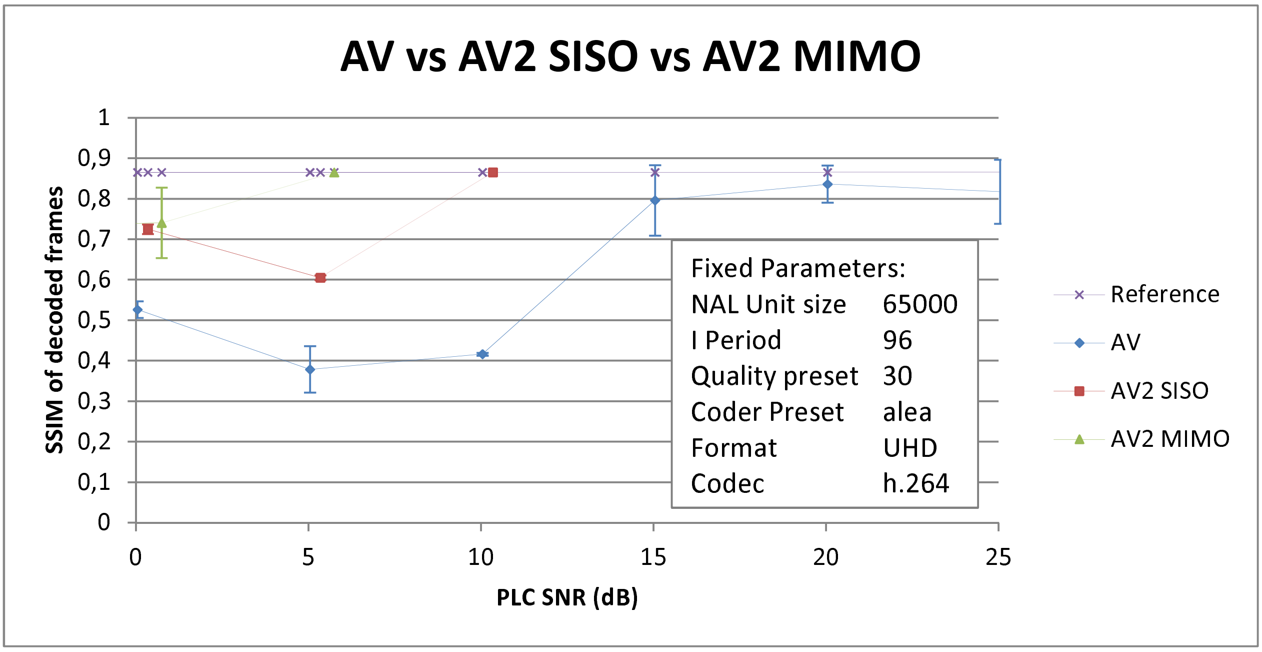


Figure 50: HP AV vs AV2 SISO vs AV2 MIMO - SSIM

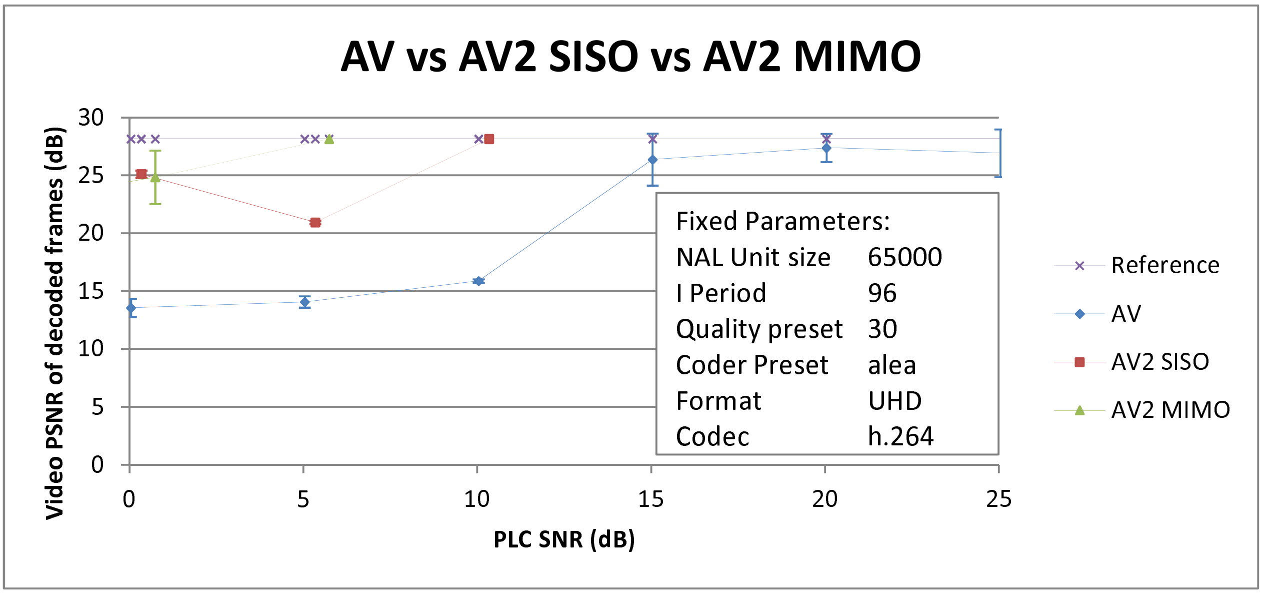


Figure 51: HP AV vs AV2 SISO vs AV2 MIMO - PSNR

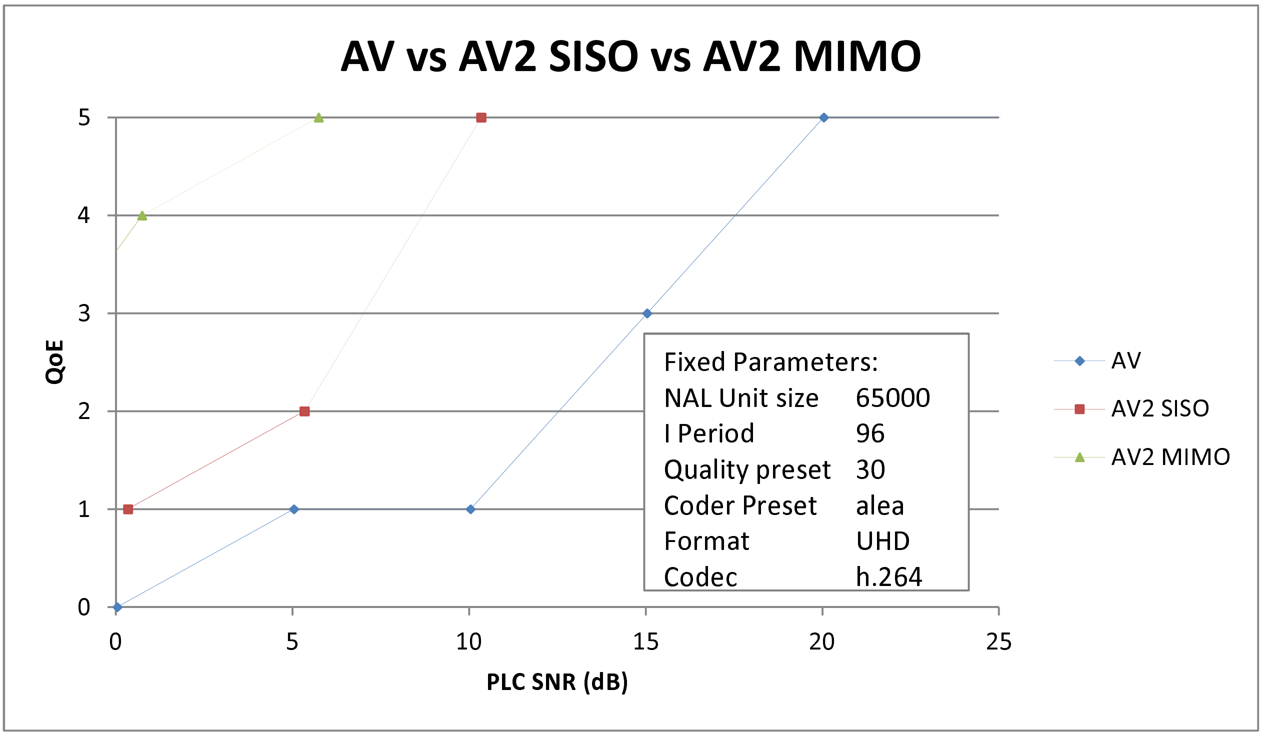


Figure 52: HP AV vs AV2 SISO vs AV2 MIMO - QoE

6.3.3 Laboratory Test Campaign Conclusions

As shown in the previous clauses, the most efficient compression parameters for H.264 and H.265 for a transmission over PLC are:

- NAL Unit of the size identical to the transmission payload size.
- I frame period of 16.
- Coding strategy "alea", although low-delay should be used for applications requiring interactivity (at a cost of a greater bandwidth need).

The comparison of H.264 with x264 and H.265 with HM (HM: ITU-T/SG16 reference software for H.265) did not show an important gap.

Nevertheless, the fact that x264 is much optimized while HM is slightly not tends to show the great potential of H.265.

The H.265 implementation was chosen because it enables the control of the parameters previously assessed in this clause (NAL unit size, in particular), which is not the case of the other implementations that were tried.

For the field test campaign, the x265 as H.265 implementation was used, which is more optimized than HM. This will permit a fairer comparison between the two codecs.

On the PLC side, the use of MIMO showed a great improvement in performances over SISO devices. One can see that the improvement permitted by MIMO over SISO between is greater than the improvement permitted by using the band 1 MHz to 90 MHz instead of 1 MHz to 30 MHz.

6.4 Field Test Campaign

6.4.1 Introduction

The Field Test Campaign approach and methodology is described in annex C. This is a field campaign of video quality measurement over PLC, based on 7 different homes from different environments.

