High efficiency wireless video networks for next generation of ENG services

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1.Introduction

Electronic News Gathering (ENG) is one of the most important services on TV production. Reporting and recording news, social and sport events is the cornerstone of most TV programs today. ENG has been traditionally a combination of recorded content on professional field cameras, and live production from field to TV studio for on-air broadcast. Digital transmission and compression technologies, such as DVB-S (Digital Video Broadcasting - Satellite) and MPEG-2 (Moving Pictures Expert Group), became available in the 1990's, and had a huge impact on ENG services, allowing high quality long distance communications over satellite networks compared to analog systems, and enabling a full digital workflow process from field to user TV set.

The digital satellite news gathering (DSNG) are at present the most useful services for live transmission, like studio-to-live interviews, live news, and any other live event. However, DSNG have strong limitations as long delay, limited coverage in urban environments, high cost uplinks terminals, and strong planning, requiring coordination with satellite operators for time slot access.

Wireless technology is rapidly becoming a power tool for news gathering, taking advantage of its ubiquitous, fast connectivity, and low cost terminals. The efficiency of the new second generation of broadcast technologies, as DVB-T2 (Terrestrial 2nd generation) [1], can be extended to terrestrial wireless ENG (TWENG) providing a robust communication, with an immediate and unplanned character, a self-managed channel coordination, and high data-carrying capacity.

ITU-R defines the ENG services generally as "Broadcast Auxiliary Services" (BAS) and "Services Ancillary to Programme making" (SAP) [2], and has published some recommendations regarding terrestrial spectrum usage for local administrations for fixed and mobile services. Bands widely assigned for these services are 2.4 GHz and 10 GHz, with 8 MHz channel bandwidth.

The natural migration from standard definition (SDTV) video format to high definition (HDTV), 3D-HDTV, or even beyond HDTV, with the new 4K and 8K formats included in Ultra High Definition Television (UHDTV) standard, requires an extra capacity from networks. In this framework, the new generation video coding standard HEVC (High Efficiency Video coding) approved in January 2013 for ITU (International Telecommunications Union) and ISO/MPEG, is revealed as a just right solution for this video resolution growth that demand an extra bandwidth, and is being also required for premium TV services.

HEVC is a successor of MPEG-4 AVC/H.264, and permits to achieve over a 50% of bit rate saving compared to H.264 for the same perceptual quality. A solid work was developed from HEVC standard research team to achieve a trade-off between compression efficiency and computing complexity, with the aim to define a real time video encoding architecture. This makes HEVC a good candidate for the "Next Generation of News Gathering" (NGNG).

At the same time, NGNG may also take advantage of the most advanced transmission techniques which are being implemented in the new generation of broadcasting standards aiming at both, increasing capacity and spectral efficiency, and also increasing transmission robustness

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to cope with the severe degradation in portable and mobile scenarios. These new technologies provide operators a larger range of options to increase the quality of the delivered services, to reach large audiences and also to increase system reliability.

In the framework of the NGNG services, the Spanish CDTI (Centre for the Development of Industrial Technology) funded FREEDOM project. FREEDOM has been conceived with the objective to studying the evolution and application of the most advanced video coding and transmission techniques to increase performance of the terrestrial real-time wireless video links in terms of capacity and coverage and also facing spectral efficiency and power saving. The project will also develop prototypes and a test-bed to evaluate the performance of the current technologies and the next generation video and transmission techniques.

This paper first reviews the state of the art of the BAS/SAP services, followed by the advanced solutions proposed for next generation of video networks focusing the performance of HEVC standard and the DVB-T2 technologies, and describing the optimal set of operational parameters. Finally the authors present the conclusions for next generation of ENG services.

2. Wireless video networks. Background

BAS/SAP services require high quality video streams that, even after several processes of encoding and decoding cycles in the so-called multi-generation process, demand a very high bandwidth. In addition, the high quality requirements of the emerging HD (High Definition) and 3D services (up to 50 Mbps) are not yet supported by the existing products in the market. This leads to make use of MPEG-2 compression technologies and COFDM (Coded Orthogonal Frequency Division Multiplexing) radio links to deliver the live content to the production centers.

At present, most of the BAS/SAP services on the market rely on the use of wireless cameras in order to cover events which are transmitted to audiences. Image from videocameras is encoded through MPEG2 video coding technologies and transmit them using a COFDM technology, to a relay node. This node encapsulates the signals from different units (e.g. reporters, motorcycles, helicopters, etc.) and sends them to a satellite that transports the signal to the TV production studios. Figure 1 depicts the architecture of common BAS/SAP delivery networks, based on the use of a satellite to carry the signals from different sources.

The major drawbacks of this architecture are the implications associated with the use of the satellite services since it increases logistics costs and service operability. The need for technical and administrative coordination with network operators for the occasional satellite links, the scarcity of spectrum in major social live events, added to end-to-end transmission delays, which degrades the quality of user experience QoE, require the development of new proposals to solve the drawbacks of the satellite architecture. Moreover, the high cost of this solution also makes operators face the necessity of new technical approaches.

In recent years, there have been alternatives based on the use of cellular networks (GSM/3G/HSPA) as a mechanism for the distribution of content from wireless cameras to the TV production studios, since it provides a more ubiquitous access to the transmission network, almost anywhere and without the necessity of extensive auxiliary deployments.

Although this architecture introduces an essential upgrade as decreased end-to-end delay, it cannot cope with HD or 3D transmission capacity requirements since current cellular networks allow capacities up to 2.5 Mbps. Furthermore, this ability depends on the congestion of the cell from which the transmissions are made, which, in most cases, coincides with great social events (e.g. football, Olympics, etc.) what often leads to the saturation of the cellular networks. Therefore, in the absence of new architectures that improve efficiency, increase capacity and reduce end-to-end delays, satellite is nowadays the most widely means of provisioning of BAS/SAP services.

