HDTV over UWB: wireless video streaming trials and quality of service analysis

Domenico Porcino [(1)], Bram van der Wal [(2)] , Ying Zhao [(3)]

(1) Philips Research, UK (domenico.porcino@philips.com)
(2) Philips Consumer Electronics, NL (bram.van.der.wal@philips.com)
(3) Department of Electronics Engineering, Tsinghua University, China (zhao-y01@mails.tsinghua.edu.cn)

ABSTRACT

The PULSERS EC Integrated Project investigated and developed leading wireless systems for high-speed short-range video transmissions. This paper presents results obtained with the PULSERS Communications Platform 2, an hardware testbed which was specified, designed and implemented to verify the feasibility of a high quality cable-less video transmission system, a wireless version of the Digital Video Interface (DVI). Our experiments analysed the use of a cascaded compression and high-speed wireless link to transmit high quality HDTV video wirelessly at short distances (2-10m).

The paper addresses the reasons for our architectural choice, comparing the video codecs and different wireless solutions both in terms of achieved throughput and perceived mean opinion score registered in subjective testing. The experimental PULSERS testbed and the corresponding field results prove that high quality and high resolution short-distance wireless UWB video links are feasible today.

1. Introduction: Wireless DVI System Concept

The Ultrawideband (UWB) technology is one of the most innovative and promising wireless means to enable cable-less transmission of high-speed data between close-by nodes. The IST Sixth Framework Integrated Project PULSERS ([1]) has investigated and developed UWB prototype hardware to verify the real-life feasibility of some of the most ambitious UWB targets and measure their corresponding quality of service for high-quality wireless video transmission.

Our study and development of the PULSERS Communication Platform 2 concentrated on Very High Data Rate (VHDR) systems in which the end-to-end target wireless troughouput data from a transmission point to a receiver is in excess of 1500 Mbit/s. The goal of our research was in fact the demonstration of the feasibility of a wireless version of a Digital Video Interface (DVI) protocol.

The DVI specifications [2] define a digital interface for use between a computing device and a display device. These specifications were developed by an industrial consortium, the Digital Display Working Group (DDWG), in the late 1990s. This interface allows transmission of bidirectional data between two electronic devices and is typically used in video transfer connections (flat panels LCD display). The simple and low-cost DVI connectors provide very good performance and allow system developers bandwidth throughputs over 1.5 Gbits/s (i.e. over 187 Mbytes/s). The specification enables manufacturers to implement a complete transmission and interconnect solutions. DVI has been designed to overcome one of the biggest problems of the analog Video Graphic Array (VGA) transmission protocol. The VGA interface, widespread in PC applications starting from 1987, had in fact been designed for analog signaling as typically used in old graphic applications. Modern devices, such as liquid crystal displays and plasma screens and PC graphic cards, are designed with internal digital signals and converting those to analog VGA for transmission over cable and then reconverting back to digital in the screen adds both to the cost and to the loss of quality in the final link budget. The necessary digital to analog conversions at source (PC) side and digital to analog at the receiver (monitor) side, which always have a finite precision, are elements which are not anymore necessary with the use of a digital interconnect protocol and should be avoided.

DVI simply allows digital signals to be transmitted directly over cable without any conversion. And the DVI standard also includes the possibility to drive analog signals using the VGA standard for back compatibility. Due to these properties, the DVI standard (and its HDMI evolution) seems to be the ideal candidate for taking over the future high-quality video connections. A wireless version of DVI, although challenging, would help filling a product need in current top of the range electronic devices. The analysis of the feasibility of a cable-less DVI standard starts with considerations on the necessary throughput. Commercial devices employing DVI connectors (projectors, TVs, camcorders, game consoles) support a variety of video resolutions (from VGA to QXGA), as shown in Table 1. As expected the biggest issues lie with the highest quality video systems (SXVGA and above), which transmit raw data in excess of 1.5 Gbit/s.

Characteristic	**VGA**	**SVGA**	**XVGA**	**SXVGA**	**UXGA**	**HDTV**	**QXGA**
Horizontal pixel count	640	800	1024	1280	1600	1920	2048
Vertical pixel count	480	600	768	1024	1200	1080	1536
Total pixel	307200	480000	786432	1310720	1920000	2073600	3145728
Total pixels @ 32bit color	9830400	15360000	25165824	41943040	61440000	66355200	100663296
Mbit/s at 25 frames/s - 32bit color	245.8	384.0	629.1	1048.6	1536.0	1658.9	2516.6
Mbit/s at 25 frames/s - 32bit color (25% blanking overheads)	307	480	786	1311	1920	2074	3146
Mbit/s at 25 frames/s - 32bit color (blanking+ DVI 8/10 encoding)	369	576	944	1573	2304	2488	3775

Table 1: Data Throughput requirements for a Wireless DVI system at different resolutions

The requirements and applications analysis presented in [3] lead to the definition of an innovative radio architecture in which a first stage of data (video) compression is cascaded to a very fast radio link in order to keep the payload over air as low as possible, while satisfying the high quality video requirements.