The results from the field test campaign are presented in the clauses below, with a clause dedicated to observations and conclusions (clause).

6.4.2 Field Tests Detailed Results

For each field tests home, the following video and PLC configurations were used:

Fixed Parameters					
PLC Technology	**AV**	**AV**	**AV2 SISO**	**AV2 SISO**	**AV2 MIMO**
NAL Unit size	Inf	Inf	Inf	Inf	Inf
I Period	100	100	100	100	100
Quality preset	30	30	30	30	30
Coder Preset	lowDelay	lowDelay	lowDelay	lowDelay	lowDelay
Format	UHD	UHD	UHD	UHD	UHD
Codec	H.264	H.265	H.264	H.265	H.265

In each test situation, a performance score upon the average achieved SSIM is affected in order to compare the performance. The following scoring methodology is used:

SSIM	Score
in the range of [0,97 to 1]	3 - GREEN
in the range of [0,90 to 0,97[	1 - ORANGE
in the range of < 0,90	0 - RED

Note that **score "3"** corresponds to a Quality of Experience (QoE) where no defect can be noticed by a non-expert eye, and the experience can be assimilated to a perfect experience.

Score "1" corresponds to defects that can be noticed by an average experimenter, but still the quality is good enough to be accepted by the operator.

Score "0" corresponds to a visual experience that cannot be accepted at all by the operator, which means the quality of the video is really poor.

6.4.2.1 Home #2

6.4.2.1.1 Overall Home Statistics

	Mean SSIM	Std dev/2	Mean Successfully read frames ratio	Std dev/2	Average Score SSIM
AV H.264	0,8891978	0,04632409	0,99934908	0,0004767	1
AV H.265	1	0	1	0	3
AV2 SISO H.264	0,92414161	0,04431784	0,99934908	0,00046027	1,5
AV2 SISO H.265	0,97396358	0,02603642	0,99840142	0,00159858	2,25
AV2 MIMO H.265	0,97311957	0,02688043	0,99995214	4,7862E-05	2,25

6.4.2.1.2 H.264 vs H.265

PLC Technology	Codec	Mean SSIM	Delta SSIM (%)	Mean Successfully read frames ratio	Delta Successfully read frames ratio (%)	Average Score SSIM
AV	H.264	0,8891978	11,08021981	0,999349083	0,065091703	1
	H.265	1		1		3
AV2 SISO	H.264	0,92414161	4,982196837	0,999349083	-0,094765861	1,5
	H.265	0,97396358		0,998401424		2,25
AV2 MIMO	H.265	0,97311957	4,897795747	0,999952138	0,060305548	2,25

Scores for the H.265 are always higher than for the H.264.

The efficiency of the H.265 encoder is especially demonstrated in the AV2 SISO above, where the H.265 encoder has successfully decoded fewer frames than in the H.264, but still the quality of the H.265 decoded stream is better than the H.264 stream.

6.4.2.1.3 AV vs AV2 SISO vs AV2 MIMO

Codec	PLC Technology	Mean SSIM	Delta SSIM (%)	Mean Successfully read frames ratio	Delta Successfully read frames ratio (%)	Average Score SSIM
H.264	AV	0,8891978		0,999349083		1
	AV2 SISO	0,92414161	3,494381075	0,999349083	1,11022E-14	1,5
H.265	AV	1		1		3
	AV2 SISO	0,97396358	-2,603641894	0,998401424	-0,159857564	2,25
	AV2 MIMO	0,97311957	-2,688042984	0,999952138	-0,004786155	2,25

H.264 quality results show that the AV2 SISO brings a strong improvement to the video quality compared to the AV technologies (0,973 in AV2 SISO against 0,889 in AV).

In the H.265 case, all test situations are almost perfect (almost loss free, almost perfect quality) tests, and the video quality is very high (greater than 0,97). AV2 SISO and MIMO however suffered from more losses in terms of successfully read frames than in the AV case (in the later case, all frames were perfectly read and decoded). This is certainly related to the nature of the PLC channel that can be affected by impulsive peaks of electrical noises or impedances changes, and may make the PLC link encounter some peak losses. It is interesting to see that these losses are however tiny and that they do not affect strongly the quality of the video.

6.4.2.2 Home #3

6.4.2.2.1 Overall Home Statistics

	Mean SSIM	Std dev/2	Mean Successfully read frames ratio	Std dev/2	Average Score SSIM
AV H.264	0,89931299	0,03800953	0,99954053	0,00017616	0,75
AV H.265	1	0	1	0	3
AV2 SISO H.264	1	0	1	0	3
AV2 SISO H.265	0,99264347	0,00735653	0,9911169	0,0088831	3
AV2 MIMO H.265	1	0	1	0	3

6.4.2.2.2 H.264 vs H.265

PLC Technology	Codec	Mean SSIM	Delta SSIM (%)	Mean Successfully read frames ratio	Delta Successfully read frames ratio (%)	Average Score SSIM
AV	H.264	0,899312989	10,0687011	0,999540529	0,045947084	0,75
	H.265	1		1		3
AV2 SISO	H.264	1	-0,735652699	1	-0,888310296	3
	H.265	0,992643473		0,991116897		3
AV2 MIMO	H.265	1	0	1	0	3

Scores for the H.265 encoder are always higher than for the H.264, except in the AV2 SISO case where one can see that the H.265 suffered from losses in the decoded frames (almost 1 % losses was observed, which is huge).

Sporadic strong losses may indeed lead to catastrophic SSIM scores, especially when some I frames are lost, making the video decoding and re-synchronization impossible after such a loss. However, the H.265 efficiency still leads to a very good average SSIM (0,992) which makes the video.

The efficiency of the H.265 encoder is especially demonstrated in the AV2 SISO case, here above, where it can be observed that the AV2 SISO H.265 encoder has successfully decoded fewer frames than in the AV2 SISO H.264 case, and fewer frames than in the AV H.264 case. Still the quality of the H.265 decoded stream is even better than these two above H.264 test cases (AV and AV2 SISO). The quality is almost perfect, which illustrates that H.265 brings a high robustness when the transmission channel is not so good.

The AV2 SISO H.265 case illustrates that H.265 can be robust to losses up to almost 1 % average.

The results obtained in AV seems also to prove that losses in AV occur mainly on I Frames, as such frames require more instantaneous bitrate compared to other types of frames. The results in AV2 SISO also tend to confirm this, as they show that H.264 is not robust to small losses, while H.265 is much more robust. Thus it is expected that losses occur more often on I-Frames rather on B-, P- frames, making H.264 more sensitive to losses. One has to keep in mind that H.264 requires more instantaneous transmission capacity (in terms of throughput) than H.265, at a constant video quality.

The above results in home #3 also show that H.265 brings most of the part of the robustness improvement, as such improvement is observed among all PLC technologies.

6.4.2.2.3 AV vs AV2 SISO vs AV2 MIMO

Codec	PLC Technology	Mean SSIM	Delta SSIM (%)	Mean Successfully read frames ratio	Delta Successfully read frames ratio (%)	Average Score SSIM
H.264	AV	0,899312989		0,999540529		0,75
	AV2 SISO	1	10,0687011	1	0,045947084	3
H.265	AV	1		1		3
	AV2 SISO	0,992643473	-0,735652699	0,991116897	-0,888310296	3
	AV2 MIMO	1	0	1	0	3

The improvement of H.265 against H.264 is demonstrated by the SSIM scores as displayed above. In good and stable conditions of transmission, PLC technologies seem to behave the same w.r.t. the video quality.

6.4.2.3 Home #4

6.4.2.3.1 Overall Home Statistics

	Mean SSIM	Std dev/2	Mean Successfully read frames ratio	Std dev/2	Average Score SSIM
AV H.264	0,909912719	0,039802743	0,999591581	0,000185943	1
AV H.265	1	0	1	0	3
AV2 SISO H.264	1	0	1	0	3
AV2 SISO H.265	1	0	1	0	3
AV2 MIMO H.265	1	0	1	0	3

Results from home #4 show an almost perfect transmission test situation within the home (loss ratios are very closed to 0 %). Small losses of 0,05 % are shown to be very impactful on the H.264 video only, where the SSIM can be degraded to some values closed to 0,9, which is the limit of an acceptable experience.

6.4.2.3.2 H.264 vs H.265

PLC Technology	Codec	Mean SSIM	Delta SSIM (%)	Mean Successfully read frames ratio	Delta Successfully read frames ratio (%)	Average Score SSIM
AV	H.264	0,909912719	9,008728107	0,999591581	0,040841853	1
	H.265	1		1		3
AV2 SISO	H.264	1	0	1	0	3
	H.265	1		1		3
AV2 MIMO	H.265	1	0	1	0	3

H.264 weakness against the transmission conditions and small losses is again demonstrated above.

6.4.2.3.3 AV vs AV2 SISO vs AV2 MIMO

Codec	PLC Technology	Mean SSIM	Delta SSIM (%)	Mean Successfully read frames ratio	Delta Successfully read frames ratio (%)	Score SSIM
H.264	AV	0,909912719		0,999591581		1
	AV2 SISO	1	9,008728107	1	0,040841853	3
H.265	AV	1		1		3
	AV2 SISO	1	0	1	0	3
	AV2 MIMO	1	0	1	0	3

6.4.2.4 Home #5

6.4.2.4.1 Overall Home Statistics

	Mean SSIM	Std dev/2	Mean Successfully read frames ratio	Std dev/2	Average Score SSIM
AV H.264	0,835294316	0,01437639	0,999042817	0,000379078	0
AV H.265	1	0	0,992267351	0,005467809	3
AV2 SISO H.264	1	0	0,999770317	0	3
AV2 SISO H.265	0,961027248	0,027557897	0,984534701	0	2
AV2 MIMO H.265	1	0	0,984534701	0	3

This home shows harsh conditions of transmission where frame losses from 0,1 to 1,6 % (average) were encountered.

