Super Hi-Vision – the 4320 line x 7680 pixels/line TV system under development by NHK, the Japanese public broadcaster – offers an astonishing user experience, thanks to a picture resolution which is sixteen times that of what we presently call ‘High Definition’ (HDTV). There are 60 progressively-scanned frames every second and, for the audio, 22.2 three-dimensional surround channels – nine at ceiling height, including one directly overhead; ten channels at the centre height of the screen; three front channels at floor level and, for the rolling thunder and other low-frequency effects, two channels at the front.

Since the bitrate of the native Super Hi-Vision signal is a massive 24 Gbit/s, the major part of the technical challenge is in developing ways of delivering the service to the final user. One of the highlights of IBC-2008 in Amsterdam was the first live transmission of Super Hi-Vision from the RAI Research uplink station in Turin to Amsterdam, via a Eutelsat Ku-band satellite using DVB-S2.

This article summarizes the studies under development at the NHK Laboratories and at the RAI Research Centre ... towards the evaluation of various SHV delivery systems, via both satellite and terrestrial broadband channels.

SHV compression

Since Super Hi-Vision (SHV) has an intrinsic resolution that is 16 times larger than HDTV, a proportionally higher bitrate should be used, further increased by the progressive scanning format. NHK tests demonstrated that, when using 16 x MPEG-4 AVC encoders, the required final audio-video bitrate ranges from 140 to 160 Mbit/s. Further progress is expected to be made in picture-coding efficiency over the next decade and, thus, a transmission bitrate of about 80 Mbit/s is assumed in the examples described in this article.
The current NHK real-time codec prototype consists of 16 encoders and decoders, using H.264 [1]. The SHV image is divided into 16 HDTV pictures, eight in the spatial dimension and two in the time (temporal) dimension (Fig. 1), each one being processed by a single H.264 HDTV encoder.

**SHV delivery by satellite**

**Ku band**

SHV delivery to the home is possible today, using state-of-the-art technologies such as high-power Ku-band satellites and DVB-S2 modulation formats. This was demonstrated by the joint NHK-BBC-RAI presentation at IBC-2008 in Amsterdam [2][3], where the SHV signals were delivered from the uplink station at the research headquarters of Italian public broadcaster RAI in Turin, over Ku-band satellite capacity provided by Eutelsat.

For this first public demonstration of Super Hi-Vision by satellite, it will come as no surprise to discover that DVB-S2 technology [4] was selected by RAI, who led the development of this second-generation DVB system in 2003. Thanks to this state-of-the-art system, recognized by the ITU as a worldwide standard for digital satellite broadcasting, the theoretical Shannon limit is approached within less than one decibel in the case of a linear channel.

In order to accommodate the 140 Mbit/s SHV signal in a 72 MHz satellite bandwidth, a symbol rate of 60 Mbaud may be adopted with 20% roll-off, combined with 8PSK modulation and rate 5/6 LDPC FEC coding, for a total required Signal-to-Noise power ratio (SNR) of around 10 dB including satellite distortions.

As shown in Fig. 2, a slightly different configuration was adopted at IBC-2008 for practical reasons (e.g., the lack of very high symbol-rate DVB-S2 demodulators). The SHV signal was split into two 70 Mbit/s MPEG Transport Streams, transmitted over two 36 MHz satellite transponders, and re-combined at the receiver using the synchronization and de-jittering features of DVB-S2 in the Adaptive Coding and Modulation (ACM) mode.

The Eutelsat satellite – Atlantic Bird 3 at 5°W – was used, offering a high EIRP (53 dBW) superbeam (Fig. 3) over central Europe, Italy and Spain, where SHV can be received with a consumer-type 80 cm antenna (leaving a 4 dB clear-sky margin).

**Perspectives for the use of the Ka band**

As the Ku band is already highly used today for many services, other frequency resources may be investigated for a future comprehensive multi-programme SHV service. An analysis of the satellite
Ka band (21.4 - 22.0 GHz), that was allocated to broadcasting services in Regions 1 and 3 during the WARC-1992 conference in Torremolinos, is in progress in the research labs of broadcasters, starting from the early studies already published in EBU Technical Review [5][6].

We are now taking into consideration some additional sophisticated technologies to help overcome the high rain attenuation in this band. These are for example:

- **dynamic power control** on the satellite [7];
- **multi-spot coverage** combined with _Adaptive Coding and Modulation_ (ACM) or;
- **Scalable Video Coding** (SVC) combined with _Variable Coding and Modulation_ (VCM).

