DVB-T HIERARCHICAL MODULATION: AN OPPORTUNITY FOR NEW SERVICES?

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ABSTRACT

The European DVB-T standard includes a large number of transmission modes able to adapt the COFDM signal to a wide variety of broadcasting services. Among them, the hierarchical modulation mode separates the RF channel in two virtual channels, each able to carry a transport streams (MPEG-TS) with a dedicated protection.

In a first approach, this DVB-T capability has been view as a way to define two distinct coverage areas for a given transmitter. Accordingly, no direct application has been seen for it.

Today, broadcaster's intend to use the DVB-T standard to cover a great variety of Services :

- Some countries intend to use DVB-T to broadcast HDTV; accordingly they have a need to simulcast the DVB multiplex in its high and standard definitions, to address the two categories of receivers which will be used during the introduction phase of Digital TV services,
- Another great expectation is to use DVB-T to address mobile receivers, in public transport : it will be a great advantage to setup a unique transmitters network to reach simultaneously indoor and outdoor receivers.

Due to the lack of frequencies available, the DVB-T's hierarchical modulation becomes an interesting way to make a single RF channel able to address two categories of receivers and, as a consequence, two market segments.

After an tutorial explanation of the hierarchically modulated DVB-T COFDM signal, the author details the technical trade-of the broadcaster has to make to broadcast the DVB-T hierarchical modulation.

Is the DVB-T hierarchical modulation an opportunity for new digital terrestrial TV services ? The author intends to bring you his conviction in this presentation.

INTRODUCTION

The European standard for Terrestrial Digital Video Broadcast (DVB-T) [1], has defined a system suitable for a wide range of broadcast applications.

This versatility is due to the possibility given to the broadcaster to adjust the modulation parameters to implement up to 120 regular modulation modes and, in theory, up to 1200 hierarchical ones.

This hierarchical modulation capability has been a long time mixed up with the hierarchical video source encoding. As a modulation scheme, it has to be considered as an additional tool given to RF network planners, to introduce new possibilities in the use of the scarce radio frequency spectrum.

These possibilities are being explored in this paper which, as a tutorial introduction, presents the basic concepts of the COFDM and highlights its hierarchical modulation feature which allows to broadcast two independents data streams (i.e.: two MPEG-TS multiplexes), over a single RF channel.

COFDM HIERARCHICAL MODULATION: HOW DOES IT WORK?

Early in the 80's, the French research laboratory CCETT - Centre Commun d'Etudes en Télédiffusion et Télécommunication (**1**) - has studied a modulation system sufficiently robust and efficient to carry digital data: the Coded Orthogonal Frequency Division Multiplex (COFDM). Their works have contributed to give two standards to the broadcasters: the Digital Audio Broadcasting system DAB [2] and the Terrestrial Digital Video Broadcasting system DVB-T [1].

COFDM: WHAT DOES IT MEAN ?

The basic idea of the COFDM comes from the observation of the impairment occurring during the Terrestrial channel propagation. The response of the channel is not identical for each of its frequency sub-bands: due to the sum of received

1 CCETT is a research centre of the France Telecom group.

carriers (main + echoes), no energy or more than the one transmitted is sometimes received.

To overcome this problem, the first mechanism was to spread the data to transmit over a large number of closely spaced frequency sub-bands. Then, to reconstruct the lost data in the receiver, to encode the useful data before transmission.

The « Coded » and « Frequency Division Multiplex » abbreviations come from these two clean and simple concepts.

COFDM: HOW TO ORGANISE THE CHANNEL?

Unfortunately, the characteristics of the transmission channel are not constant in the time domain. But, during a short interval of time, the terrestrial channel propagation characteristics are stable.

Channel partitioning

Accordingly, as shown in figure 1, COFDM implements a partitioning of the terrestrial transmission channel both in the time domain and in the frequency domain, to organise the RF channel as a set of narrow « frequency sub-bands » and as a set of small contiguous «time segments ».

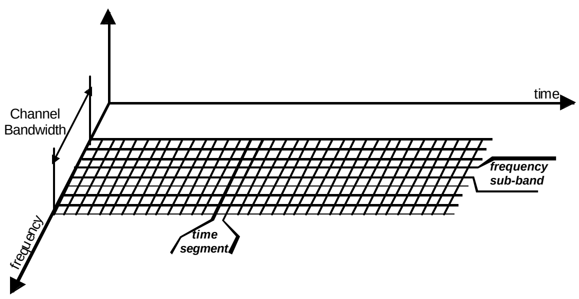

Figure 1: Channel partitioning

Sub-carriers insertion

Inside each time-segment, named OFDM symbol, one sub-carrier equipped each frequency sub-band. To avoid inter-carrier interference, the inter-carrier spacing is set to be equal to the inverse of the symbol duration: sub-carriers are orthogonal.