AV2 SISO and AV2 MIMO for H.265 videos show the hardest conditions where losses of more than 1,5 % were observed in average. They demonstrate the efficiency of H.265, even in presence of losses, and show that the video quality can be sustained to some high levels, even in presence of hard transmission conditions.

While transmission conditions look better for H.264 (successfully decoded frames are higher), this latter encoder is still very sensitive to small losses, which are suspected to happen mainly on I-Frames.

6.4.2.4.2 H.264 vs H.265

PLC Technology	Codec	Mean SSIM	Delta SSIM (%)	Mean Successfully read frames ratio	Delta Successfully read frames ratio (%)	Score SSIM
AV	H.264	0,835294316	16,4705684	0,999042817	-0,677546684	0
	H.265	1		0,992267351		3
AV2 SISO	H.264	1	-3,897275205	0,999770317	-1,523561612	3
	H.265	0,961027248		0,984534701		2
AV2 MIMO	H.265	1	0	0,984534701	-1,523561612	3

These results confirm the quality improvement brought by H.265 over H.264.

Even in case of strong frame losses (AV2 SISO H.265), H.265 maintains an acceptable video quality.

6.4.2.4.3 AV vs AV2 SISO vs AV2 MIMO

Codec	PLC Technology	Mean SSIM	Delta SSIM (%)	Mean Successfully read frames ratio	Delta Successfully read frames ratio (%)	Score SSIM
H.264	AV	0,835294316		0,999042817		0
	AV2 SISO	1	16,4705684	0,999770317	0,07274999	3
H.265	AV	1		0,992267351		3
	AV2 SISO	0,961027248	-3,897275205	0,984534701	-0,773264939	2
	AV2 MIMO	1	0	0,984534701	-0,773264939	3

6.4.2.5 Home #6

6.4.2.5.1 Overall Home Statistics

	Mean SSIM	Std dev/2	Mean Successfully read frames ratio	Std dev/2	Score SSIM
AV H.264	0,862982783	0,041112843	0,999208833	0,00035824	0,333333
AV H.265	1	0	0,984610095	6,52933E-05	3
AV2 SISO H.264	1	0	0,999923439	6,63037E-05	3
AV2 SISO H.265	1	0	0,98468549	6,52933E-05	3
AV2 MIMO H.265	1	0	0,98468549	6,52933E-05	3

This table tends to show that in AV, frame losses are more impactful onto the H.264 encoder. The results obtained in AV H.264 and AV2 SISO H.264 that a level of 0,03 % in the unsuccessful read frames can impact deeply the video quality under H.264.

6.4.2.5.2 H.264 vs H.265

PLC Technology	Codec	Mean SSIM	Delta SSIM (%)	Mean Successfully read frames ratio	Delta Successfully read frames ratio (%)	Score SSIM
AV	H.264	0,862982783	13,70172174	0,999208833	-1,459873736	0,33333333
	H.265	1		0,984610095		3
AV2 SISO	H.264	1	0	0,999923439	-1,523794956	3
	H.265	1		0,98468549		3
AV2 MIMO	H.265	1	0	0,98468549	-1,523794956	3

When operating in relatively good transmission conditions, PLC technologies have little difference on the H.265 video quality. H.265 is relatively immune to transmission losses of frames up to 1,6 % average.

6.4.2.5.3 AV vs AV2 SISO vs AV2 MIMO

Codec	PLC Technology	Mean SSIM	Delta SSIM (%)	Mean Successfully read frames ratio	Delta Successfully read frames ratio (%)	Score SSIM
H.264	AV	0,862982783		0,999208833		0,3333333
	AV2 SISO	1	13,70172174	0,999923439	0,071460637	3
H.265	AV	1		0,984610095		3
	AV2 SISO	1	0	0,98468549	0,007539416	3
	AV2 MIMO	1	0	0,98468549	0,007539416	3

H.265 takes it all against H.264.

6.4.2.6 Home #7

6.4.2.6.1 Overall Home Statistics

	Mean SSIM	Std dev/2	Mean Successfully read frames ratio	Std dev/2	Score SSIM
AV H.264	0,930971359	0,059780557	0,999642634	0,000309488	2
AV H.265	1	0	0.985113182	0,000305099	3
AV2 SISO H.264	1	0	1	0	3
AV2 SISO H.265	0,843275877	0,079109345	0,984760884	0	1
AV2 MIMO H.265	1	0	0,985226245	0,000196446	3

Only a few test runs (3) could be executed in this home, thus making the statistics not really representative. Moreover this home was actually located in a dense area, and had prongs equipped with no earth wires, thus making the AV2 MIMO turn into a AV2 SISO case.

It also shows that even in case of identical level of losses (in AV2 SISO H.265 and AV2 MIMO H.265), the SSIM scores may be very different (one score is good, while the other one is small). This is due to the fact that the video quality and the SSIM criterion are very sensitive to the nature of the losses (I-, B6, P- frames).

Weak values of SSIM mainly means that I-Frames were lost, impacting greatly the SSIM criterion.

6.4.2.6.2 H.264 vs H.265

PLC Technology	Codec	Mean SSIM	Delta SSIM (%)	Mean Successfully read frames ratio	Delta Successfully read frames ratio (%)	Score SSIM
AV	H.264	0,930971359	6,902864139	0,999642634	-1,452945211	2
	H.265	1		0,985113182		3
AV2 SISO	H.264	1	-15,67241227	1	-1,523911628	3
	H.265	0,843275877		0,984760884		1
AV2 MIMO	H.265	1	0	0,985226245	-1,477375465	3

6.4.2.6.3 AV vs AV2 SISO vs AV2 MIMO

Codec	PLC Technology	Mean SSIM	Delta SSIM (%)	Mean Successfully read frames ratio	Delta Successfully read frames ratio (%)	Score SSIM
H.264	AV	0,930971359		0,999642634		2
	AV2 SISO	1	6,902864139	1	0,035736621	3
H.265	AV	1		0,985113182		3
	AV2 SISO	0,843275877	-15,67241227	0,984760884	-0,035229796	1
	AV2 MIMO	1	0	0,985226245	0,011306368	3

6.4.2.7 Home #8

6.4.2.7.1 Overall Home Statistics

	Mean SSIM	Std dev/2	Mean Successfully read frames ratio	Std dev/2	Score SSIM
AV H.264	0,672002595	0,077871702	0,91643374	0,058223882	0
AV H.265	0,752884224	0,174737241	0,984760884	0	1,5
AV2 SISO H.264	0,911015644	0,062921441	0,999674541	0,000230134	1,5
AV2 SISO H.265	1	0	0,984760884	0	3
AV2 MIMO H.265	1	0	0,98522625	0,00019645	3

Only a few test runs (2) could be executed in this home, thus making the statistics not much representative. However, it is interesting losses here always present at different levels depending on the PLC technology considered. While frame losses were huge for the AV case (8 % or more), they seem to be reduced in the AV2 cases.

6.4.2.7.2 H.264 vs H.265

PLC Technology	Codec	Mean SSIM	Delta SSIM (%)	Mean Successfully read frames ratio	Delta Successfully read frames ratio (%)	Score SSIM
AV	H.264	0,672002595	8,088162841	0,91643374	6,832714324	0
	H.265	0,752884224		0,984760884		1,5
AV2 SISO	H.264	0,911015644	8,898435588	0,999674541	-1,491365777	1,5
	H.265	1		0,984760884		3
AV2 MIMO	H.265	1	8,898435588	0,985226245	-1,444829613	3

6.4.2.7.3 AV vs AV2 SISO vs AV2 MIMO

Codec	PLC Technology	Mean SSIM	Delta SSIM (%)	Mean Successfully read frames ratio	Delta Successfully read frames ratio (%)	Score SSIM
H.264	AV	0,672002595		0,91643374		0
	AV2 SISO	0,911015644	23,90130489	0,999674541	8,324080101	1,5
H.265	AV	0,752884224		0,91643374		1,5
	AV2 SISO	1	24,71157764	0,999674541	8,324080101	3
	AV2 MIMO	1	24,71157764	0,985226245	6,879250488	3

The whole results obtained in this home, demonstrates that, in harsh transmission conditions, where H.264 associated with AV fails, AV2 associated along with H.265 allows achieving acceptable or even almost perfect video quality.

6.4.2.8 Prongs location analysis

6.4.2.8.1 Overall statistical prongs location results

	Prong Category	Mean SSIM	Std dev/2	Mean Successfully read frames ratio	Std dev/2	Average SSIM Score
AV H.264	1	0,860778187	0,062440823	0,985663885	0,023867585	0,833333333
	2	0,892168443	0,062348861	0,999081151	0,000538738	1,5
	3	0,871630308	0,015561711	0,999530957	0,000102949	0,25
	4	0,89570432	n/a	0,999425661	n/a	0
	all	0,870487503	0,053004347	0,991516224	0,018037508	0,80952381
AV H.265	1	0,958814037	0,07133618	0,991072818	0,003940378	2,75
	2	1	0	0,996133675	0,003866325	3
	3	1	0	0,996190221	0,003809779	3
	4	1	n/a	1	n/a	3
	all	0,976465164	0,053925083	0,993436638	0,003883102	2,85714286
AV2 SISO H.264	1	0,971143182	0,033713219	0,999744747	0,000284469	2,5
	2	0,966219888	0,033780112	0,99977985	0,000153456	2,25
	3	1	0	1	0	3
	4	1	n/a	1	n/a	3
	all	0,977076083	0,028987944	0,999812208	0,000225785	2,57142857
AV2 SISO H.265	1	0,954323511	0,048802259	0,989802892	0,003765763	2,333333333
	2	1	0	0,996133675	0,003866325	3
	3	0,966607054	0,024582959	0,985708542	0,007738901	2,25
	4	1	n/a	1	n/a	3
	all	0,967538588	0,038634953	0,990714456	0,004790528	2,476190476
AV2 MIMO H.265	1	0,992970541	0,01217538	0,989802892	0,003765763	2,833333333
	2	0,97311957	0,02688043	0,996085814	0,003850635	2,25
	3	1	0	0,996190221	0,003809779	3
	4	1	n/a	1	n/a	3
	all	0,990863084	0,014544452	0,99270185	0,003912567	2,761904762

The prong location results do not allow to derive pertinent conclusions about the influence of the prong location on the quality video transmitted within the home via PLC. Note that standard deviations could not be derived on the prong category #4 because only one test prong situation could be tested over the whole field test campaign.