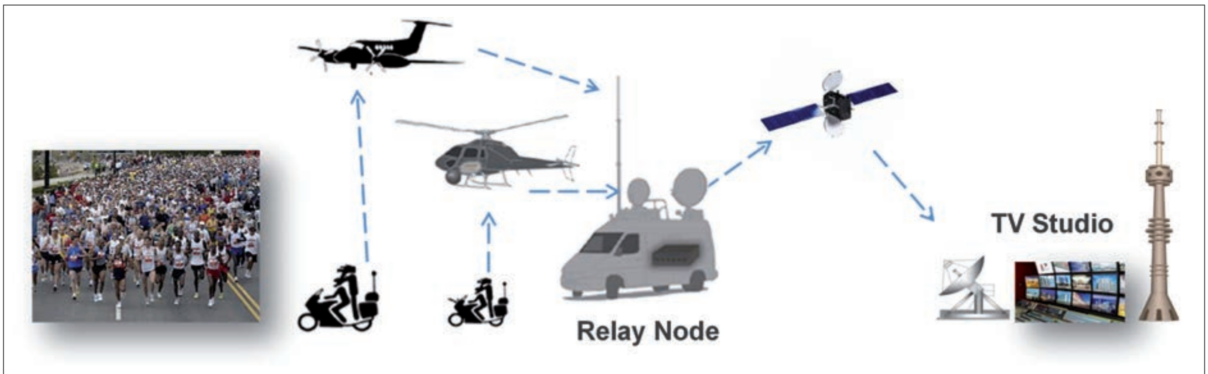
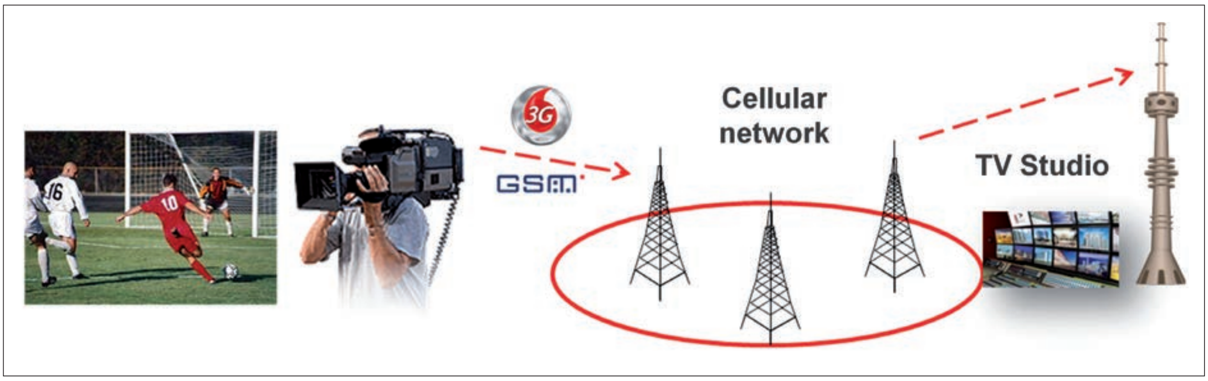


Figure 1. *BAS/SAP scenario based on a satellite solution.*



■ **Figure 2.** *BAS/SAP scenario based on cellular networks.*

That is the reason why FREEDOM project aims at improving video compression efficiency, based on the new HEVC (High Efficiency Video Coding) standard, and improving wireless transmissions by means of the new broadcasting standards as DVB-T2 and the mobile broadcasting standard DVB-NGH (Next Generation Handheld) [3]. In addition, FREEDOM will also study the inclusion of the most advanced transmission techniques, such as MIMO (Multiple Input Multiple Output) to further increase performance and robustness.

The combined use of these technologies allows to reduce the high end-to-end transmission delay, compared to the satellite transmission, and also provides higher capacity in comparison to the existing cellular networks. This new solution is also necessary for the provision of ENG services with HD and 3D formats, which are seen as the most advanced requirements for the near future.

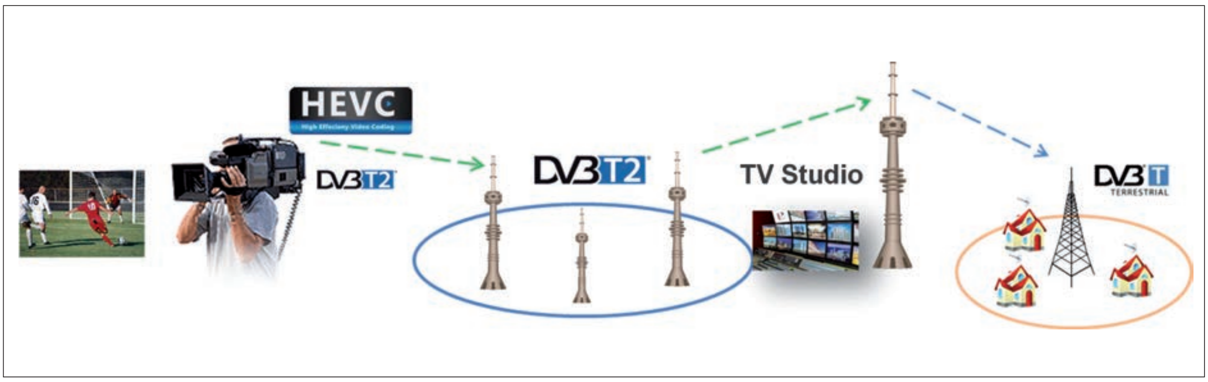
3. Advance solutions for improved wireless video networks

The new proposals for the NGNG services are addressed based on next generation of transmission and compression technologies. The improvement of channel coding efficiency allows increasing the data-carrying capacity, which, at the same time, may be used more efficiently by means of new compression schemes that allow over 50% data rate reduction for the same quality of services. These two approaches will require new video coding techniques to ensure the best quality at the required bit rate, and also improved transmission techniques that will cope with the robustness demands for portable and mobile scenarios.