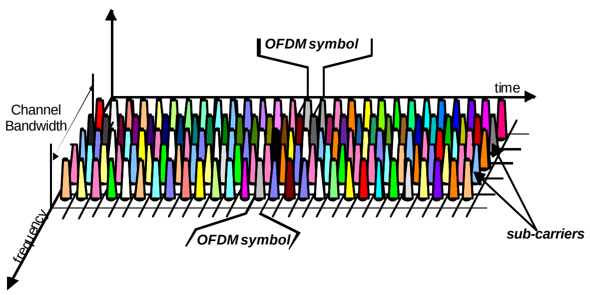

Figure 2: Sub-carriers insertion

Guard interval insertion

As « echoes » are constituted with delayed replicas of the original signal, the end of a given OFDM symbol can produce an inter-symbol interference with the beginning of the following one. To avoid this effect, a guard interval is inserted between each OFDM symbols as shown in figure 3.

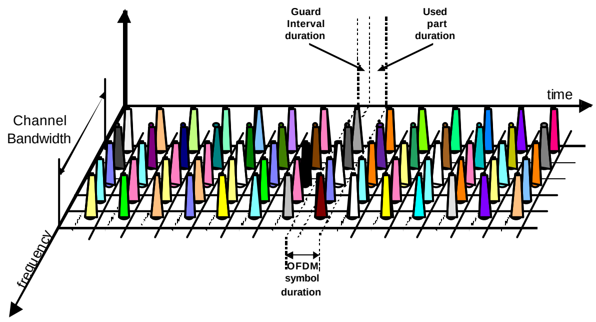

Figure 3: Guard interval insertion

During the guard interval period, corresponding to an inter-symbol interference one, the receivers shall ignore the received signal.

Channel synchronization

To demodulate properly the signal, the receivers have to sample it during the useful period of the OFDM symbol (not during the guard interval). Accordingly, a time window has to be accurately placed in regard to the instant where each OFDM symbol occurs on air.

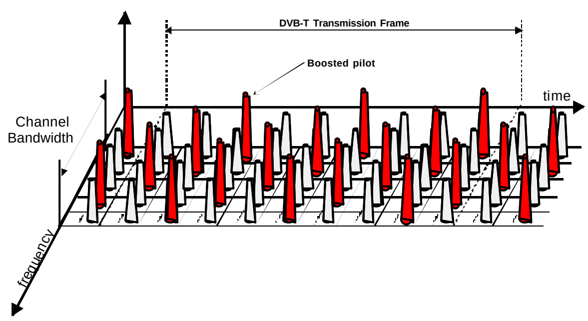

Figure 4: Synchronization markers

The DVB-T system uses « pilot » sub-carriers, regularly spread in the transmission channel, as synchronisation markers, as shown in figure 4.

These different features (channel partitioning, data encoding, guard interval and synchronisation markers insertions) constitute the basic characteristics of the COFDM modulation.

Unfortunately, all these features imply a lost of the channel payload or a reduction of its useful bitrate. A contrario, they allow to trade off between channel robustness and channel capacity.

Then, to give to the broadcasters as much liberty as possible to adapt the terrestrial transmission to their specific situations, the DVB-T standard has defined a range of value for these parameters: their combinations constitute the DVB-T modes.

COFDM: HOW TO CARRY DATA?

The COFDM allows to spread the transmitted data in the time & frequency domains, after protected them by convolutionnal coding.

As the frequency fading occurs on adjacent frequency sub-bands, contiguous data bits are spread over distant sub-carriers inside each OFDM symbol. This feature known as frequency interleaving is illustrated in figure 6.

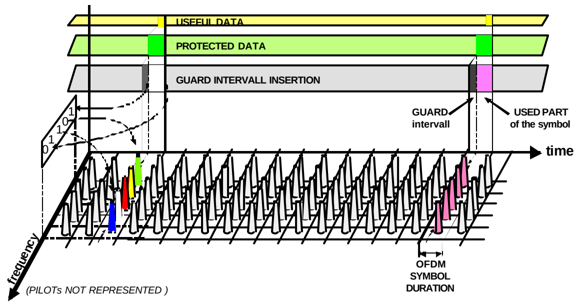

Figure 6: Data mapping on OFDM symbols

Basic constellation

Mapping data onto OFDM symbols means to individually modulate each sub-carrier according to one of the three basic DVB-T complex constellations. These regular constellations are shown in figure 7.

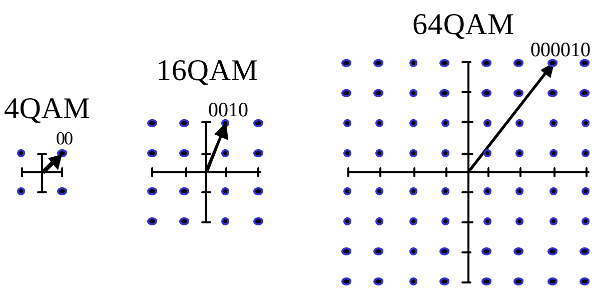

Figure 7: Basic DVB-T constellation

Depending on the constellation chosen, 2 bits (4QAM), 4 bits (16QAM) or 6 bits (64QAM) are carried at a time on each sub-carrier. Each constellation has a dedicated robustness, in regard to the minimum C/N they tolerate for viable demodulation. Roughly, 4QAM is 4 to 5 times more tolerant to noise, than 64QAM.