6.4.3 Field Test Campaign Conclusions

The following scoring method was used to illustrate the results of the field test campaign:

SSIM	SSIM Score
in the range of [0,97 to 1]	3
in the range of [0,90 to 0,97[	1
in the range of < 0,90	0

Figure 53 summarizes the cumulative SSIM scores obtained with all PLC technology and H.264/H.265 encoding methods during the field tests within 7 different homes.

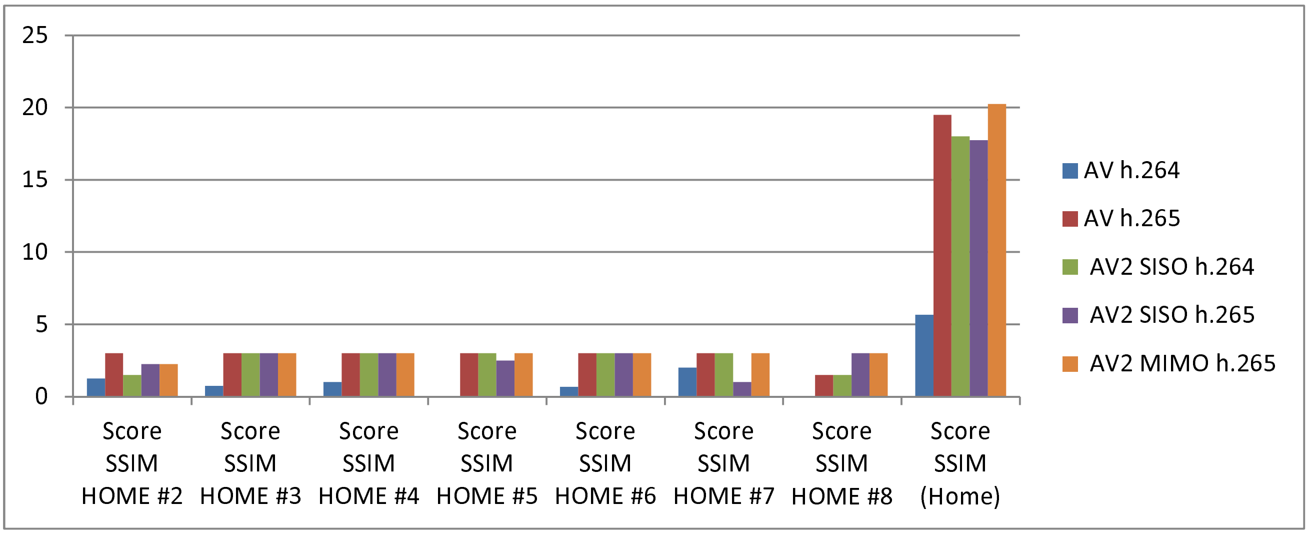


Figure 53: Cumulative SSIM scores

H.265 vs H.264

The field test campaign clearly demonstrates that when using H.265 encoder, all test situations are almost perfect, i.e. they achieve high SSIM score and are almost loss free, with almost perfect quality score (the maximum cumulative score, as shown in the bar graph above, is 21, and all H.265 situations are close to this value).

H.264 sensitivity to transmission losses

It is important to note that sporadic transmission losses may lead to catastrophic SSIM scores, especially when I frames are lost: such losses actually makes the video decoding and re-synchronization impossible during the analysis. In such situations, catastrophic levels of SSIM are then obtained and should be attenuated a bit when coming to analyse such low levels. This is especially the case for the AV H.264 tests, where the SSIM score approach tends to even accentuate the low SSIM levels achieved.

This is however true that H.265 always achieves very good average SSIM levels. The efficiency of the H.265 encoder is especially demonstrated in the AV2 SISO case where one may observe that the AV2 SISO H.265 successfully decodes fewer frames than in the AV2 SISO H.264 case, and also fewer frames than in the AV H.264 case, but still achieves better quality than the two other H.264 cases (AV and AV2 SISO).

Also, the field test results demonstrates that, in H.265 situations where AV2 SISO and MIMO suffers from more losses than in the AV case, the video quality is still very high and remains equal or close to the video quality observed in H.264.

On the reverse, test situations where H.264 transmission suffers from tiny frame losses lead in most cases to low SSIM scores, showing that H.264 is specifically sensitive to frame losses, even when they are.

This however does not mean that H.265 is totally immune to frame losses, but the field results demonstrate that, in presence of frame losses, H.265 sustained a better video score than H.264 (AV2 SISO H.265 case particularly illustrates this).

This proves that H.264 is globally less reliable than H.265 in the presence of transmission losses.

AV vs AV2 SISO

To well understand the underlying mechanisms at stake, one also has to recall the nature of the PLC transmission and its physical channel. PLC transmission channel from the field can be affected by impulsive electrical noise peaks or abrupt changes of electrical impedance in any part of the network. Such impairments may affect strongly the PLC link and may result in video frames losses. None of these technologies is actually immune to all type of electrical disturbance and noise, and may suffer from losses on the line.

But there are differences. If AV2 SISO offers more bandwidth and more theoretical capacity compared to AV, it however does not provide any improvement compared to AV in terms of robustness to noises or physical impairments. AV2 SISO provides higher bitrates than AV only in physical contexts where PHY impairments are weak. But such an improvement is not expected in terms of robustness in physical situations like field tests, where physical impairments and noises are likely to occur: AV2 SISO is not designed to provide any improved robustness to peak losses compared to AV.

This explains why AV2 SISO (H.264 ad H.265) performs at comparable levels of AV H.265. Most of the time AV2 SISO would provide higher bitrates than AV, but when peak losses would occur in AV in the field tests, they are likely to occur also in AV2 SISO.

Improvement brought by AV2 MIMO

On the other hand, AV2 MIMO provides more robustness compared to AV2 SISO: it actually makes use of the channel diversity (MIMO beamforming) brought by the two pairs formed by the Line, Neutral or Ground wires (i.e. Line - Neutral, Line - Ground or Neutral - Ground) and provide a higher immunity to peak losses at the PHY layer.

This is especially seen in the AV2 MIMO H.265 case, which almost reaches the maximum SSIM score (21) among all the homes.

What if video transmission in relatively good PHY conditions?

As previously shown, H.265 is relatively immune to noise peaks conditions and peak transmission losses, which does not appear to be the case for H.264 which require more bandwidth to be well decoded. But, when operating in relatively good transmission conditions, without noise peaks, PLC technologies show little difference on the H.265 or H.264 video quality as long as the capacity provided by the PLC technology sustains the PLC peak bitrate needed for the video stream.

Indeed, each PLC technology offers a specific transmission capacities, as characterized and illustrated in clause 6.3.2.6.

This later study actually shows that at different levels of SNR levels the following performance could be reached:

	SNR 30 dB	15 dB	5 dB
AV2 MIMO	300 Mbps	150 Mbps	80 Mbps
AV2 SISO	150 Mbps	70 Mbps	30 Mbps
AV	80 Mbps	50 Mbps	20 Mbps

This clearly illustrates the fact that AV has a limited capacity that may not allow to dealing with the transport of UHD streams that would require peak bitrates of more than 80 Mbps, and clearly show that AV2 MIMO is a better technology candidate for such a transport.

This is especially illustrated in the AV H.264 tests, where H.264 systematically suffers from low SSIM levels ad scores.

7 Conclusion

Exploring three emerging technologies as MIMO-PLT for powerline networks, HEVC/H.265 for video codec instead of AVC/H.264 and UHD increasing users experiences compared to well known HD, tests and measurements on selected reference HD video sequences and real world UHD sequences were performed.

The Powerline transmission sensitivity was observed with regard to video quality measured using PNSR and SSIM criteria for both HEVC/H.265 and H.264/AVC encoding parameters are:

- NAL Unit of the size identical to the transmission payload size.
- I frame period of 16.
- Coding strategy "alea", although low-delay should be used for applications requiring interactivity (at a cost of a greater bandwidth need).

The benefit of MIMO-PLT compared to SISO-PLT, within this study is clearly established by tests and measurements done in labs and also performed in real houses with HD and UHD video sequences in burst mode.

Therefore MIMO-PLT networks are recommended for high speed internet services such as UHD (Ultra High Definition) SVOD and video streaming services for whole home distribution.

Annex A: Coding parameters collection

Video sequence	NAL Units Size	Encoding schema	Format	Codec	GOP size / I Period	Quality
Park_joy	1 500	Low delay	HD	H.264	4	30
						35
					12	30
						35
					48	30
						35
					100	30
						35
	65 000	Low delay	HD	H.264	4	30
						35
					12	30
						35
					48	30
						35
					100	30
						35
				H.265	4	30
						35
					12	30
						35
					48	30
						35
					100	30
						35
			UHD	H.264	4	30
						35
					12	30
						35
					48	30
						35
					100	30
						35
				H.265	12	30
						35
					48	30
						35
		Alea	HD	H.264	8	30
						35
					16	30
						35
					48	30
						35
					96	30
						35
				H.265	8	30
						35
					16	30
						35
					48	30
						35
					96	30
						35
			UHD	H.264	8	30
						35
					16	30
						35
					48	30
						35
					96	30

Video sequence	NAL Units Size	Encoding schema	Format	Codec	GOP size / I Period	Quality
						35
				H.265	8	30
						35
					16	30
						35
					48	30
						35
					96	30
						35

Annex B:
Laboratory Test Campaign Description

B.1 Test Bench Presentation

In order to perform video quality and bitrate measurements over the powerline channel, a laboratory test bench is elaborated, allowing:

- SISO and MIMO powerline communications on the 1 MHz to 90 MHz band and with controlled SNR, by control of:
  - the line impedance, and the use of PLC LISNs and coupler to a coaxial transmission line;
  - the line attenuation, and the use of coaxial attenuators;
  - the level of powerline noise, and the use of a noise generator on the coaxial transmission line.
- The generation of a network stream, with a fixed bitrate, and measure how much of the stream is received.
- The Streaming and the reception of H.264 and H.265 compressed video sequences over an Ethernet network (PLC modems indeed transport Ethernet packets).
- The Storage of the received video sequences and their associated parameters (video format, codec used, codec parameters, PLC SNR).
- The calculation of quality metrics of the received video sequences.
- Allowing operators to watch the received video sequences.