3.1. Next generation of Video Coding standard for BAS/SAP services

Ten years after the approval of AVC standard (Rec. ITU-T H.264 | ISO/IEC 14496-10), a new collaboration between ITU and ISO/IEC research groups called JCT-VC (Joint Collaborative Team - Video Coding), has concluded with the approval of the new video coding standard, known at development stage as HEVC (High Efficiency Video Coding. HEVC will be formally standardized as ITU-T H.265 [4], and MPEG-H Part2 (ISO / IEC 23008-2) by the ITU and ISO respectively. It was originally designed with the aim to achieve high compression efficiency for high resolution format beyond HD, such as the emerging 4k and 8k formats, however video quality assessments [5] show that HEVC can reach bit rate savings as large as 50% for the same H.264 visual quality, for a wide range of resolutions including QCIF, WVGA and Standard Definition (SD).

The increase of multimedia consumption in addition to the massive use of higher video resolution formats has caused a sharp network traffic growth, especially over wireless networks, which demands adoption of more efficient compression technologies. For this reason, it is expected that HEVC will go on the consumer and professional markets faster than H.264 did, especially for services with bandwidth constraints like OTT, Live Internet



■ **Figure 3.** *FREEDOM BAS/SAP solution with HEVC and DVB-T2.*

DVB-T2 is the world's most advanced DTT system, offering more robustness, flexibility and at least 50% more efficiency than any other.

Streaming, mobile personal video communications, storing and media exchange, and the new 3D and UHDTV broadcasting services. DVB has been one of the first international organizations to establish a liaison statement with ISO/IEC [6] and ITU-T SG16 [7], with the aim to include the HEVC video coding profiles in a new version of the DVB audio-visual coding specification TS 101 154, used for services delivered by IPTV, cable, satellite and terrestrial broadcasting.

The approval of the HEVC standard in January 2013, has reached the first version of the standard, which gives support to 4:2:0 chroma subsampling, and 8-bit and 10-bit pixel depths collected in "Main" and "Main10" profiles, respectively. The JCT-VC is already working on a new profiles family named "Range Extensions" in order to cover the needs of high quality professional production environments, covering the 4:2:2 and 4:4:4 chroma subsampling structure, and pixel depths beyond 10-bits. HEVC Range Extensions will be completed in January 2014, and it revolutionizes BAS / SAP services, allowing encoding HD and UHDTV services with half of current H.264 data rate.

The first steps in the HEVC development began in April 2009 with the "Call for Evidence" [8], and the results confirmed the existence of technology that allowed the improvement of the perceptual quality offered by the High Profile of H.264. In January 2010, the "Call for Proposals" [9] was released from the JCT-VC, and the best tools were selected to develop the initial HEVC architecture. Preliminary video quality assessments carried out during standard development, shown that HEVC can achieve equivalent perceptual quality as H.264/MPEG-4 AVC using approximately 50% less bit rate [10]. These results have been confirmed recently by new subjective tests revealing that HEVC can achieve a 66% data rate saving [11], compared to previous standard, for UHDTV resolutions.

HEVC can be considered an H.264 extension, using the same approach that has been used in most of the video coding standards, where the image pixels are processed in discrete blocks exploiting their spatial and temporal redundancies. An Intra-Frame and Inter-Frame (Motion Estimation and Motion Compensation) prediction model is applied to original blocks obtaining the residue blocks. These blocks are transformed by a two-dimensional discrete cosine transform (DCT), and transformed coefficients are quantized to reduce the data rate. Finally, the quantized coefficients are reordered in a zigzag scanning and efficiently compressed using an entropy coding. With the aim to avoid encoder/decoder drifting, the encoder computes the Intra and Inter predictions from the decoded blocks. For this reason the encoder includes the inverse quantization or scaling, and the inverse DCT to reconstruct the decoded residue. Adding the prediction block to this residue block, the decoded image can be achieve within encoder side, after deblocking filter, also named In-loop filter. HEVC architecture is depicted in Figure 4.

Some of HEVC gains come from the improvements of coding tools supported in previous standards, including more Intra-picture prediction angles (33 modes), merging of neighbouring prediction blocks, more Inter-prediction modes, and larger transform sizes (until 32x32), among others. However, HEVC also introduces new tools such as the new block partitioning structure [12], and a nonlinear amplitude mapping, called Sample Adaptive Offset (SAO) [13], that applied to decoded pixels after In-loop filter improves the perceptual quality.