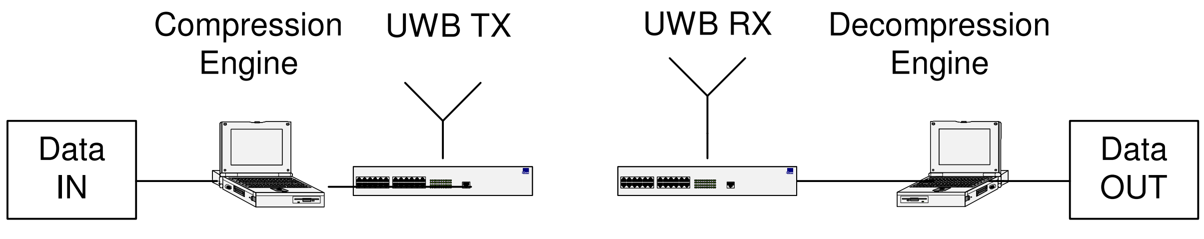

Figure 1: Schematic representation of the PULSERS architecture for wireless DVI

2. Video Compression Choice and Comparison

While the principle of cascading a fast compression engine and a fast radio interface might be easy to understand, the challenges associated in the development/choice of an appropriate compression/decompression (*codec*) for such case are many. In the context of this work we aimed to adopt the most suitable commercially available solution that would enable a good quality wireless transmission. Our goals were the highest possible payload with the lowest wireless throughput while maintaining a good subjective quality of the resulting received image even in the case of heavy interference, as might happen in wireless transmissions (blockages, temporary external interference etc).

The theory of video coding presents us two distinct categories of video codecs:

- Lossless algorithms based on the known or guessed entropy of the content to be transmitted and on adequate generally small compression ratios and
- Lossy algorithms, which make use of more advanced techniques to achieve higher compression ratios, at the cost of some data loss in the original content.

In order to estimate the visual quality of lossy codecs, we introduce two potential objective indicators of the quality of the received video signals: the Mean Square Error (MSE) between an original and a compressed image and the Peak Signal to Noise Ratio (PSNR) of the compressed image. The MSE between an uncompressed monochrome *m* x *n* image U and its compressed form C can be defined as:

$$MSE = \frac{1}{m \cdot n} \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} \left| U(i,j) - C(i,j) \right|^2 \qquad (1)$$

In the case of colour images with a Red Green Blue (RGB) representation the MSE is calculated over the three separate (R, G and B) colour channels as:

$$MSE = \frac{1}{m \cdot n} [\frac{1}{3} \cdot \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} \left| U_R(i,j) - C_R(i,j) \right|^2 + \frac{1}{3} \cdot \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} \left| U_G(i,j) - C_G(i,j) \right|^2 + \frac{1}{3} \cdot \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} \left| U_B(i,j) - C_B(i,j) \right|^2]$$

This indication of the relative difference between the two images is the basis for the PSNR parameter:

$$PSNR = 10 \cdot \log_{10}(\frac{MAX_U^2}{MSE}) = 20 \cdot \log_{10}(\frac{MAX_U}{\sqrt{MSE}}) \qquad (2)$$

where MAX_U refers to the maximum pixel value of the uncompressed original image. With a linear pulse coded modulation that employs k bits per sample, MAX_U equates to (2^k-1). For example in typical pixels representations of 8 bits per sample, MAX_U is 255.

Compression type	**Picture quality**		**PHY bandwidth (in Mbps) needed for visually lossless video**						
	visually lossless (PSNR~40dB)		**QXGA**	**HDTV**	**UXGA**	**SXVGA**	**XVGA**	**SVGA**	**VGA**
	Compression Ratio (CR)	*1/CR*	*2831*	*1866*	*1728*	*1180*	*708*	*432*	*276*
M-JPEG 2000	10:1	0.1	283	187	173	118	71	43	28
M-JPEG	8:1	0.13	368	243	225	153	92	56	36
H.264	7:1	0.14	396	261	242	165	99	60	39
MPEG-4	6:1	0.17	481	317	294	201	120	73	47
WMV9	6:1	0.17	481	317	294	201	120	73	47
DivX	6:1	0.17	481	317	294	201	120	73	47
MPEG-2	4:1	0.25	708	467	432	295	177	108	69

Table 2: ***Compression types and PHY bandwidth needed***

Besides the MSE and PSNR, other objective quality indicators have been proposed in the literature in recent years. One example of an objective method successfully tested for measuring quality of video tests is the Structural Similarity Index Measure (SSIM) [4]. This latest metric compares local patters of pixel intensities after these have been normalised for luminance and contrast, allowing a more precise assessment of the perceptual errors seen by the human eyes in a disturbed video transmission.

The aim of our work is to evaluate very high quality solutions, so we decided to set our specifications towards a video codec with quasi-lossless properties and set a reference point at a PSNR of 40 dB (i.e. at a level where visually impeding errors are unlikely). Using this picture quality reference we compared MPEG codecs (MPEG-2 and MPEG 4) with M-JPEG, M-JPEG 2000 and also very recent H.264, Windows Media Video 9 and DivX codecs, as shown in Table 2.