The test bench may be split in four parts:

- A PLC transmission test bench
- A traffic generation and measurement test bench
- A video diffusion test bench
- A video processing test bench

Those four test benches are described in the next clauses.

B.1.1 PLC Transmission Test Bench

The PLC Transmission Test Bench makes the powerline SNR vary between two PLC modems (SISO or MIMO).

It includes:

- Two MIMO LISNs (Line Impedance Stabilization Network).
- Two wideband (DC-5GHz) coaxial attenuators.
- Two power dividers.
- One noise generator with two separate, independent outputs.
- One spectrum analyzer.

The synoptic of this test bench is described on figure B.1, and a photography is available on figure B.2.

The two LISNs set and stabilize the powerline impedance at the powerline socket side. It also allows PLC signal to be transmitted over 50 Ω coaxial lines. Because these LISN are MIMO, they split the signals between Line and Neutral (L-N) on one coaxial port, and between Line and Ground (L-G) on another port.

On both ports, a coaxial attenuator is used in order to vary the signal power, seen by the receiver, and a 50 Ω power divider in order to inject white Gaussian noise with a 50 Ω noise generator (the noise injected on one line is independent from the one injected on the other line).

Additionally, a 50 Ω Spectrum Analyzer may be connected to the power splitter in order to measure the SNR (see figure B.3).

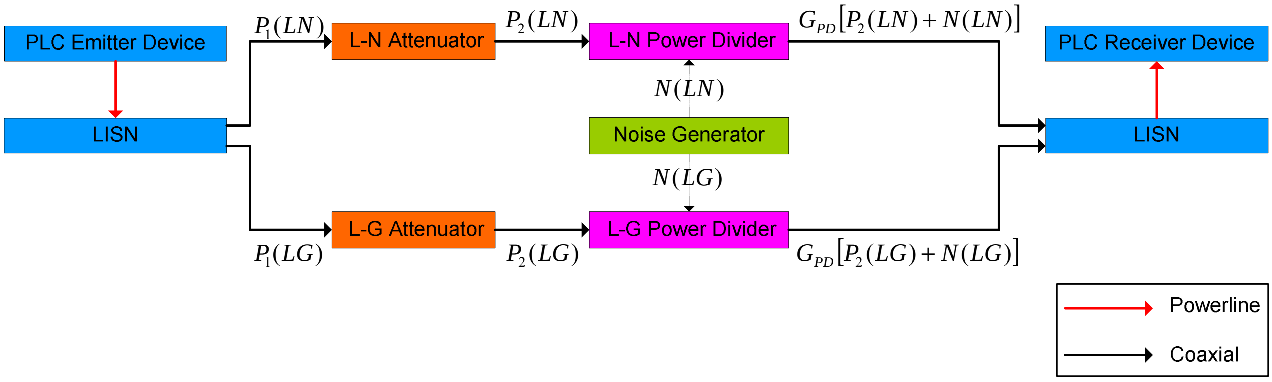


Figure B.1: PLC Test Bench synoptic

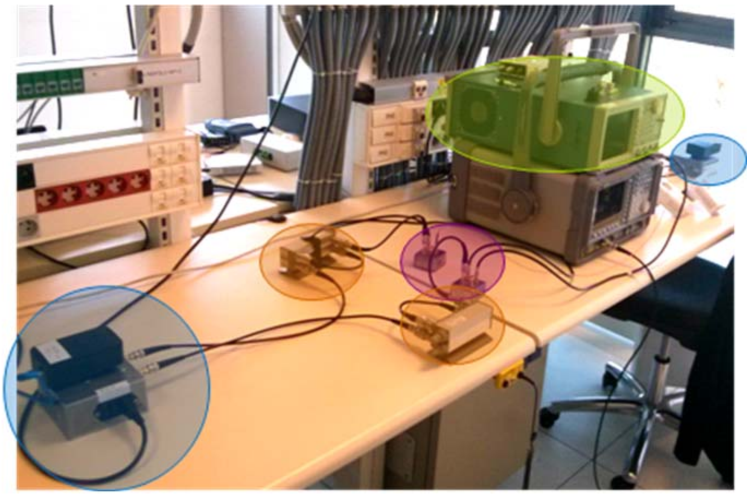


Figure B.2: PLC Test Bench

During the setup of the PLC Transmission Test bench, it is verified that, when two independent white noise of identical power are injected on the two coaxial ports of the LISNs, three independent white noises are observed on the three ports of the electrical socket (L-N, L-G and Neutral-Ground). This means that if two independent signals with equal power are present on two coaxial ports, it will result on three independent signals power of equal magnitude on the three available ports of the electrical socket (L-N, L-G and N-G).

This setup allows the two modems to transmit on an AWGN channel on which the SNR can vary on both coaxial lines (L-N and L-G). Furthermore, when seeking to set a same SNR value on the two coaxial lines (to obtain an identical MIMO channel on each transmission path), one may characterize the AWGN channel by setting the SNR on only one single LISN (among the two available LISNs).

In the SISO transmission case, the attenuation is set to its maximum on the L-G line. This blocks any PLC transmission to occur on this line, that would result in a multiple path SISO channel (the PLC signal sent by a SISO modem on a L-N transmission line might indeed couple on other transmission lines).

Whereas the noise injection level is controlled and calibrated over the coaxial transmission lines, the power of the PLC signal, which is dependant of the modems models & manufacturer, cannot be controlled by the test operator. Thus, the power of the signal emitted by the emitter PLC modem is measured to compute the SNR seen by the receiver modem.

This PLC signal power measurement is made modifying the test bench in accordance with figure B.3. A Traffic Generation and Measurement Test Bench is used, as described in clause 6.3.2.2, to maximize the emitter modem speaking time on the powerline channel. Coaxial attenuators are also set to the maximum value that does not break the PLC link, in order to minimize the contribution from the receiver modem signal into the measured power, especially in case of signal collision (PLT- technology uses CSMA/CA (see note) for Media Access Control). Finally, to avoid taking into account timings where the receiver modem transmits (which are also timings where the emitter modem does not transmit) measurement are done using a MAX HOLD preset on the spectrum analyzer.

NOTE: CSMA/CA: Carrier Sense Multiple Access with Collision Avoidance.

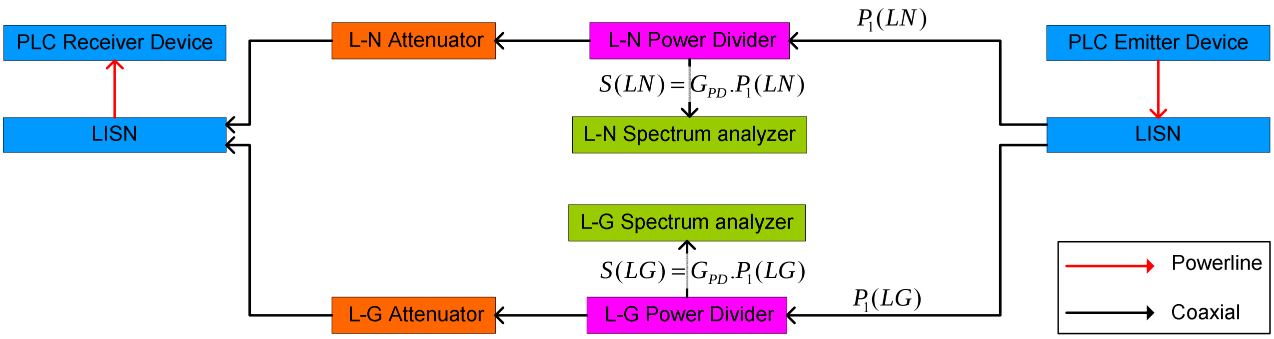


Figure B.3: Synoptic of the PLC Test Bench configuration for signal power measurement

The SNR seen by the receiver modem may be then computed with the two following formula:

$$SNR(LN)_{dB} = S(LN)_{dB} - A_{dB} - N_{dB}$$

$$SNR(LG)_{dB} = S(LG)_{dB} - A_{dB} - N_{dB}$$

Where

- $S(LN)_{dB}$ is the signal power delivered by the PLC modem model under study, and previously measured,
- N_{dB} is the injected noise power,
- A_{dB} is the attenuation between the emitter and the receiver,
- given that the attenuation induced by the power devider is equal between any of his ports.

When considering SISO modems, the first formula $SNR(LN)_{dB}$ only is used.

When considering MIMO modems, one may verify that $S(LN)_{dB} = S(LG)_{dB}$, in order to make sure that the assumption $SNR_{dB} = SNR(LN)_{dB} = SNR(LG)_{dB}$ still holds.

B.1.2 Traffic Generation and Measurement Test Bench

Objective of this test bench is to generate a network flux which characteristics are identical to the flux transmitted when a video is streamed with the Video Diffusion Test Bench, except from the bitrate point of view.

The bitrate of the generated traffic is the maximum permitted by the Ethernet interface of the modem. In order to get a very stable bitrate and a precise bitrate measurement, a traffic generator is used (Spirent Test Center).