It should be noted that ACM and VCM are already included in the DVB-S2 system, and SVC profiles are included in MPEG-4 AVC coding.

The Ka band for broadcasting allocates 600 MHz over two polarizations. Hence, for example, 24 SHV programmes at 82 Mbit/s may be allocated per service area, assuming the use of DVB-S2 parameters (see Fig. 4):

- 8PSK 2/3 modulation/coding;
- symbol rate = 41.4 Mbaud;
- total bandwidth BW = 49.7 MHz
- required SNR of around 8.6 dB, with 1 dB implementation margin and 1 dB of channel distortions).

In order to guarantee service availability for 99.9% of the time, we can assume for example that 13 dB of clear-sky margin is required [8]. For precise computations, the specific rain statistics for a given country have to be considered, leading to a required clear-sky SNR = 21.6 dB in a noise bandwidth of 41.4 MHz.

In the event of broadband modems being devised, picture coding might benefit from statistical multiplexing (e.g., BW = 200 MHz, four SHV programmes per bouquet).

**NHK studies on dynamic power control and shaped antenna beams on board the satellite**

NHK has developed prototypes of a 300 MHz wideband modulator and demodulator. The broadcaster has carried out an indoor Super Hi-Vision transmission experiment through the 21 GHz band experimental transponder, via a single carrier, to verify the performance of the hardware and evaluate the wideband transmission characteristics [9]. The equipment used for the transmission experiment is shown in Fig. 5. The signal from the Super Hi-Vision encoder was modulated, up-converted to a 21 GHz band signal and amplified by a miniature Travelling Wave Tube (TWT) which simulates a transponder in the broadcasting satellite. The modulated signal was radiated...
from a horn antenna and after going through the air, it was received by a parabolic broadcasting antenna whose diameter was equal to a typical home satellite antenna, i.e. 45 cm in diameter.

The modulation parameters are indicated in Table 1. Through the experiment, NHK confirmed the possibility of broadcasting the Super Hi-Vision signal via a 21 GHz band satellite.

In 2009, NHK plans to perform a transmission experiment with Super Hi-Vision, using the WINDS (Wideband InterNetworking engineering test and Demonstration Satellite) that was launched in Japan during February 2008.

The 21.4 - 22.0 GHz band, however, suffers from large rain attenuation [8]. Consequently, we have been studying rain-fade mitigation techniques, in which the radiation power is increased locally in the area of heavy rainfall ("boosted" beam) while keeping the "nationwide" beam with the same frequency by using an onboard phased array antenna (see Fig. 6).

Fig. 7 shows an example of a phased array antenna and its radiation pattern. The antenna boosts the beam radiation power in areas suffering from heavy rain-fall [10].

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centre frequency</td>
<td>21.85 GHz</td>
</tr>
<tr>
<td>Modulation</td>
<td>QPSK</td>
</tr>
<tr>
<td>Symbol rate</td>
<td>250 Mbaud</td>
</tr>
<tr>
<td>Occupied Bandwidth</td>
<td>295 MHz</td>
</tr>
<tr>
<td>Information Rate</td>
<td>500 Mbit/s</td>
</tr>
</tbody>
</table>

Figure 6
Compensation of rain attenuation by using a phased array antenna

Figure 7
Example of a phased array antenna and its radiation pattern
Left: Radiation pattern
Bottom Left: Structure of antenna
Bottom Right: Feed array and the feed power distribution
Fig. 8 shows part of a feed array (3 horns) for the 21 GHz satellite-broadcasting band. It consists of a beam-forming network, a TWT [11], a band-pass filter and a horn.

**Rai studies on ACM and VCM modulation techniques**

The examples given in the following sections are not the result of detailed optimizations nor specific proposals for real services, but they are intended as preliminary exercises to assess the potential of the proposed technologies and the use of the Ka band for SHV.

The examples given here are based on the DVB-S2 characteristics described in ETSI EN 302 307, and summarized in Table 2. For the sake of simplicity, a 1 dB implementation margin and 1 dB satellite distortion are assumed in the examples, for any transmission mode.