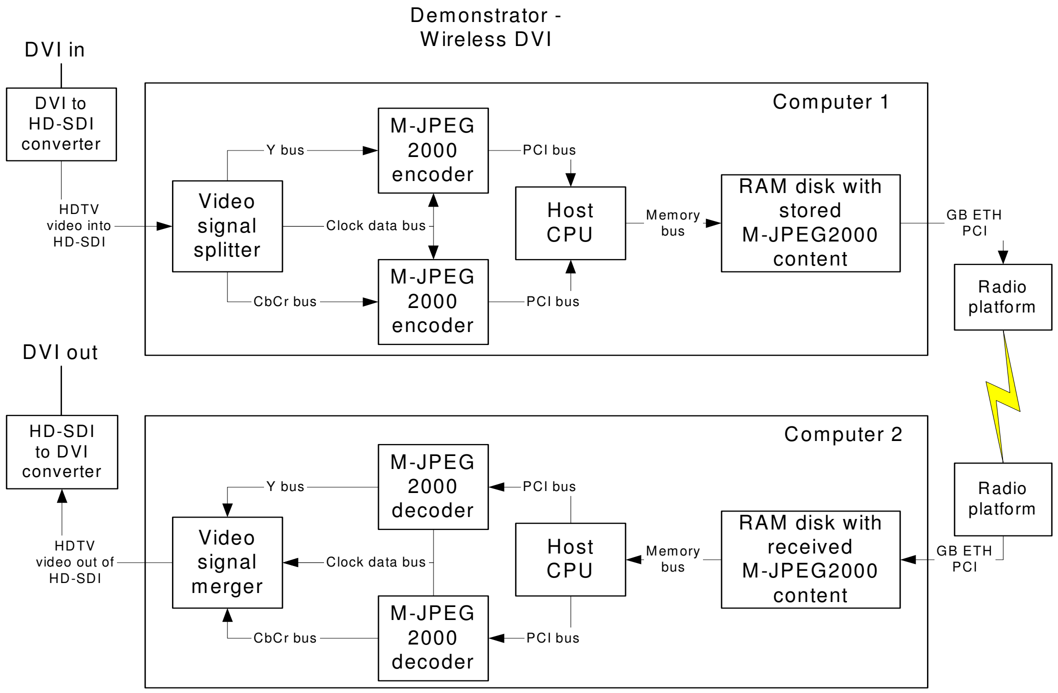

Figure 2: Final configuration of the PULSERS Communications Platform 2 – VHDR transmissions

The minimum video resolution we intended to transmit wirelessly was HDTV, but the data payload that could be sent over air was limited by the physical layer characteristics of the underlying radio technology, so a strong compression was needed anyway to support our video streaming.

Comparing different types of codecs we noticed that Motion-JPEG2000 was the most robust of the video compression techniques. With built-in resynchronisation, error detection and concealment mechanisms, Motion-JPEG2000 can tolerate bursty and single-bit errors and a fundamental feature for the wireless transmission was the fact that errors did not propagate to successive sequences as in the case of MPEG-2 and do not appear in blocks. Real-time symmetric (compression and decompression) dedicated hardware exists on the market for MJPEG 2000 and represents an optimal choice for high-resolution wireless video transfers.

Our final system architecture for the wireless transmission of high quality (HDTV and above) video streams is represented in Figure 2. The key elements in our testbed were therefore the high performance (MJPEG 2000) video codec and the wireless (UWB) transceiver.

3. Wireless Video Streaming Tests

After the definition of the system architecture and the practical realisation of the hardware prototypes we set up a testing campaign to verify the quality of service achievable by our wireless video streaming testbed. The tests started with the selection of a set of video sequences at HDTV resolutions. The video content source we used was formed by uncompressed (raw) YUV sequences (1920x1080 pixels), part of the Philips portfolio of videos inside the Innovation Lab of Philips. They are also used for HDTV plasma and LCD experimental panels quality checks.

Each video frame is saved in uncompressed YUV format and putting a lot of them in one container file (DPX for example) results in a video sequence of uncompressed HDTV material. The sequences used come from movies and sport events, as the PULSERS wireless DVI setup will mostly be used in a home environment.

We used 2 different video sources:

<u>Video Source n.1:</u>

Philips HDTV Promotion video showing recent movie scenes and sport event (47 seconds)

- Shows a mix of very fast changing action scenes as well as slower moving scenes
- Detailed explosions, fast moving objects and panoramic overviews with lots of warms colours and flashing lights.