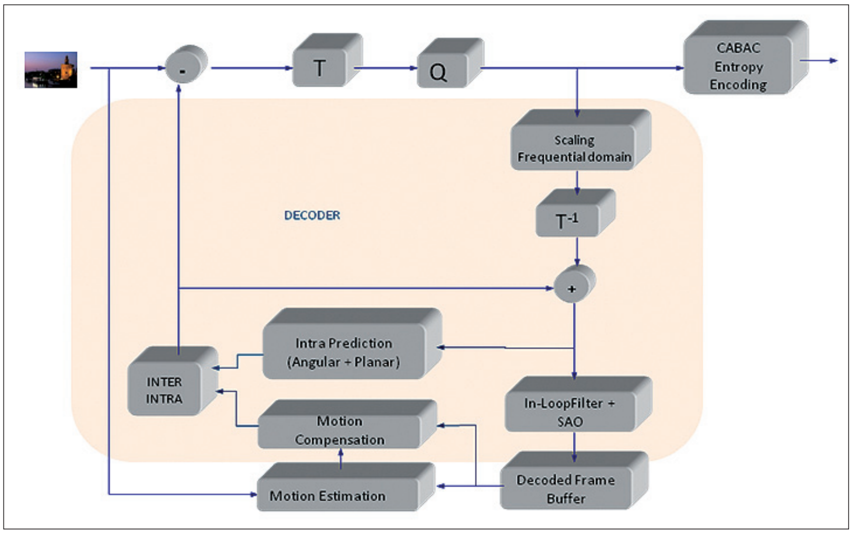


Figure 4. *HEVC encoder architecture.*

Undoubtedly, the most efficient tool included in HEVC is the new Coding Tree Block (CTB) partitioning structure; it is an adaptive version of Macroblock (MB) coding unit used in previous standards. The picture is divided into square blocks restricted to a maximum size of 64x64, and it can be recursively split into smaller quad-blocks called Coding Units (CU), with a minimum allowed size of 8x8. Each CU is the root of two new trees, containing the Prediction Units (PU) and Transform Units (TU), composing a three-level hierarchical structure, to perform the coding, prediction and transform stages.

Figure 5 shows the CTB optimal partitioning of first frame of "RaceHorses" sequence from JCT-VC, where it is perceptible how the CU sizes are adapted to picture com-

Figure 5. *Picture partitioning into Coding Tree Blocks.*

plexity. The smallest CUs are selected for more complex areas, such as borders, textured objects and structural information, and the largest CUs are selected for smooth areas. This feature is especially efficient for high spatial resolution formats, where large uniform areas can be encoded in a lowest bit rate.

The PUs can be further partitioned into smaller sub-blocks depending on Inter-picture or Intra-picture prediction mode. A coding unit (CUs) with a size of 2Nx2N pixels can be Intra-picture predicted as 2Nx2N or NxN PUs, or can be Inter-picture predicted using four symmetric block sizes (2Nx2N, 2NxN, Nx2N, NxN), or four asymmetric sizes (2NxU, 2NxD, nLx2N, nRx2N). Intra PU and inter PUs partitioning modes are depicted in figure 6.

The transform coding is applied to prediction units (PUs) using also a quadtree structure, called Residual QuadTree (RQT) [14], allowing to split the TU into smaller transform units, and limiting its size from a maximum of 32x32 to a minimum of 4x4. The TUs use an integer version of 2D-DCT analogous to H.264 DCT transform, except if the TU belong to PU of 4x4 with Intra-picture prediction in this case a 4x4 DST (Discrete Sine Transform) is applied only to luma component [15].

A new Angular Intra Prediction [16] algorithm is defined by HEVC, which uses the above and left neighbouring pixels of PU, as reference samples for prediction in a similar way of H.264, however it introduces a high number of improvements compared to H.264. Angular Intra Prediction can be applied to CUs ranging from 32x32 to 8x8, and only the smallest CUs (8x8) can be split into four 4x4 PUs. The number of directional prediction modes is increased from 8 to 33, in addition to DC and Planar modes [17], which present small differences with H.264.

The 33 prediction modes are non-uniformly distributed in 16 horizontal and 16 vertical angles, together with a diagonal angle. This distribution sets more density modes close to horizontal and vertical directions (0° and 90°), and less modes close to diagonal direction, because less frequently patterns occur in this direction (±45°). The reference sample location for each angle is computed with a noninteger accuracy of 1/32 of pixel, if the prediction projection does not fit into integer pixel position. Figure 7 depicts the 33 Intra Angular Prediction modes, where the scale of horizontal and vertical axes represents the fractional pixel position between two pixels.

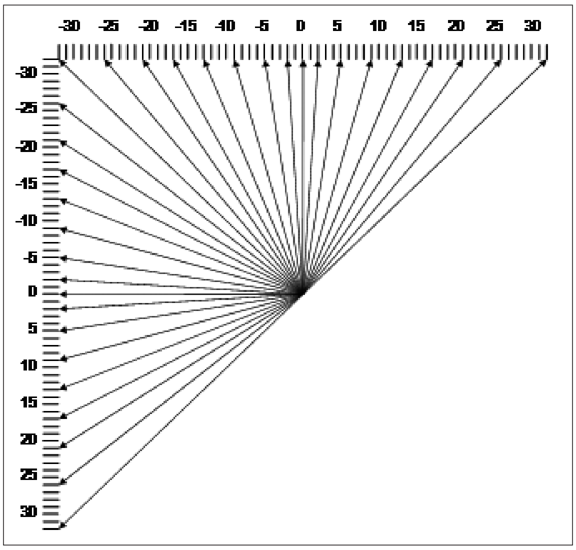


Figure 7. *Angular Intra Prediction modes.*

Inter-picture prediction, implements the Motion Estimation (ME) algorithm to find the best prediction of current block, using as reference the forward or backward picture. To be more efficient, the ME algorithm computes the block matching using fractional pixel position (1/2 and 1/4), and selects the Motion Vector (MV) which obtains the best residue for the current block. The Motion Compensation (MC) algorithm implements the inverse process, reconstructing the prediction block with the fractional position indicated for MV, and adding the decoded residue to achieve the decoded block.

Motion Compensation algorithm at HEVC uses a new 7-tap filter for interpolation of 1/4 fractional pixel position, and also a new AMVP (Advanced Motion Vector Prediction) is defined to improve Motion vector signalling efficiency. Finally the entropic coding is constrained to CABAC (Context Adaptive Binary Arithmetic Coding) with some improvements over H.264, such as highest compression efficiency, and the support for parallel processing that allow highest throughput speed, with reduced memory requirements. Table I summarizes some of the different features of HEVC and H.264.