<table>
<thead>
<tr>
<th>DVB-S2 mode</th>
<th>Required SNR (dB)</th>
<th>Spectrum efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>QPSK 1/4</td>
<td>-2.35</td>
<td>0.490243</td>
</tr>
<tr>
<td>QPSK 2/5</td>
<td>-0.30</td>
<td>0.789412</td>
</tr>
<tr>
<td>QPSK 1/2</td>
<td>1.00</td>
<td>0.988858</td>
</tr>
<tr>
<td>8PSK 2/3</td>
<td>6.62</td>
<td>1.980636</td>
</tr>
<tr>
<td>8PSK 5/6</td>
<td>9.35</td>
<td>2.478562</td>
</tr>
</tbody>
</table>

**ACM and multi-spot coverage**

As a countermeasure against heavy rain attenuations at Ka band frequencies, RAI analyzed a multi-spot country coverage approach, combined with Adaptive Coding and Modulation.

Let us assume that the total number of spots per country is N, and each spot uses a different frequency to avoid interfering with the adjacent spots (thus reducing the spectral efficiency of the plan by a factor of 3 or 4). Furthermore, it is assumed that within the service area there is a widespread network of rain-attenuation sensors, which could be implemented by connecting all user receivers with a feedback channel carrying real-time information on the reception margin (in ten years time, the availability of hybrid broadcast-broadband receivers is highly probable, thus this
The approach may become much more viable than it is today. This feedback information may be collected and aggregated to produce an “effective margin indicator” for each spot.

As widely described in the literature [12], Adaptive Coding and Modulation is a technique which may be used as a powerful countermeasure against rain fades: when signal attenuations occur, the source bitrate is reduced using a closed-loop feedback (thus reducing the picture quality) and the remaining capacity is exploited by selecting a more robust channel coding and modulation format, as depicted in Fig. 9.

The local nature of heavy rain attenuation ensures that the percentage of affected areas decreases when increasing the total number of spots.

In the scenario described, further studies are required to evaluate the service continuity versus the clear-sky margin, taking into account the spot dimensions and the different ways of computing the “effective spot margin”. In the best case of very small spots, the service continuity can be computed as for a single reception point; this simplification will be adopted in the following example.

In order to assess the potential of this approach, let us assume that full-quality SHV is guaranteed for 99% of the year (about 4 dB clear-sky margin) and ACM is used to maintain service continuity for 99.9% of the time (about 9 dB of additional SNR variations). Let us for example use DVB-S2 8PSK 5/6 to transport 82 Mbit/s SHV. To cope with a further SNR variation of 9 dB, we can select the DVB-S2 mode QPSK 2/5, offering a capacity of 26.11 Mbit/s. To satisfy service quality targets, we need to design the satellite link budget for a clear-sky SNR of 15.35 dB in a noise bandwidth of about 33 MHz, and the required total bandwidth per SHV programme is about 40 MHz. In the total available bandwidth of 600 x 2 MHz, we can allocate around 30 carriers, but 3 to 4 different frequencies need to be used to avoid inter-spot interference, resulting in 7 to 10 available SHV programmes per location.

**Scalable Video Coding and VCM**

Another approach to overcome heavy rain attenuation in Ka band may be to combine Scalable Video Coding and Variable Coding and Modulation (VCM) as provided by DVB-S2. This approach was already proposed in the early 90s for digital TV/HDTV broadcasting over terrestrial and satellite channels, but it did not find consensus due to the less demanding transmission environments and the inherent complexity.

While ACM is dynamically controlled by reception conditions at the receiver, VCM is static and does not require any feedback from the receivers. In this approach, the video signal comprises:

a) a **high-priority stream** which is permanently associated with a highly-protected modulation and coding format, and;

b) a **low-priority stream** that is associated with a high-efficiency format.
When reception conditions at a given location are good, both streams are correctly demodulated and jointly decoded to provide the full SHV quality. On the other hand, when reception conditions are bad, only the high-priority stream can be correctly demodulated, and the decoder passes on a scaled-down version of the picture (in terms of resolution and/or coding noise).