Figure 3 Sample screenshots from video sequence n.1

<u>Video Source n.2:</u>

HDTV Air show (32 seconds)

- Shows a mix of very fast changing action scenes as well as slower moving scenes
- Detailed zoom-in of aircraft and people faces, detailed clouds

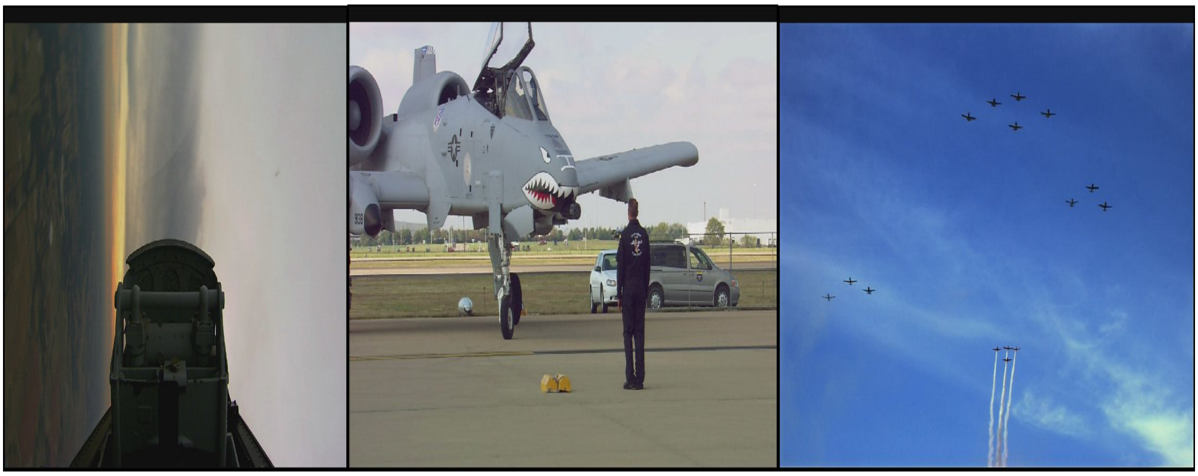

Figure 4 Sample screenshots from video sequence n.2

In order to test the different possible options and resolution we pre-processed the video sequences and pre-recorded different files representing the video sequences at different resolutions and with different compression ratios.

4. Streaming Quality Tests Results

We were able to perform both a physical layer test related to the wireless part of the high quality video streaming platform (effective throughput) and a full quality of service analysis if the end-to-end gigabit video link. The main results are presented in the following paragraphs.

Initial reference tests – effective PHY throughput
In the initial (reference setting) wireless video testing set-up we connected the transmitting streaming PC to different potential physical layer wireless transceivers interfaces, among which commercial 802.11g equipment, 802.11 Pre-N equipment, Ultrawaves UWB transceivers, free space optical transceivers. We also set a reference point with a wired Gigabit Ethernet IP connection.

The first metric we selected for our video tests was the *effective throughput,* which combines throughput with coverage area of the wireless network. All of our platforms were tested on their throughput in Mbps over distances from 1, 2, 3, 4, 6, 8, 11 and 15 meters. We could measure the exact data rates of the platforms that we used for the compressed scenario using the software package IPerf. IPerf was originally developed as a modern alternative for measuring TCP and UDP bandwidth performance over an IP network. It is therefore a good tool to measure the effective throughput of a wireless network, as in the PULSERS test configuration. IPerf is also a tool to measure maximum TCP bandwidth, and allows the fine tuning of parameters connected to the UDP protocol. Iperf reports in an easy format bandwidth, delay jitter, datagram loss.