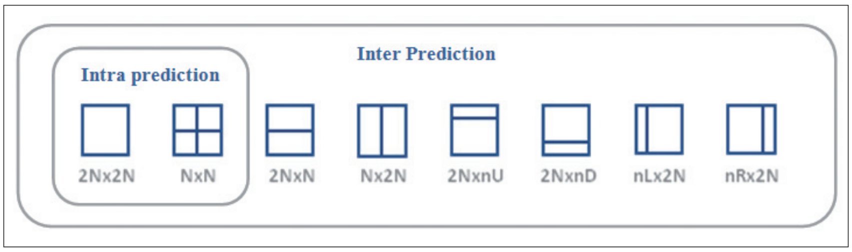


Figure 6. *Intra and Inter Prediction Units partitioning.*

	H.264	HEVC
Coding Unit	Macroblock of 16x16	CTB with CUs from 64x64 to 8x8
Intra prediction size	16x16, 8x8 and 4x4	PU from 32x32 to 4x4
Intra Prediction modes	4 modes(16x16), and 9 modes (8x8 and 4x4)	35 modes (33 angular prediction modes + DC + Planar)
Motion compensation	6-tap filter for ½ sample + bi-linear interpolation of ¼ sample position	7-tap filter for interpolation of 1/4 of fractional pixel AMVP
Transform type	Integer DCT	Integer DCT + integer DST (only luma 4x4 intra prediction)
Transform size	8x8 and 4x4	32x32, 16x16, 8x8 and 4x4
In-Loop filter	Deblocking filter	Deblocking filter + SAO
Entropic coding	CAVLC and CABAC	Enhanced CABAC
Parallel processing	Slices	Slices, Tiles and WPP (Wavefront Parallel Processing)

Table 1. *HEVC vs. H.264 coding tools comparison.*

3.2. DVB-T2 on the provision of ENG services.

The current transmission schemes used for wireless communications services, including BAS/SAP services, are based on COFDM technology. COFDM stands as a robust technique against multipath echoes (thanks to the use of a guard interval) and frequency selective channels (thanks to the use of multiple sub-carriers). However, the delivery of mobile services to users requires of additional robustness to cope with Doppler effects. These technologies were included in the DVB-T standard [18] which is currently deployed in many countries for the provision of terrestrial broadcasting. Its benefits for mobile reception in terms of capacity and required C/N with QPSK and 16 QAM, are, however, very limited. Table II shows the performance of the standards with the most suitable configurations for the described scenarios, classified according to the guard interval and the selected FEC (Forwards Error Correction):

It can be observed that the maximum capacities provided by the standard do not cover the capacity demands required for BAS/SAP HD video formats (approximately over 20 Mbps), and C/N levels in NLOS (Non Line of Sight) conditions, which drastically reduce the coverage for mobile terminals.

DVB-T2 standard [1] is, therefore, considered as a more suitable technology to meet the requirements of BAS/SAP services, since it provides significant spectral improvement of between 30% and 50% over its predecessor, DVB-T. DVB-T2 includes the most advanced transmission techniques [19], such as LDPCs (Low Density Parity Check) codes for improved error correction, an extended range of Fast Fourier Transform (FFT) sizes to provide significantly improvement in spectral efficiency, a new time interleaver to cope with impulsive interference, and a very flexible frame and logical structure with the so-called PLPs (Physical Layer Pipes), to address the demands of different robustness and capacity associated to different services. The availability of a large number of modes in DVB-T2, allows to fitting the specific area of application. In addition, the inclusion of 256-QAM modulation increases the number of bits carried per data cell.

DVB-T2 achieves increased robustness under critical conditions thanks to new transmission diversity techniques as MISO (Multiple Input Single Output), new mechanisms as Rotated Constellation, or several PAPR (Peak-to-Average Power Ratio) reduction techniques. DVB-T2 in turn permits the use of future extension frames FEF (Future Extension Frames), to access the same RF channel by time division, which could also get a bidirectional transmission system between the wireless camera and the mobile unit, if needed.

The DVB-T2 standard also provides a large set of transmitter configurations in order to adapt the transmission to the robustness requirements, to cope with the channel characteristics, and also to cope with the capacity requirements. The choice of some parameters is also dictated by the network deployment, such as the GI (guard interval) duration and the pilot pattern configuration. Other parameters, such as the code rate and constellation size, are selected according to propagation conditions, coverage requirements, and channel statistics.

Modulation	FEC	C/N (Rayleigh)	Data Rate (8 MHz)			
			GI 1/4	GI 1/8	GI 1/16	GI 1/32
QPSK	1/2	5.9 dB	4.98 Mbps	5.53 Mbps	5.85 Mbps	6.03 Mbps
QPSK	2/3	9.6 dB	6.64 Mbps	7.37 Mbps	8.81 Mbps	8.04 Mbps
16QAM	1/2	11.8 dB	9.65 Mbps	11.06Mbps	11.71Mbps	12.06Mbps
16QAM	2/3	15.3 dB	13.27Mbps	14.75Mbps	15.61Mbps	16.09Mbps