In order to assess the potential of this approach, let us use an example in line with the ACM case. Assuming, as in the previous ACM example, that full-quality SHV is guaranteed for 99% of the year (about 4 dB clear-sky margin) while VCM is used to maintain service continuity for 99.9% of the time (about 9 dB of additional SNR variations). The low-priority + high-priority bitrate is assumed to be 88 Mbit/s, 6 Mbit/s more than in the case without SVC. We further assume that this capacity is split into $R_1 = 70.4$ Mbit/s for low-priority and $R_2 = 17.6$ Mbit/s for high-priority (see Fig. 10). We use DVB-S2 8PSK 2/3 and QPSK 1/4 to achieve about 9 dB SNR difference between the high-priority and low-priority streams. The bandwidth occupation per carrier is the weighted sum of the bitrates over the spectrum efficiency of each mode:

$$BW = (R_1/1.9806) + (R_2/0.490) \times 1.20 = 85.75 \text{ MHz}$$

BW = 85.75 MHz \( R_s = 71.46 \text{ Mbaud} \)

In conclusion, we need to design the satellite link budget for a clear-sky SNR of 12.62 dB in a noise bandwidth of 71.46 MHz.

In the total available bandwidth of 600 x 2 MHz, we can allocate 7 x 2 carriers. This solution may be easily combined with the dynamic satellite power-control techniques under study at NHK, thus reducing the SNR difference between high-priority and low-priority streams and improving the spectrum efficiency.

In the previous example, a large part of the bandwidth occupation is associated with the high-priority stream, using a very low code-rate, and this also penalizes the power requirements for the low-priority stream. In order to achieve the same 99.9% service availability using QPSK 1/2 for the high-priority stream, 2.1 dB of additional satellite EIRP would be required, but the spectrum efficiency would be significantly improved (BW = 64.02 MHz, corresponding to 22 SHV programmes instead of 14 in the 600 x 2 MHz Ka band).

Comparing the two solutions, ACM and VCM, the first approach requires less bandwidth per carrier (about half in the examples) for similar satellite power per programme, but the capacity loss due to the multi-spot configuration heavily penalizes the ACM approach (7 to 10 SHV programmes versus 14). Regarding the overall quality of service, the examples show a higher picture quality when using ACM at service threshold (26 Mbit/s versus 17.6 Mbit/s), but this has to be confirmed by a more precise evaluation of service availability. This first comparison seems to indicate that the ACM approach is less attractive, also taking into account its global complexity which includes:

- a direct feedback from users, for measuring the local reception margin in real time;
- a more sophisticated terrestrial head-end ... and last but not the least;
- a complex satellite multi-spot architecture.

1. It should be noted that this corresponds to an SNR of 15.96 dB in the noise bandwidth of 33.08 MHz of the ACM example and, therefore, the two methods are well aligned (within 0.6 dB) in terms of satellite power requirements per SHV programme per country-wide coverage.
Let us now compare VCM with the conventional approach using 8PSK 2/3 without ACM/VCM (requiring a clear-sky SNR = 21.6 dB in a noise bandwidth of 41.4 MHz). In the conventional approach, the satellite power requirements per programme would be significantly higher (6.6 dB in the examples) than for VCM, with a better bandwidth exploitation (24 SHV programmes instead of 14 in the VCM approach). Instead, by trading off capacity versus ruggedness in the conventional approach through using QPSK 1/2, the satellite power requirements would decrease by 2.6 dB (i.e., 4 dB more than the VCM solution) and the number of SHV programmes would decrease to 12 (compared with 14 programmes in the VCM solution).

As a last synthesis from the Ka band examples, we may extrapolate that the VCM approach offers around 5 dB gain in satellite power requirements for the same number of SHV programmes and service availability (target: 99.9% of the year), but at the cost of a significant reduction in picture quality for around 1% of the time.

**SHV delivery via terrestrial channels**

DVB-T2 is the second-generation digital-delivery system over terrestrial VHF/UHF channels. It was recently developed by DVB [13] and allows for a variety of modulation and coding rates, with capacities up to 33-35 Mbit/s and a minimum SNR of about 16 dB (+2 dB implementation margins), assuming the use of directional receiving antennas. It is based on OFDM, with up to 32k multicarrier modulation and the same state-of-the-art LDPC coding as in DVB-S2.

The system's configuration flexibility allows us to devise modulation and coding modes which offer higher capacities, provided that the SNR is sufficiently high: if a 2 - 3 dB increase in SNR is available in the coverage area, the capacity can reach 37 - 39 Mbit/s. This capacity is however incompatible with the estimated full SHV bitrates to be delivered via terrestrial channels and, therefore, the development of a scaled version of SHV seems advisable.