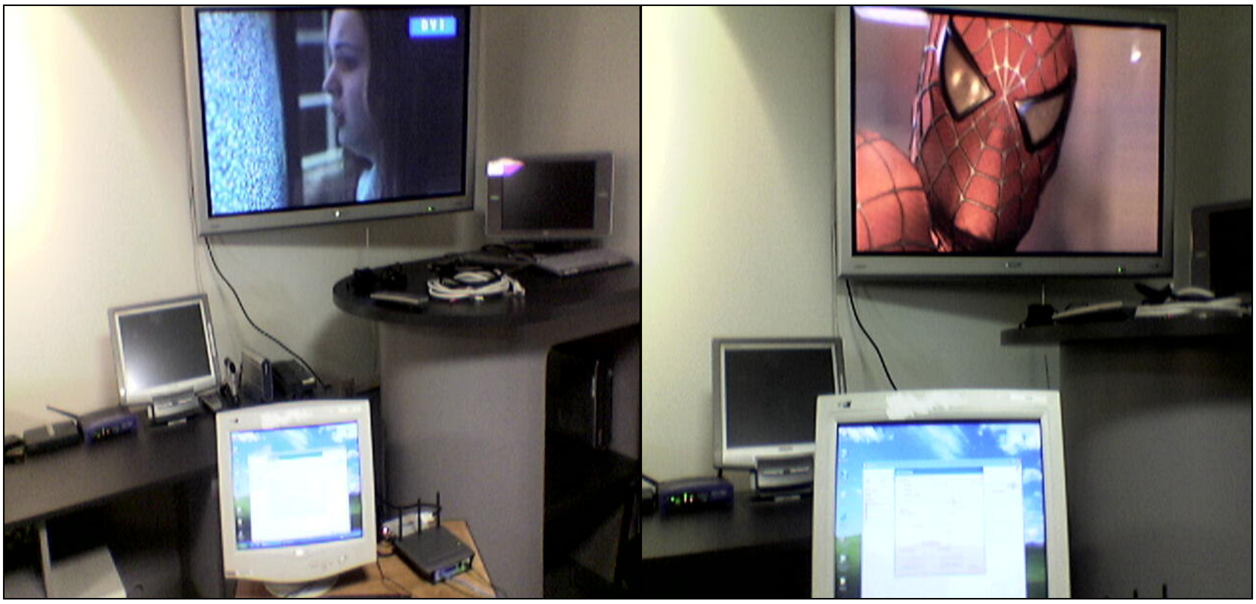

Figure 5: Initial wireless video testing set-up

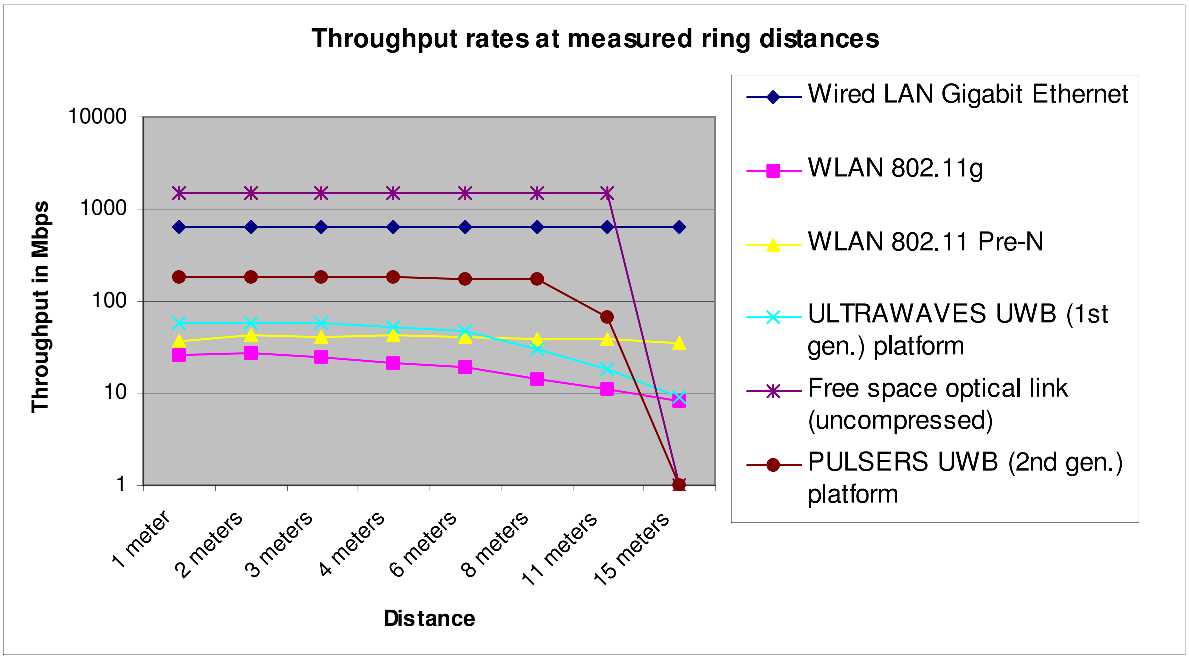

Figure 6: Effective (uncompressed) throughput from different physical layers for the PULSERS VHDR Platform

Final tests – video sequences QoS

For the final tests we placed the receiving platform on a stationary table below a flat screen high quality Philips TV. The transmitter was moved on a trolley along a straight line at constant spacing away from the receiver, as shown in Figure 7.

.