Table 2. *Data rates for DVB-T.*

	DVB-T	DVB-T2 (new/improved options in bold)
FEC	Convolutional Coding+Reed Solomon 1/2, 2/3, 3/4, 5/6, 7/8	LDPC + BCH 1/2, **3/5**, 2/3, 3/4, **4/5**, 5/6
Modes	QPSK, 16QAM, 64QAM	QPSK, 16QAM, 64QAM, **256QAM**
Guard Interval	1/4, 1/8, 1/16, 1/32	1/4, **19/128**, 1/8, **19/256**, 1/16, 1/32, **1/128**
FFT Size	2k, 8k	**1k**, 2k, **4k**, 8k, **16k**, **32k**
Scattered Pilots	8% of total	**1%**, **2%**, **4%**, 8% of total
Continual Pilots	2.0% of total	**0.4%-2.4%** (0.4%-0.8% in 8K-32K)
Bandwidth	6, 7, 8 MHz	**1.7**, **5**, 6, 7, 8, **10** MHz
Max. data rate (@20 dB C/N)	31.7 Mbit/s (using 8 MHz)	**45.5 Mbit/s** (using 8 MHz)
Required C/N ratio (@24 Mbit/s)	16.7 dB	**10.8 dB**

Table 3. *Comparison between DVB-T and DVB-T2 [20].*

The following table summarizes the differences in the configuration parameters of DVB-T and DVB-T2, and also gives some figures for the maximum achievable data rates and required C/N (carrier-to-noise ratio).

In order to give a real case of the capabilities of DVB-T2 over DVB-T, we have evaluated one scenario that corresponds to the Spanish DTT network. By fixing a network configuration in DVB-T2 which requires approximately the same C/N as the current DVB-T deployment, it is potentially possible to double the capacity of the system, as depicted in the table IV.
This result not only confirm the advantages of using DVB-T2 but also open a large range of possibilities in order to increase the number of services that can be allocated in one multiplex or, even, increase the quality of the services by means of HDTV or 3D contents.

The implementation of DVB-T2 together with new video coding techniques, will lead to a substantial increase in the robustness of the transmission, which facilitates the transmission of contents in mobile and portable scenarios, and also an increase in terms of capacity, that will make possible the transmission of high quality contents with the required reliability.

	Current DVB-T network	Proposed DVB-T2 configuration
Bandwidth	8 MHz	8 MHz
FFT size	8K	32K extended
Guard Interval	¼	1/128
Modulation	64-QAM	64-QAM
Code Rate	2/3	5/6
Capacity	19.91 Mbps	37.9 Mbps
Required C/N (Rician channel)	17.3 dB	17.2 dB

Table 4. *Proposed network update to DVB-T2 in Spain.*

In the context of the FREEDOM project, some scenarios have been proposed in order to study the achievable performance gains of DVB-T2 over DVB-T for ENG services, and evaluate the potential improvements in the provision of these services. Moreover, one of the most important issues is that the frequency bands in which BAS/SAP services are implemented are different to those intended for broadcasting services. In Spain, the spectrum regulation defines two bands in which BAS/SAP services can be delivered (2.4 GHz and 10 GHz). Therefore, since degradation is considered to be higher at these frequencies, the increased robustness provided by DVB-T2 will suppose a positive effect on the coverage of these services.

4. Experimental results

4.1. HEVC performance evaluation for BAS/SAP services

With the aim to evaluate the HEVC efficiency for BAS/SAP scenario under HDTV format, two experiments have been carried out with HEVC reference software. The first experiment is a H.264 vs. HEVC comparison in term of objective quality using the PSNR metric, allowing to know the HEVC data rate saving compared to H.264 standard. The second experiment explores the impact of HEVC cascaded encoding-decoding cycles, aimed to evaluate the quality losses for each multi-generation process. After a first transmission the content is usually encoded several times for different reasons, such as adaptation to editing and archive formats, a new transmission to another broadcasting facility, or the broadcast to end user with different encoding characteristics (different video coding standard, bit rate, or GOP lengths). We have evaluated the HEVC performance for three cascaded encoding-decoding cycles, because it can be considered a realistic figure in real-life of studio production workflow.

To implement these experiments, we have selected two uncompressed 8-bits@420 test sequences, with 10 second length and 720p50 HD format. Test sequences are especially complex in spatial and temporal domains in order to stress the encoding algorithms. First sequence is called "Dancer" and is available at [20], supplied by EBU (European Broadcasting Union), while second sequence is named "CrowdRun" and is supplied by SVT (Sveriges Television) at [21]. Figure 8 shows the first frame of both sequences.

In order to run the simulations, we have configured both reference software, JM 18.0 for H.264 and HM 7.1 for HEVC, with similar simulation conditions, following the recommendations made by ITU-T in [22] for high resolution video coding. The most relevant configuration parameters are shown at Table V, where it can be noted that QP parameters used for HEVC encoding are slightly lower

Dancer sequence.

CrowdRun sequence.

Figure 8. *Dancer and CrowdRun test sequences.*

Parameter	H.264	HEVC
Profile	Hi422@8bits	Main (8bits)
Intra Period	32 frames	32 frames
B Frames (GOP size -1)	7 B frames with 3 hierarchical layers	7
RD Optimization	1	
Search Range	64	64
QP	22, 27, 32, 37	20, 24, 28, 32
Largest CU	-	64
Maximum Partition Depth	-	4
RQT Max Depth Inter/Intra	-	3

Table 5. *H.264 and HEVC encoding configuration parameters.*

than H.264 QPs, with the aim to achieve similar bit rates. The "Dancer" sequence has been used for this test.

		QP22(20)	QP27(24)	QP32(28)	QP37(32)
PSNR-Y (dB)	HEVC	39.02	36.59	34.26	31.87
	H.264	37.68	34.81	31.72	28.72
PSNR-U (dB)	HEVC	40.83	38.79	37.09	35.74
	H.264	39.27	36.66	34.59	33.00
PSNR-V (dB)	HEVC	42.44	40.39	38.74	37.45
	H.264	40.57	38.04	36.19	34.68
PSNR-YUV (dB)	HEVC	39.67	37.34	35.17	33.05
	H.264	38.24	35.45	32.64	30.00

Table 6. *HEVC and H.264 PSNR of "Dancer" sequence.*

PSNR figures for the luminance (Y), chrominance (U and V) components and the average YUV, are shown in the table VI, and Rate-Distortion results are depicted in the figure 9. It can be observed that for the same PSNR quality, HEVC can reduce the bit rate over 50% regarding H.264, especially for high bit rates. Should be noted that operational point used for HDTV BAS/SAP services is beyond 20 Mbps.