The parameters of the generated network stream are:

- Encapsulation: RTP in UDP in IP in Ethernet

- RTP header length: 12 bytes
- RTP payload size: 1 436 bytes
- RTP header field values
  - Version: 1
  - Padding: False
  - Extension: False
  - CSRC Count: 0
  - Marker: True
  - Payload Type: 33
  - Sequence number: 0
  - Timestamp: 0
  - SSRC: 0
- UDP header length: 8 bytes
  - Source port: 1 024
  - Destination port: 5004
- IP header length: 20 bytes
  - Version: 4
  - Header length: 5
  - ToS: 0
  - Total length: 1476
  - Identification: 0
  - Reserved bit: 0
  - Don't Fragment bit: 1
  - More Fragment bit: 0
  - Fragment offset: 0
  - Time To Live: 128
  - Protocol: 17
  - Source: 192.168.1.1
  - Destination: 192.168.1.2
- Ethernet header length: 14 bytes
- Ethernet trailer size: 4 bytes
- Total Ethernet frame size: 1 494 bytes
- Physical (on wire) bitrate:
  - 1 000 Mbps if modem Ethernet interface is 1000Base-T

- 100 Mbps if modem Ethernet interface is 100Base-T

The traffic generator reports the physical received bitrate (Ethernet frame bitrate).

To retrieve the RTP payload's bitrate, the following formula is applied:

$$RTPBitrate = ETHBitrate * \frac{RTPPayloadSize}{ETHFrameSize} = ETHBitrate * \frac{1436}{1494}$$

B.1.3 Video Diffusion Test Bench

The Video Diffusion Test Bench is made of two computers: an emitter and a receiver.

The emitter computer is able to:

- Store compressed video sequences.
- Broadcast those video sequences thanks to a streaming server software.

The receiver computer is able to:

- Store received video sequences
- Decompress those sequences
- Display those sequences
- Analyse their quality in comparison to the original (non-compressed) sequences
- Store the original (non-compressed) sequences.

Some features are common to the two computers:

- Instantaneous per-frame bitrate analysis
- Traffic generation for PLC modems warming purpose

B.1.3.1 Software configuration

In order to enable those features, the two computers run Linux Ubuntu Trusty Tahr (kernel version: 3.13).

Specific software configurations and versions are used as described in the tables below.

Table B.1: Emitter PC software configuration

library/software description	Name of the library/software
Video decoding library for H.264 and H.265	libav 10
Broadcasting software	live555 Media Server
Traffic generator	iperf
Software enabling instantaneous per-frame bitrate analysis	tcpdump, tshark and GNU Octave

Table B.2: Receiver PC software configuration

library/software description	Name of the library/software
Video decoding library for H.264 and H.265	libav 10
Traffic generator	Iperf
Video reception software	openRTSP
Video decompression software	avconv (included in libav 10)
Video playing software	avplay (included in libav 10)
Video quality software analyzer	qPSNR (LAB2-patched for libav 10 compatibility)
Software enabling instantaneous per-frame bitrate analysis	tcpdump, tshark and GNU Octave

B.1.3.2 Protocol stack for video streaming

Live555 Media Server and openRTSP tools use the Real-Time Streaming Protocol (RTSP). Such a protocol handles signalization between the video client (PC receiver) and the video server (PC emitter), i.e. they allow to perform: video requests, streaming parameter negotiations, etc. RTSP is an application layer protocol (layer 7 of the OSI stack), using RTP as a transport protocol (layer 4 of the OSI stack) for the video flux. So, for the transport itself, the Test Bench behave as if only RTP was used (no RTSP signalization is exchanged during the video transmission).

The transport of both H.264 and H.265 over RTP is based on the same mechanisms. Referring to the protocol stack used for this Test Bench and described in figure B.4:

- The coder divides the compressed bitstream into NAL units which are stored in a file (which is commonly referred as the "compressed video file").
- The streaming software reads the NAL units contained in this file.
- The streaming software then delivers the NAL units to the RTP stack:
  - If the NAL unit size is greater than the RTP payload size, then it will be split into several RTP datagrams.
  - If the NAL unit size and the RTP payload size are the same, then the NAL unit will be transmitted within one RTP datagram.
  - If the RTP payload size is large enough to contain *n* NAL units, then these *n* NAL units will be transmitted within one RTP datagram.
- Each RTP datagram is then encapsulated in a UDP datagram, then in a IP packet and finally in an Ethernet frame.

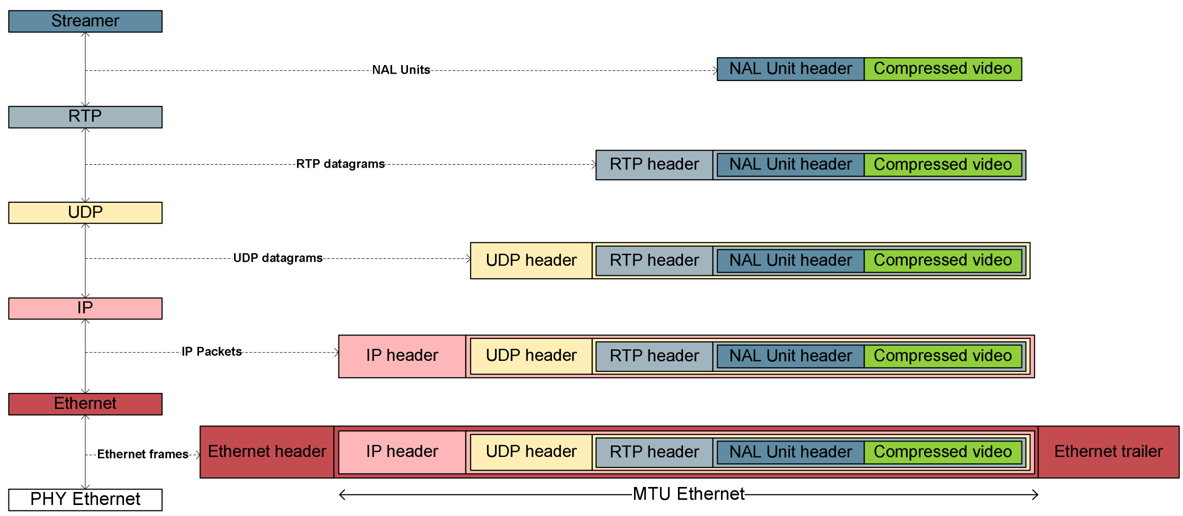


Figure B.4: Protocol stack used for video streaming

B.1.4 Video processing test bench

B.1.4.1 Presentation

Given the fact that the video streaming is a repetitive task, different software scripts were written to minimize the human contribution & operation to the test, and consequently, minimize a potential human (error) factor. These scripts are located on the receiver computer and allow the following operations:

- To request the streaming of a video, referenced by its name, its format (UHD/HD), its quality, its compression type (H.264 or H.265) and its compression parameters (I frame period, NAL Unit size and coding strategy). This is handled by the script named "STF468Client.sh"

- The received video to be stored in a way allowing its identification (each received file has a unique name, and a correspondence table helps to link a file with the compression and diffusion parameters). This is also handled by the script named "STF468Client.sh"
- To request the streaming of several different videos sequentially (several sequential calls to STF468Client.sh) in one line. This is handled by the script "STF468TestSerie.sh"
- To compute the quality metrics (PSNR and SSIM) of each received video received in one command line. This is handled by the script named "STF468Statistics.sh"
- To export the entire folder containing all the received video, and the related quality metrics, or only the files containing PSNR and SSIM quality metrics (default behaviour) in a single zip file. This is handled by the script STF468StatisticsExport.sh
- To import the test results into an Excel document, in order to make statistics in an easy way

B.1.4.2 Results collection

To work properly, scripts are placed in a specific folder tree, in which it is also convenient to put the compressed and reference video files, and manually browse the results. This file tree (see figure B.5) is composed of:

- The STF468* scripts (described above), in the root folder.
- The reference (non-compressed) video sequences in /home/lan/videos/y4m/HD for HD sequences and /home/lan/videos/y4m/UHD for UHD sequences.
- The H.264 compressed sequences in /home/lan/videos/H.264/HD for HD sequences and /home/lan/videos/H.264/UHD for UHD sequences, respectively /home/lan/videos/H.265/HD and /home/lan/videos/H.265/UHD for H.265 sequences:
  - In both UHD and HD directories, one directory is created for each couple (NAL unit size; coding strategy) with the following convention: "NAL[NAL Unit size]-[coding strategy name]".
  - In those sub-directories, one directory is created for each I frame period with the following convention: "I[I frame period]".
  - In those sub-sub-directories, the compressed sequences are placed with the following convention: "[seq_name]_[format][p/i][fps]-[quality].[extension]" where:
    - [seq_name] is the name of the sequence
    - [format] is "1080" for HD sequences and "2160" for UHD sequences
    - [p/i] is "p" for progressive scan sequences, and "i" for interleaved sequences
    - [quality] is the number reflecting the quality of the video (the lesser the better)
    - [extension] is the extension of the file (mkv, 265 or 264)