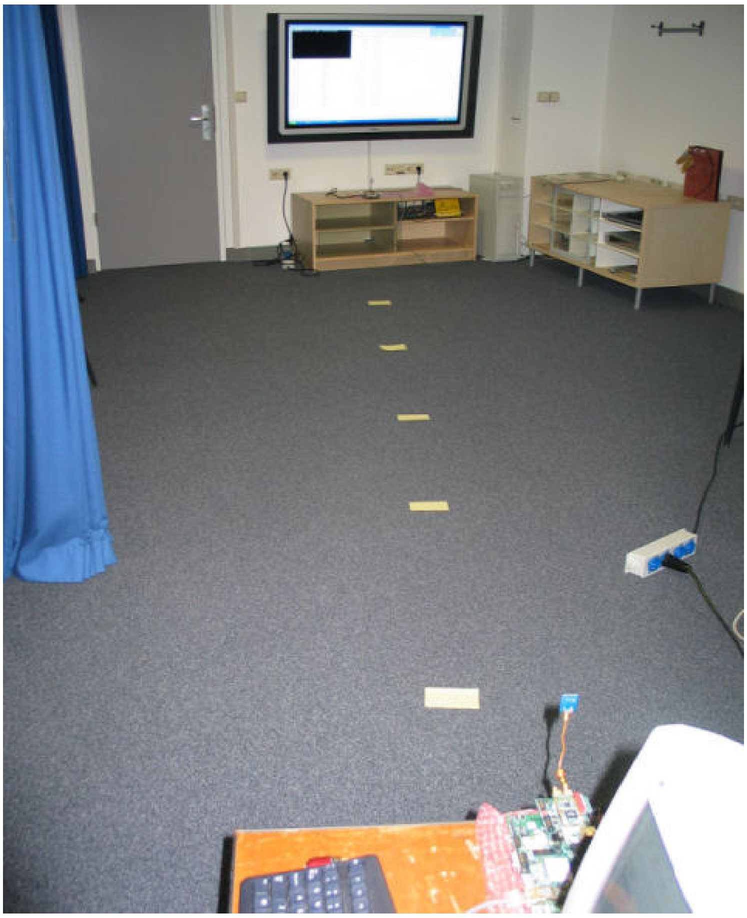

Figure 7 PULSERS VHDR: TX (bottom in the picture) and RX (top) components 6 meters apart.

As explained in the Chapter 2, different metrics exist and can help in measuring the quality of a video signal. What has been found however is that the measured subjective quality of a video sequence is not always perfectly correlated to the objective inverse mean square error or to the peak signal to noise ratio. Therefore in order to evaluate the quality of our wireless video streaming solution we called in a panel of experts that scored each particular sequence seen on screen.

Having registered good and stable connectivity results in the throughput of the PULSERS UWB platforms up to 5 meters, we were expecting good QoS in the video sequences transmissions as well. But the subjective QoS tests at this distance were very disappointing. We therefore decided to reduce the test distance between transmitter antenna and receiver antenna to 1,5 meter, which was the maximum distance at which we could have error-free MPEG-2 transmissions. The Motion-JPEG2000 content was stable up to about 3 meter, before noticeable blurring artefacts came on the screen. But for the sake of comparison we had to keep the transmitter-receiver distance fixed to 1.5 meter for all different physical layers. This 1,5-meter distance between transmitter and receiver also represents a typical cable replacement distance.

The first set of tests were performed in ideal conditions, without interference of other wireless links. The second set of tests were performed in conditions where we interfered the wireless links by placing obstructive objects (person, flowers and cabinet) between transmitter-receiver. To add emulated errors in the Wired LAN (reference) setup we used a utility that overloaded the traffic over the Wired LAN link called ‘Network Traffic Emulator’ from Nsasoft.

We compressed our Philips promotion video from raw video into H.264, MPEG-2 and Motion-JPEG2000 formats. We made compressed content that would be able to run on the WLAN MIMO pre-N, Wired LAN and PULSERS UWB platforms.

In the table below you see the description of bit rates used for each type of HDTV 1080i compressed video on the different platforms, which were evaluated. Note that we were not able to reproduce visual lossless video (PSNR ~40 dB) for the WLAN MIMO 802.11 pre-N platform. In that case we were bound to the hardware platform's maximum throughput of 42 Mbit/s, which was short of achieving a full PSNR of 40 dB.

	Final subjective QoS test - 1080i content description PSNR ~40dB (except for MIMO)		
	MPEG-2	**H.264**	**M-JP2000**
Platforms	Mbit/s	Mbit/s	Mbit/s
Wired Gigabit LAN	80	50	150
WLAN MIMO pre-N	40	40	40
PULSERS UWB	80	50	150

Table 3 Final subjective QoS test - content description

The marks from 1-10 were assigned exclusively for the subjective visual quality of the video on the receiving display. Effects like skipping of frames (all), MPEG artefacts (MPEG-2 and H.264), motion blurring (Motion-JPEG2000) and complete black screens (FS optical link) in the sequences affected the subjective impressions of the testers. The tested video resolutions were the ones allowed by the related platforms. Only Gigabit Ethernet, PULSERS UWB platform and Free-Space optical links were able to transmit sequences at high quality resolutions (HDTV). The other (compressed) links were limited by the underlying radio technology.