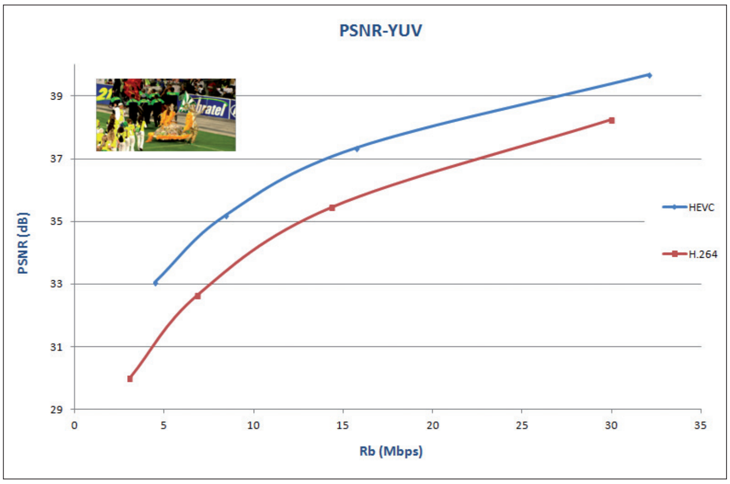
	Y	U	V	YUV
BD-PSNR (dB)	-1.53	-1.86	-2.04	-1.63
BD-Rate (%)	48.46	57.61	111.05	57.61

Table 7. *BD-PSNR and BD-Rate, of HEVC vs. H.264 (Dancer).*

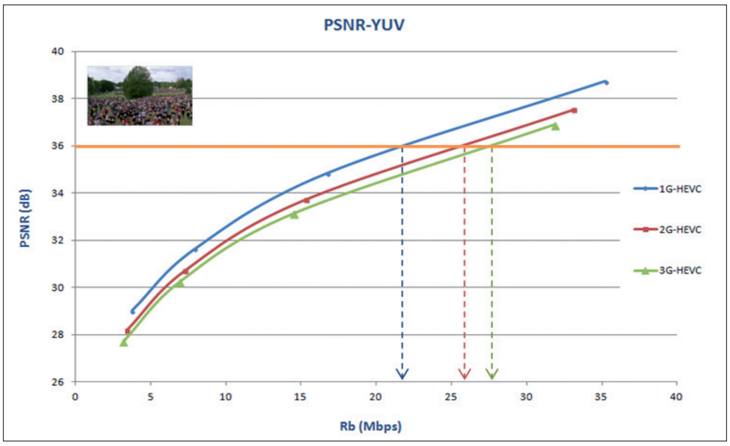
We have applied the Bjøntegaard Delta methodology defined by ITU at [23], to calculate the average differences between two Rate-Distortion curves from HEVC and H.264 through 4 data points (four used QPs), computing the rate saving (BD-Rate) and quality losses (BD-PSNR). Table VII shows the BD-PSNR and BD-Rate simulation results, it can be observed how HEVC overcomes the average PSNR quality of H.264 around 1.6dB, allowing a bit rate saving over 57% for the same H.264 quality. This fact demonstrates the high efficiency and high profits that HEVC can provide to BAS/SAP services.

Regarding cascaded encoding-decoding cycles experiments, we have encoded the "CrowdRun" sequence using the HEVC reference encoder software, keeping the same configuration previously described (Main Profile, Random Access, Intra Period of 32 frames, and 4 QPs). The decoded sequence (1G) was re-encoded in order to get the second generation (2G), and reiterating the same process with the second decoded sequence, we accomplish the final generation (3G). The three generations Rate-Distortion curves of average YUV, are depicted in figure 10.

In order to calculate the multi-generation losses, we have computed the BD-Rate and BD-PSNR between first generation and following generations figures are collected at table VII. The results show that the average quality losses (YUV) is 0.65dB for second generation and close to 1dB for third generation. Concerning bit rate penalty, the BD-Rate for average YUV, shows that the second



■ **Figure 9.** *PSNR-YUV HEVC vs H.264 for Dancer sequence.*



■ **Figure 10.** *PSNR-YUV multi-generation performance for CrowdRun sequence.*

generation would require a 16% of the bit rate increase to get the same objective quality (PSNR-YUV) of the first generation, while a third generation would require to use an average of 26% higher bit rate to achieve the same PSNR score of first generation.

The three arrows depicted in figure 10, show the different encoding bit rate required to achieve the same video quality, set to 36 dB in this example. Can be observed how the first generation needs a data rate near 22Mbps, however if our chain includes three encoding-decoding cycles, the encoding data rate should be around 27.5Mbps to reach the video quality of 36dB at the end of the chain (third generation), confirming the BD-Rate figures of Table VIII.

		Y	U	V	YUV
1G vs. 2G	BD-PSNR (dB)	-0.70	-0.46	-0.50	-0.65
	BD-Rate (%)	15.82	20.05	21.15	16.61
1G vs. 3G	BD-PSNR (dB)	-1.08	-0.68	-0.74	-0.99
	BD-Rate (%)	25.66	30.92	33.02	26.78

■ **Table 8.** *BD-PSNR and BD-Rate. HEVC multi-generation (CrowdRun).*

4.2. DVB-T2 performance evaluation for BAS/SAP services

In the context of the new DVB-T2 standard and according to the requirements for the BAS/SAP services provisioning, the advantages of the DVB-T2 standard may be addressed from two different sides: a coverage gain and a capacity gain.