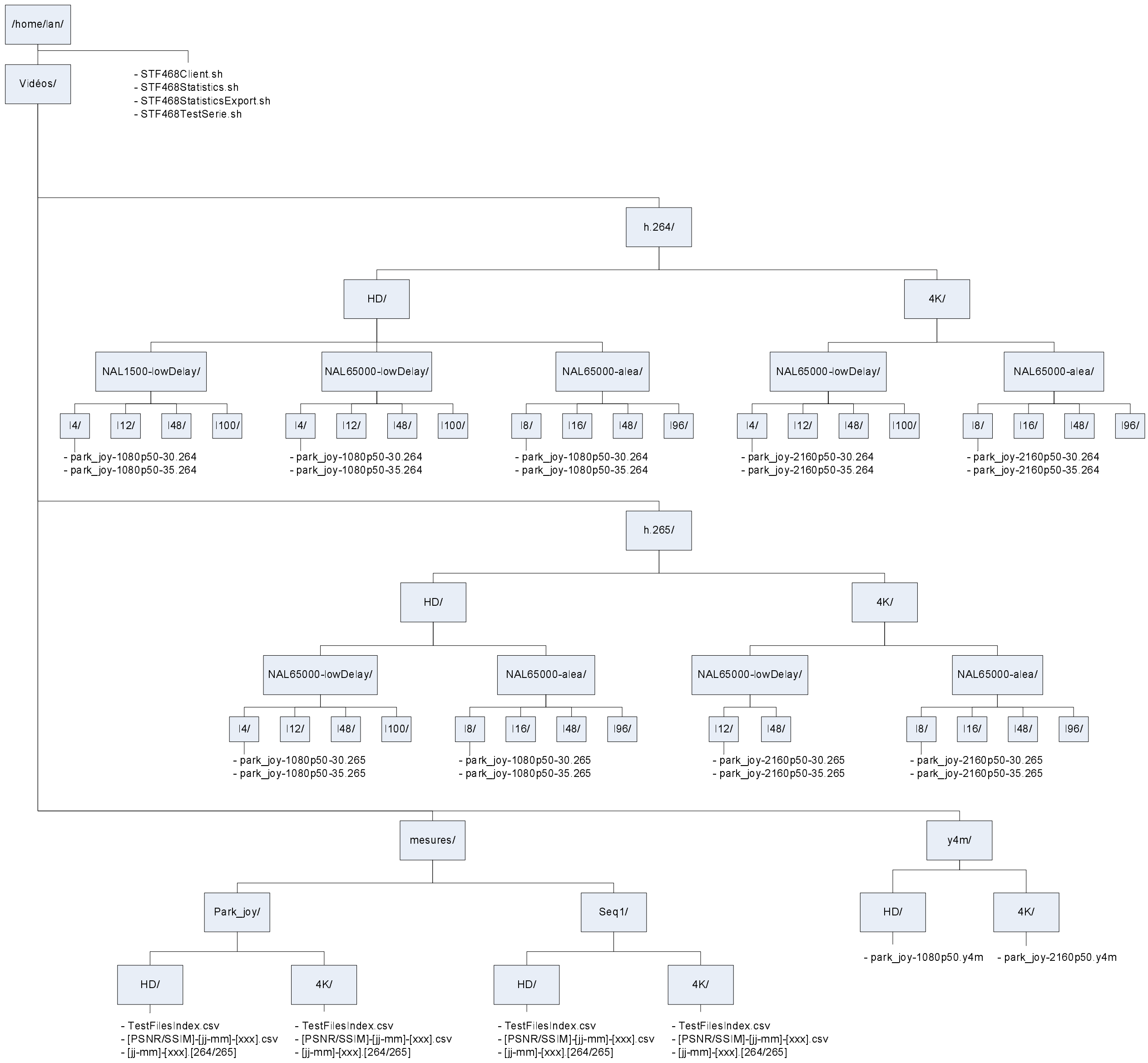


Figure B.5: Folder tree

B.2 Test Plan

As raw PLC performance testing and video over PLC testing are two different types of tests, with two different setups, the test plan is split into two parts, corresponding to the two kinds of tests:

- Raw PLC Performances on AWGN Channel
- Video Streaming Performances over PLC on AWGN Channel

These tests are described in the following two clauses below.

B.2.1 Raw PLC Performances on AWGN Channel

Raw PLC performances tests consist in determining the average unidirectional bitrate achievable between a pair of PLC modems, at a given SNR (seen by the receiver modem). Therefore, it is a point-to-point performance test in a calibrated test environment conditions.

To achieve such a test, the PLC Transmission Test Bench is used (see clause B.1.1) in association with the Traffic Generation and Measurement Test Bench (as in clause B.1.2).

For each SNR value of interest, traffic is generated over 3 runs of five minutes each, and the achieved bitrate is measured and reported over these 3 runs. The mean and the standard deviation values are also derived from these three bitrate measurements.

It should be noted that, prior to the measurement themselves, a 100 Mbps or 1 Gbps (depending on the Ethernet interface of the modem) dummy, unidirectional traffic streams are generated between the modems during five minutes in order to let them reach a stabilized and nominal state (to let the electronic parts reach their nominal temperatures, and allow the PLC traffic to settle in the right conditions).

Furthermore, when coming to switch the SNR under study to another value, the two modems are then booted (the emitter modem is powered first, this way one can ensure that the Central Coordinator role is held by this device).

To summarize, the test sequence for the Raw PLC Performance assessment of one PLC device is as follows:

1) Test Bench Setup for SNR calculation:

   a) Set up PLC Transmission TestBench as described in figure B.3.

   b) Boot up two modems.

2) PLC Signal measurement (when not already done):

   c) Generate a 100 Mbps or 1 Gbps (depending on the capabilities of the modem's Ethernet interface) unidirectional bitrate from emitter to receiver PLC modem with the Traffic Generation and Measurement Test Bench.

   d) Set L-N and L-G attenuators in order to reach the maximum attenuation possible, without breaking the PLC link (if SISO modem, set L-G attenuator to its maximum value).

   e) Measure the emission power (if modem is SISO, only $S(LN)$ is measured, else $S(LN)$ and $S(LG)$ are measured).

   f) Stop traffic generation.

   g) Shutdown the two modems.

   h) If PLC modem is MIMO, verify that $S(LN)$ and $S(LG)$ are close.

3) Test Bench Setup for Raw PLC Performances measurement:

   i) Set up PLC Transmission TestBench as described in figure B.3.

   j) In this setup, the SNR as seen by the receiver PLC modem is:

$$SNR_{dB} = S(LN)_{dB} - A_{dB} - N_{dB} = S(LG)_{dB} - A_{dB} - N_{dB}$$

   k) Where
   $S(LN)_{dB}$ is the signal power measured on $\mathrm{L-N}$, $S(LG)_{dB}$ is the signal power measured on $\mathrm{L-G}$, A_{dB} is the attenuator preset, and N_{dB} is the power of noise injected on both L-N and L-G channels.

4) Modems warmup:

   l) Boot up the two modems.

   m) Generate a 100 Mbps or 1 Gbps (depending on the capabilities of the modem's Ethernet interface) unidirectional bitrate from emitter to receiver PLC modem with the Traffic Generation and Measurement Test Bench (see clause 6.3.2.2).

   n) Wait for 5 minutes.

   o) Stop traffic generation.

5) Raw PLC Performances measurement for one SNR value:

p) Shutdown the two modems.

q) Set the attenuators in order to obtain the desired SNR value.

r) Boot up the two modems (in order to keep PLC modems warm, time between 5.a and 5.c should be less than one minute).

s) Generate a 100 Mbps or 1 Gbps (depending on the capabilities of the modem's Ethernet interface) unidirectional bitrate from emitter to receiver PLC modem with the Traffic Generation and Measurement Test Bench (see clause 6.3.2.2), and mesure how much of it is received during 5 minutes.

t) Return to d. in order to do at least 3 measurements.

u) Return to 5.a to make a measurement with another SNR value.

Once all measurements are done, they are processed and the mean and the standard deviation of the bitrate values are calculated for each PLC SNR investigated value. Curves and figures then show the available video bitrate depending on the PLC SNR for each PLC technology.

B.2.2 Video Streaming Performance over PLC on AWGN Channel

The video streaming tests over AWGN channel consist in the transmission of a set of compressed video sequences with:

- Several coding parameters (see annex A).
- Several PLC SNR.
- Several PLC technologies (PLT- AV, PLT-AV2 SISO, PLT-AV2 MIMO).

The goal is to determine the impact of these parameters on the quality of the received video sequences. In order to quantify the video quality, PSNR and SSIM metrics and QoE evaluation are used. Also the percentage of the original video successfully read by the decoder (frames read can still contain errors) is determined.

The test consists in transmitting each compressed video over the three PLC technologies, and with different PLC SNR. More specifically, only PLT- AV is used for the analysis of the NAL Unit size impact, the I frame period and the comparison of H.264 and H.265 (it was shown indeed that this technology has the greatest impact on the video quality compared to AV2). Furthermore, only one reference video (park_joy) is used for all the laboratory measurements. At least 10 streaming iterations for each pair (coding parameters; PLC SNR) are performed to allow the average and the standard deviation of PSNR/SSIM to be computed.

The QoE measurement is only achieved for the H.264 vs H.265 comparison and also for the PLT- AV against PLT-AV2 SISO against PLT- AV2 MIMO comparison. For this measurement, the NAL unit size, the I-frame period and the coding strategy are fixed to the values leading to the best video quality, as stated by the PSNR and SSIM metrics. Furthermore, for this particular and time consuming measurement, only one sequence for each pair (coding parameters; PLC SNR) is analysed.

To summarize, the test sequence for the Video Streaming performance assessment with one PLC device is as follow:

1) Test Bench Setup for SNR calculation:

   a) Set up PLC Transmission Test Bench as described in figure B.3.

   b) Boot up the two modems.

2) PLC Signal measurement (if not already done): see previous clause.

3) Video performance Test Bench Setup:

   c) Edit the file STF468TestSerie.sh in order to make it request sequentially all the desired video sequences at least 10 times when executed.

4) Modems warm-up: see previous clause.

5) Video transmission for one SNR value:

   d) Shutdown the two modems.

   e) Set the attenuators in order to obtain the desired SNR value.

   f) Boot up the two modems (in order to keep PLC modems warm, time between 5.a and 5.c should be less than one minute).

   g) Execute the script STF468TestSerie.sh.

   h) Wait until the completion of the script.

   i) Return to 5.a to make measurements with another SNR value.