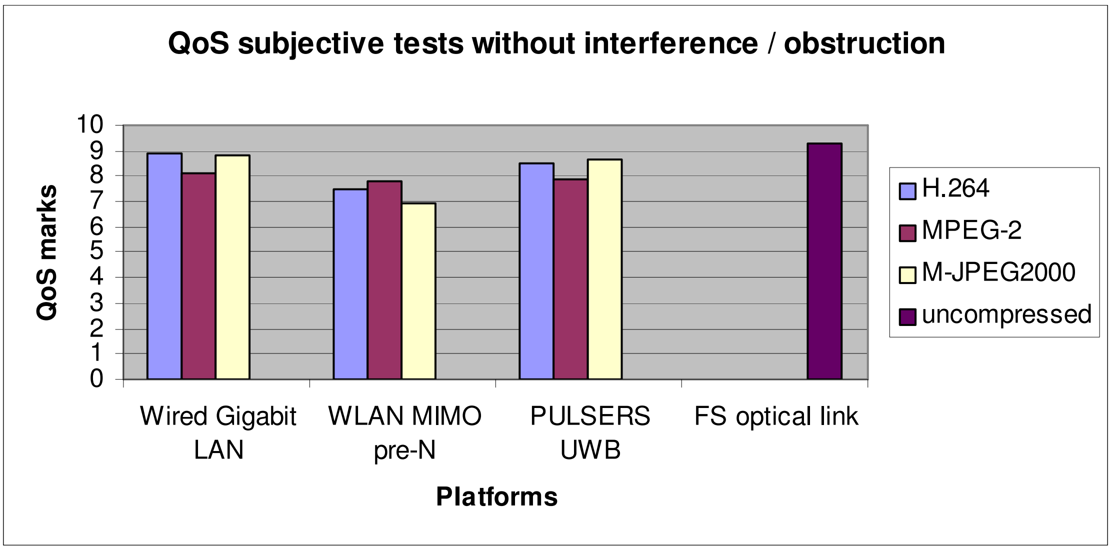

Figure 8 Final PULSERS MOS in LOS at 1,5m distance – comparison of different PY and compressions –LOS conditions

When our subjective group took place in front of the display for the analysis of perceived quality for the HDTV 1080i content, they were asked to give marks for the visual quality of the different video compression types used and the different platforms used. The results were then averages and formed the so callled Mean Opinion Score (MOS), the basis for comparison of the quality of service offered by our cascaded compression and wireless transmission HDTV link.

As we can see from Figure 8, our evaluators perceived the uncompressed Free-space optical link as the absolute best, as expected. Close to this platform mark we see that the M-JPEG2000 and H.264 compressed video on the PULSERS UWB and Wired LAN platforms are perceived almost with the same quality as the uncompressed free space optical link. M-JPEG2000, H.264 and MPEG-2 were perceived lower on the WLAN MIMO system, confirming the fact that this platform was not capable of supporting high quality/low compressed video data, compared to the Wired LAN and PULSERS UWB platform.

When the QoS tests in LOS conditions were completed, the test group sit in front of the display again and they were asked to give new marks for the visual quality of the different HDTV 1080i video compression types. This time the radio link was not in full line of sight, but was disturbed by obstructions and interference in the radio path as introduced with hand waving and walking trough the link as it might happen in normal domestic situations. The results for these tests in Non Line of Sight (NLOS) obstructed conditions are mentioned in the Figure 9.

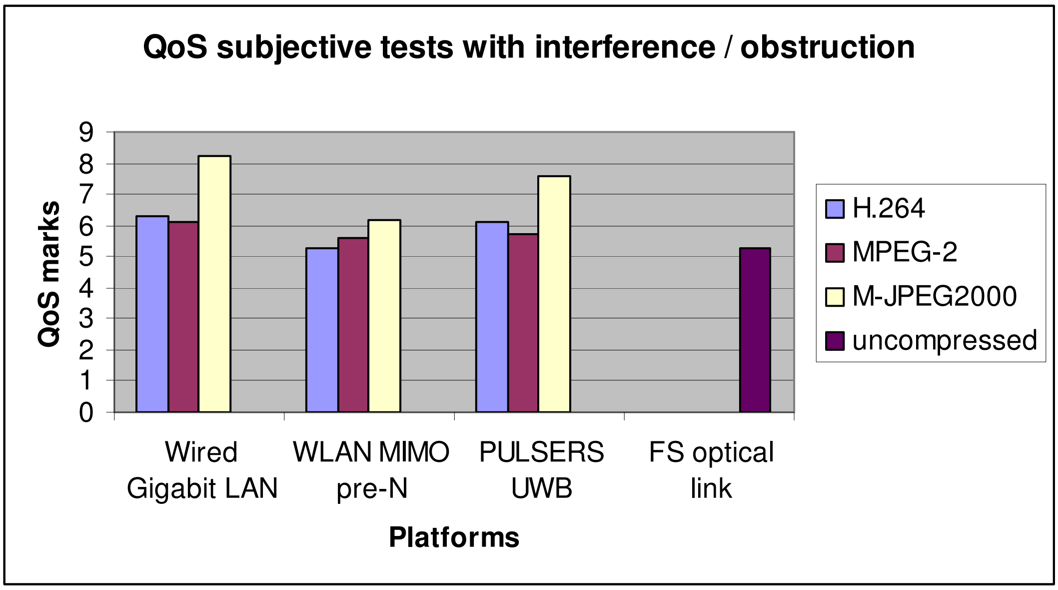

Figure 9 Final PULSERS MOS in LOS at 1,5m distance distance – comparison of different PY and compressions – with obstructions

In the case of severe interference we can notice how the free space optical link was not judged as ideal anymore. This was because it showed black frames as soon as the line of sight path between transmitter and receiver was blocked and this is a noticeable and clearly unacceptable behaviour.