The FEC coding of DVB-T2 is at the cutting edge of coded modulation technologies, since the performance of LDPC codes is close to the Shannon capacity with a gap lower than 1dB in Gaussian channels. Compared to the Convolutional Coding (CC) used in DVB-T, the achieved gain ranges from 2.3 dB of C/N for low bit rate services to more than 3.2 dB for high bit rate services, in stationary channels. The FEC gain is higher in mobile channels, but DVB-T2 also introduces a time interleaver which significantly improves the robustness of the transmission for mobile services, achieving an overall gain in the order of 9 dB in high speed scenarios (i.e. 144Km/h) [24].

Rotated constellations also provide additional robustness, especially for low-order constellations and high coding rates. The actual gain depends on the channel, ranging from 0.5 to 2 dB, but for high-order modulations (64QAM and 256QAM) and low code rates, rotated constellations do not provide gain.

The use of 256-QAM increases the spectral efficiency to 8 bits per symbol, 33% more compared to the highest modulation order of DVB-T, 64-QAM. The improved performance of the FEC coding can also be translated into a capacity gain, being possible to use for a given CNR requirement a modulation and coding rate with a higher spectral efficiency.

With these considerations, an example of the affordable coverage increase from DVB-T to DVB-T2 for ENG services is described below.

For this example, a service bit rate of 25 Mbps has been selected for the delivery of a HDTV video stream in a fixed scenario, which, may correspond to a typical live link in a news programme to cover an event. For coverage estimation, a 1 meter height transmitter (wireless TV camera) has been situated in an urban area in the city centre of Valencia (Spain). Taking into account the geographical and building information of this area, the coverage of the service has been calculated for both DVB-T and DVB-T2 standards.

According to the spectrum regulations in Spain, the operation frequency has been selected within the UN-50 band (from 2.3 GHz to 2.4 GHz), which is intended for the provision of BAS/SAP services.

	Current DVB-T network	Proposed DVB-T2 configuration
Bandwidth	8 MHz	8 MHz
FFT size	8K	32K extended
Guard Interval	1/4	1/128
Modulation	64-QAM	16-QAM
Code Rate	5/6	5/6
Capacity	24.88	25.26
Required C/N (Rician channel)	22.7	13.2

Table 9. *Network configuration for DVB-T and DVB-T2 for HDTV BAS/SAP service.*

Since the idea was to compare the coverage performance between the standards, two different transmission modes have been selected with the particularity of providing the necessary data rate to allocate the HDTV service. The following table depicts the transmission configuration for the same kind of service being transmitted in DVB-T and DVB-T2.

With this configuration, the coverage provided by both systems is evaluated in the scenario. Figure 11 shows a coverage map of the service with DVB-T and DVB-T2, and it evidences the improvement of the latest.

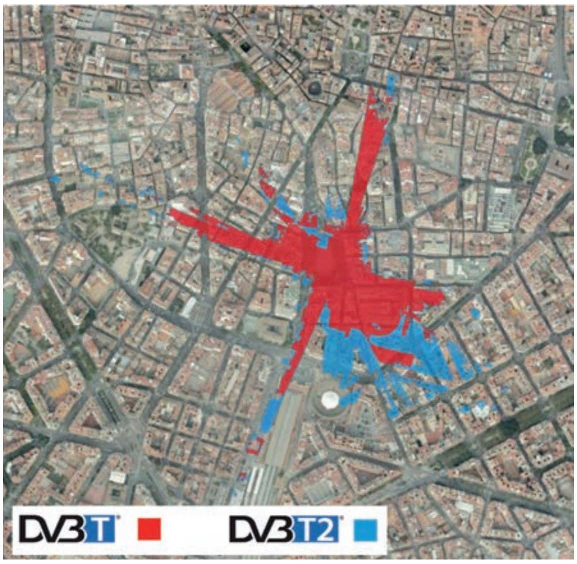


Figure 11. *Coverage map of a 25 Mbps HDTV service over DVB-T and DVB-T2 in Valencia.*

The restrictions in coverage with DVB-T provide a reduced radius of action around the wireless camera. Hence, a relay node (e.g. a mobile unit van) should be placed near the camera in order to retransmit the signal to another relay node (access point) of the network, or directly to the TV studio. The increased coverage with DVB-T2 may lead, in some cases, to directly reaching the TV studio or a network operator access point without the necessity of auxiliary logistics that will decrease the cost of the transmission. It will also lead to reach earlier places where important events occur and also providing immediate video contents of them.

5. Conclusions

This paper has presented a new approach to the provision of ENG services through the most advanced video and transmission techniques, which make possible increased data rate and video quality (e.g. HDTV or UHDTV) and robustness to cope with the particularities of portable and mobile scenarios. Moreover, the possibility to reduce energy consumption and infrastructure costs, make the proposed solutions in the framework of FREEDOM project come out as a real alternative for the future.

HEVC is the new video coding standard, providing a high compression efficiency and high video quality, especially for high resolutions and very low bit rates, thanks to new coding tools such as new block partitioning structure into quadtree blocks, more Intra-picture prediction angles, larger residual transform sizes, and a non-linear amplitude mapping of decoded pixels, among others.

The experiment results show HEVC can achieves a huge bandwidth saving, close to 60% regarding current H.264, even for complex sequences such as "Dancer", confirming HEVC can give support to HDTV and 3D formats for BAS/SAP with half of H.264 data-rates.

From the transmission system point of view, DVB-T2 and its evolutions (DVB-T2 Lite, DVB-NGH) confers a very significant increase both in capacity and transmission robustness, allowing wider coverage and extending the scope where BAS/SAP services can be applied.

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