As a first rough estimation, a 4k TV system should require 1/4 of the full SHV bitrate – down from 40 Mbit/s with current MPEG-4 encoding to 20 Mbit/s with future-generation coding. Furthermore, DVB-T2 implements VCM, thus offering the possibility of differently protecting the various signals to be transported; this allows us to think of possible solutions combining SVC and VCM – also for the terrestrial environment.

**Conclusions**

The challenges facing SHV are manifold, ranging from production requirements to the type of display required by the end-user. For signal delivery, the IBC-2008 demonstration has already shown that 72 MHz Ku-band satellites and state-of-the-art transmission technologies such as DVB-S2, can today deliver SHV by satellite to the home, using reasonably-sized receiving antennas. Unfortunately, the Ku-band is already widely used today for many services.

This article has investigated the possible use of the satellite Ka-band, allocated to broadcasting services in 1992, for SHV delivery. This is made possible, thanks to the implementation of sophisticated technologies to overcome the high rain attenuation that affects signal propagation in this band. Such technologies include dynamic power control and shaped antenna beams on board the satellite, and Scalable Video Coding combined with Variable Coding and Modulation (which is already included in the MPEG-4 coding scheme and DVB-S2 satellite transmission system).

Furthermore, delivery of SHV via terrestrial channels has also been considered here. The capacity offered by novel terrestrial broadcasting systems, such as DVB-T2, seems incompatible with the estimated full SHV bitrates required and, therefore, the development of a 4k TV system seems advisable.
Alberto Morello graduated in Electronic Engineering from the *Politecnico di Torino* in 1982, and took his doctorate degree in 1987. He joined the RAI Research Centre in 1985 and became its Director in 1999.

Dr Morello has been engaged in research on advanced digital modulation and coding techniques for television and sound broadcasting, and has participated in a number of European Research and Development Projects. He is author of technical/scientific articles in leading reviews such as IEEE Transactions and EBU Technical Review, and he regularly contributes to national and international Conferences.

Alberto Morello had a primary role in the RAI digital HDTV experiments via the Olympus satellite (Italy '90), and in the definition of the DVB systems for TV broadcasting by satellite and terrestrial channels (DVB-S, DVB-T and DVB-T2). Furthermore, he was Chairman of the DVB groups which defined the DVB-DSNG and DVB-S2 systems. Currently, he is Chairman of the EBU Technical Committee.

Vittoria Mignone received the *Laurea in Ingegneria Elettronica* degree from *Politecnico di Torino*, Turin, Italy in 1990.

In 1991 – in co-operation with the Electronics Department of *Politecnico di Torino* – she became engaged in studies of satellite broadcasting, on behalf of the National Research Council. Since 1992, she has been with the RAI Research Centre, involved in studies on the definition of the ETSI Standards for digital TV broadcasting by satellite, cable, terrestrial and DSNG. Her current activities are in the field of advanced digital modulation and channel coding techniques for satellite and terrestrial transmissions. She is the author of several technical papers.

Dr Kazuyoshi Shogen joined NHK (Japan Broadcasting Corporation) in 1979. In 1982, he moved to NHK’s Science and Technical Research Laboratories to carry out research on broadcasting satellite systems, especially on contoured beam antennas for Japanese direct-broadcasting satellites. From 1998 to 2003, he worked in NHK’s Engineering Administration Department. engaged in media planning and international affairs, and working with groups such as the ABU (October 1999 -), ITU-R (May 1995 -) and APT (December 1998 - 2003).

In 2003, Dr Shogen transferred back to NHK’s Science and Technical Research Laboratories. Since then, he has become Chairman of the ABU Technical Committee (November 2006 -) and was a vice chairman of ITU-R SG6 WP6S (March 2002 - October 2007). He is an IEEE Senior Member and is currently Director of NHK’s Science and Technical Research Laboratories.

Hisashi Sujikai joined NHK (Japan Broadcasting Corporation) in 2001. He worked initially at the Engineering Administration Department, where he contributed to the planning and installation of NHK’s TV networks and stations. In 2005, he transferred to NHK’s Science and Technical Research Laboratories and has been engaged in research on advanced satellite broadcasting since then. He is now Principal Research Engineer in the Laboratories.

References


[2] NHK article on these IBC demos: [http://tech.ebu.ch/docs/techreview/trev_2009-Q0_SHV-NHK.pdf](http://tech.ebu.ch/docs/techreview/trev_2009-Q0_SHV-NHK.pdf)


NAB-2008.