When we take a look at the M-JPEG2000 ratings we see that people prefer this compression method instead of MPEG-2 and H.264 on all platforms. This can be explained because of the different visual errors appearing on the screen and noticed by our test group. People found much more annoying to see the MPEG block artefacts coming on the screen and blocking a lot of visual information, rather than the blurred errors coming of the M-JPEG2000 final visual compressed videos (see Figure 10).

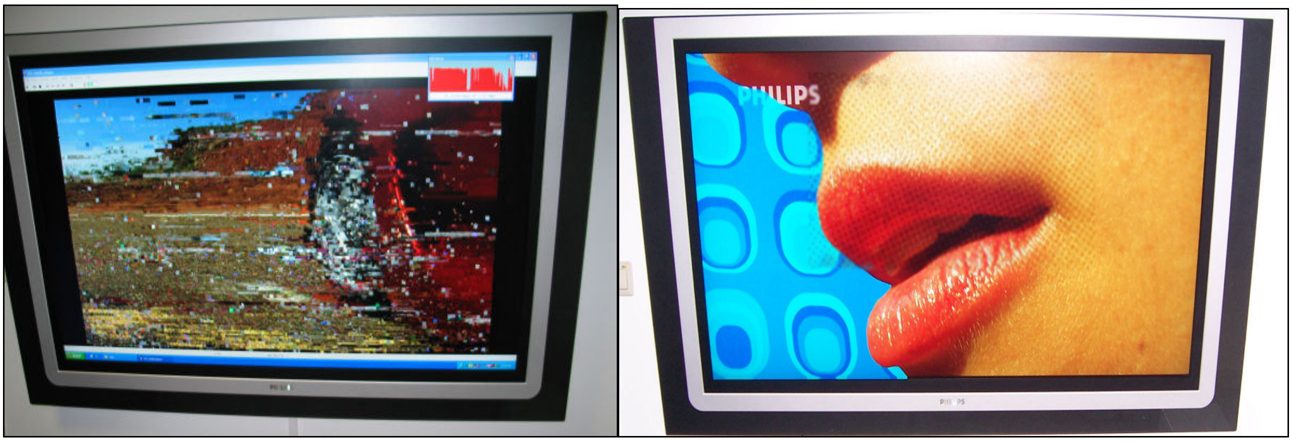

Figure 10: Different types of errors: blocky (left) for the MPEG-2 and blurred (right) for the M-JPEG2000 codec

Even in very badly obstructed conditions, our test people were still able to see the content of the MJPEG 2000 video and only in some places in the screen the image was a bit blurrier, which is perceived as acceptable given the conditions.

We also registered a noticeable difference between the ratings for M-JPEG2000 and those for H.264 in the UWB PULSERS platform. This could be due to the fact that high bandwidth M-JPEG2000 compared to MPEG-2 and H.264 is more resilient to block errors, with an efficient use of entropy encoding and frame by frame compression with no memory that could cause in the H.264 propagation of errors.

5. Conclusions

The IST Sixth Framework Integrated project PULSERS has specified and developed an innovative experimental hardware architecture to allow high quality wireless video transmission and to help verify the feasibility of a cable-less replacement of an advanced wired video transmission protocol, known as Digital Video Interface (DVI).

The cascaded combination of fast compression (based on M-JPEG 2000, MPEG-2 and H.264 techniques) and fast UWB radio links has been analysed and compared with reference fast wired links (Gigabit Ethernet) and wireless Optical Links. The quality of the resulting link has been measured both in terms of throughput and subjective perceived quality (Mean Opinion Score analysis).

From our experiments we can conclude that:

- For low quality (VGA-type) video, all the analysed radio platforms (802.11g, 802.11N, UWB) in conjunction with a hardware compression engine can deliver reasonably long radio links (typically over 10m), even if the subjective quality of the received video is not excellent.
- For high-resolution videos (HDTV or above) only free-space optical links and the UWB PULSERS platform have been able to match the quality of wired solutions. The subjective testing confirmed that the quality of wireless videos is not yet exceptional in all conditions, but is already perceived as good for short (1.5m) distances.

The wireless DVI system implemented and tested in PULSERS during 2005 was top of the class and was a good testbed to demonstrate feasibility of what could become a killer application of the future. Future work should now start also addressing possibilities for lower cost and lower complexity compression techniques which could be coupled with the faster UWB platforms expected on the market in the next few years.

References

[1] Sixth Framework Integrated Project PULSERS, IST FP6 506897, www.pulsers.net

[2] Digital Display Working Group, "Digital Visual Interface DVI", 02 April 1999

[3] Domenico Porcino (Philips Research, UK), Bram van der Wal (Philips Consumer Electronics, NL), Ying Zhao (Department of Electronics Engineering, Tsinghua University, China), "A simple architecture for a Wireless DVI system", IEEE International Conference on Ultra-Wideband 2005 (ICU 2005), Zurich, Switzerland, September 5-8, 2005

[4] Zhou Wang, Alan Bovik, Hamid Sheikh, Eero Simoncelli, "Image Quality Assessment: From Error Visibility to Structural Similarity", IEEE Transactions on Image Processing, Vol 13, N4, April 2004