6) Video quality calculation:

   j) Execute the script STF468Statistics.sh in order to compute the PSNR and SSIM of all the transmitted video sequences.

   k) Import the test results into Excel, for statistical analysis purpose.

7) QoE assessment:

   l) Select the parameters (coding scheme, I frame period, NAL unit size) leading to the best PSNR.

   m) Find the maximum PLC SNR for which the PSNR in HD is at least 10 dB inferior to the reference (see note) PSNR when the video sequence compressed in H.264 is transmitted through a PLT- AV PLC modem.

   n) Find the maximum PLC SNR for which the PSNR in UHD is at least 10 dB inferior to the reference PSNR when the video sequence compressed in H.264 is transmitted through a PLT- AV PLC modem.

   o) At this point, the following parameters are fixed:

      i) Coding scheme

      ii) I frame period

      iii) NAL unit size

      iv) Maximum PLC SNR

   p) Consider one of the transmitted video sequences matching those parameters:

      i) In HD format

      ii) In UHD format

      iii) Compressed with H.264

      iv) Compressed with H.265.

   q) Assess each of the watched video with the following score:

      0: video cannot be read by the software

      1: very low video quality

      2: low video quality, but one can correctly distinguish the scene

      3: medium video quality, with artefacts

      4: good video quality, very few artefact

      5: perfect video quality.

NOTE: Here, the reference PSNR design the PSNR computed on the originally compressed video sequenced (i.e. non-transmitted over PLC).

As before, the mean and standard deviation for SSIM, PSNR and percentage of successfully decoded frames are computed (using the ten transmissions of each video sequence). Plot curves showing those metrics and the QoE are displayed as a function of the PLC SNR.

The goal is to assess the impact of the following parameters:

- The NAL unit size
- The Coding scheme
- The I frame period

Two video codecs, H.264 and H.265, and three PLC technologies, PLT- AV, PLT- AV2 SISO and PLT- AV2 MIMO are considered to conduct the comparison and the cross analysis.

In order to perform this analysis, a curve showing the video quality with respect to the PLC SNR is displayed for each value of the parameters assessed (NAL unit size/coding scheme/I frame period/Codec/PLC technology).These figures are then grouped by parameter to assess their impact. Table B.3 shows how this parameter assessment is done (one line corresponds to one figure with one curve by value taken by the parameter).

Table B.3: Parameters set for the evaluation of each parameter

Parameter & impact under study		**Value set for the other parameters**					
Name	**Values taken**	**NAL Unit size**	**Coding scheme**	**I period**	**Codec**	**PLC Technology**	**Video Format**
Nal Unit Size	1 500		Low delay	4	H.264	PLT- AV	HD
	65 000						
Coding scheme	Alea	65 000		48	H.264	PLT- AV	UHD
	Low delay						
Coding scheme	Alea	65 000		48	H.265	PLT- AV	UHD
	Low delay						
I frame period	8	65 000	Alea		H.264	PLT- AV	UHD
	16						
	48						
	96						
I frame period	8	65 000	Alea		H.265	PLT- AV	UHD
	16						
	48						
	96						
Codec	H.264	65 000	Alea	96		PLT- AV	HD
	H.265						
Codec	H.264	65 000	Alea	96		PLT- AV	UHD
	H.265						
PLC technology	PLT- AV PLT- AV2 SISO	65 000	Alea	96	H.264		UHD
	PLT- AV2 MIMO						

Annex C: Field Test Campaign Description

C.1 Introduction

C.1.1 Objectives and Goals

The goal of this field test campaign is to quantify the benefits of H.265 and MIMO PLC on the video service coverage in real in-home environments.

C.1.2 Selected Approach

To fulfil this goal, a set of 7 homes are selected for the field test campaign:

- Isolated house(s) in a rural environment **home #4**
- Apartment(s) in a small city **home #2 #3**
- Apartment(s) in a dense urban area **home #5 #6 #7 #8**

In those typical homes, a limited set of electrical prongs is selected. One specific prong is exclusively used to host the emitter modem, and is chosen as close as possible on the electrical network to the home gateway.

Each video sequence, compressed with H.264 and H.265 codecs, are transmitted through each pair of the selected prongs, with each PLC technology (PLT- AV, AV2 SISO and AV2 MIMO). Transmitted video are then assessed in terms of video quality (PSNR, SSIM, QoE), and statistically analysed.

The operator takes note of different information about the home under test, its electrical network architecture and the test events that might occur during the testing (e.g. start of a washing machine, a lightning from a storm, etc.). This information is stored on a pre-formatted field test description sheet.

C.2 Description of selected locations

In order to process the results with a maximum of data describing the conditions during the tests, the characteristics are gathered for each building in the field test description sheet. This includes:

- Construction date.
- Geographical description.
- Number of floors.
- Number of rooms.
- Is the house occupied? How many persons live in this location?
- Power distribution structure in the house:
  - Wires & prongs type used for the tests.
  - Number of phases? Which phase is used for testing?
  - Diagram of the electric path used for testing / electrical (estimated wiring length between tested prongs).
  - Short electrical description of the neighbourhood around the tested prongs.

- Electrical cupboard description or picture.

C.3 Test Methodology

C.3.1 Test Pairs Selection

In order to do the test in a configuration close to what is generally encountered in a domestic environment, a specific prong is selected as close as possible to the Internet gateway location within the home as the transmitter prong. This prong hosts the modem on which the emitter computer is connected to.

A set of 5 receiver prongs maximum is selected within a specific home (i.e. prongs on which the receiver modem, connected to the receiver computer, is connected to during the testing).

When feasible, at least one prong should belong to each of these four categories:

1) Close prongs (geographically located less than 10 meters away from the emitter prong)

2) Far prongs (geographically located more than 10 meters from the emitter prong)

3) + 1 floor prongs (geographically located on the $1st$ floor above or below the emitter prong)

4) + 2 floor prongs

The two computers of the Video diffusion Test Bench are used, as for the Video processing Test Bench (see previous clause).

C.3.2 Test Plan

As previously described, the Field Test plan takes into account the description of each test place and the tests themselves.

The detailed procedure to conduct the test campaign in one house is described below:

1) Give a unique identifier to the house.

2) Print a pre-formatted field test description sheet for this house.

3) Fill this sheet with as much details as possible:

    a) Handwritten plan of the house, showing which prongs are used.

    b) Construction date.

    c) Geographical description.

    d) Number of floors.

    e) Number of rooms.

    f) Is the house occupied? How many persons live in this location?

    g) power distribution structure in the house:

        i) Wires & prongs type used for the tests.

        ii) Number of phases? Which phase is used for testing?

        iii) Diagram of the electric path used for testing / electrical (estimated wiring length between tested prongs).

        iv) Short electrical description of the neighbourhood around the tested prongs.

v) Electrical cupboard description or picture.

4) Plug the emitter computer on a filtered prong close to the gateway.

5) For each pair of prongs:

    h) Plug the receiver computer on a filtered prong close to the receiver modem.

    i) Plug the emitter PLC modem to a (non-filtered) prong next to the emitter computer.

    j) Plug the receiver PLC modem to a (non-filtered) prong next to the receiver computer.

    k) Warm-up the PLC devices by sending a network flux with iperf during 5 minutes (TCP flux, that will automatically reach the maximum achievable bitrate).

    l) Unplug the two PLC modems.

    m) Plug the emitter PLC modem and the receiver PLC modem (the time between 5.e and 5.f should not exceed 1 minute).

    n) Execute the script STF468FieldTestSerie.sh that will request every video sequences needed.

    o) Wait until the completion of the script.

    p) Unplug the two PLC modems.

    q) Go back to 5.b with other PLC modems.

6) Execute the script STF468Statistics.sh.

7) Import the test results into Excel, for statistical analysis purpose.

It should be noted that, video performances over PLC technologies based on the transmission of and H.264 compressed video sequences is considered only here. Performance of H.264 and H.265 codecs is also considered when transmitted over PLT- AV PLC network.

Those field tests are processed in order to provide the mean and standard deviation of quality metrics depending on the category of the electrical prongs.

By combining these results, one may then compare the difference of performances of the three PLC technologies for video transmissions, and the difference of performance between H.264 and H.265 when transmitted over PLC (see clauses from clauses 6.4.2.1 to 6.4.2.8).

C.3.3 Results collection

For each home, the synthesis results are provided under the form of a directory named "LAN14STF0xx" where xx is the index of the tested Home. Such a directory includes:

- The scanned version (pdf file) of the field test description sheet for the tested home #xx.
- This sheet includes a map of the home, with a description of prongs and electrical network from the test operator.
- A file result named "results-ed07-LAN14STF0xx.xlsm" including all results and statistics. These statistics are stored in the tabs "statistics ", "H.264 vs H.265" and "AV vs AV2 SISO vs AV2 MIM".

Detailed results are stored in the same way as s in clause B.1.4.2, only difference is the sequence's name.

Annex D: General principle of HEVC

D.1 Introduction

Both MPEG4-AVC and HEVC are called hybrid video codecs (coder/decoder). These codecs are based on motion estimation, which allows providing a temporal prediction, and on the coding of the temporal prediction error (residual). The temporal prediction is done thanks to the so-called 'block matching' algorithm and the residual coding is performed in the DCT (discrete cosine transform) domain. The main functional block diagram can be found depicted in figure 1 of [i.5].

D.2 HEVC - What is new compared to MPEG4-AVC?

The paper in [i.6] gives an overview of the main difference between the two codecs MPEG4-AVC and HEVC considered within the present work. These differences have been considered in the study in order to provide fair performance comparison.

D.2.1 Principal similarities

- both codecs work in YUV colour format;
- both codecs use motion prediction;
- use of I, P and optionally B frames (Intra, Predicted, Bidirectional); and
- variable size of blocks.

D.2.2 Principal dissimilarities

Some of the new features proposed by HEVC:

- new coding mode;
- more movement prediction directions; and
- more adaptability of block size: use of quadtrees.

Annex E: Bibliography

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History

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