Hierarchical constellation

Hierarchical modulation constitutes an alternative interpretation (and usage) of the basic 16QAM and 64QAM constellations. As shown in figure 8, hierarchical modulation can be viewed as a separation of the RF channel in two virtual circuits, each having a specific bitrate capacity, a specific roughness and accordingly, covering two slightly different areas. The different characteristics of these two virtual channels comes from different combinations of the constellation & coding rate applied on them.

Practically, it means that a first data stream is mapped using a 4QAM constellation. Each bit pair of this data stream will define the quadrant occupied by the sub-carrier in the constellation. Then, a second data stream is used to modify inside the defined quadrant, the real and imaginary components of the sub-carrier.

If the second data stream is mapped by bit pairs, then the hierarchical constellation is as a "4QAM over 4QAM". Then the resulting constellation will look like a 16QAM.

If four bits are used instead, then it will be a "16QAM over 4QAM", resulting on a 64QAM constellation.

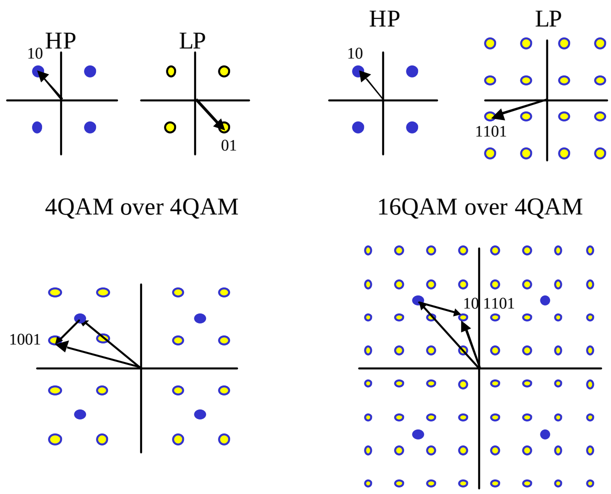

Figure 8: Hierarchical DVB-T constellation

The first data stream will always use a 4QAM modulation, then, as it will be more rugged, it is named High Priority stream (HP).

The second one, less rugged, either in the 4QAM or 16QAM cases, is named Low Priority stream (LP).

The hierarchical modulation modes offer an additional variant: the alpha factor. This one provides an offset to each quarter of the constellation, inside the quadrant.

Mainly, this offset make the HP-4QAM modulation more robust but unfortunately, the over LP modulation one, will then suffer an additional weakness.

HIERARCHICAL MODULATION CHARACTERISTICS

The two major characteristics of the DVB-T hierarchical modulation are:

- to allow broadcasting, on the same Radio Frequency channel, of two independent MPEG-Transport Streams,
- to give a dedicated protection, then a dedicated coverage, to each transport stream,

For sure, the difference of roughness between HP & LP will depend both on the constellation (4QAM or 16QAM) and on the Coding rate applied to LP.

The HP stream, always modulated as a 4QAM, will have a maximum useful bitrate payload depending only on the coding rate used to protect it.

The companion LP stream introduced as an over modulation of the HP one, can be viewed by the receiver, as an additional noise in the quadrant of the received constellation. Then, the HP stream will suffer from a penalty, in term of admissible C/N, in comparison to a regular 4QAM.

There are two ways to compensate or to mitigate the HP's C/N penalty:

- if the useful HP bitrate has to be preserved, then by increasing the alpha factor, the HP penalty can be quasi-cancelled,
- if a small reduction of the HP stream bitrate is admissible, then the HP penalty is mitigated by increasing its protection (its coding rate).

The choice between these two strategies will depend on the penalty the broadcaster accepts to report on the LP stream (there will be one whatever the chosen solution).

Concerning the LP stream, its bitrate is directly governed by the constellation / coding rate combination used. It is strictly homogeneous with the regular 4QAM & 16QAM modulation modes.

But as the LP's 4QAM or 16QAM modulation is applied over the HP's 4QAM one, the C/N required to demodulate the LP is far more important than it will be in non-hierarchical 4QAM & 16QAM modes. The C/N required for LP is, in fact, comparable with the one needed for the whole constellation (i.e.: regular 16QAM or 64QAM).

This situation is aggravated for the LP, when increasing the alpha factor to reinforce the HP protection.

HIERARCHICAL MODULATION: WHY?

In many countries, the introduction of digital TV services is performed sharing the UHF/VHF bands with the existing analogue TV services, often using the taboo channels.

The network planning is realised to optimise the useful bitrate of the DVB-T channel, then this drives generally the network planners to select a high density modulation scheme, to minimise the coding rate (at the expanse of the transmitter power) then to reduce the guard interval as far as possible in regard to the geographical situation of the transmitter (i.e.: urban vs rural).

In short, 64QAM constellation and 2/3 coding rate protection, are often chosen, then the network & the field coverage topologies drive the further choices:

- the 2K/8K choice is influenced by the network operating mode (MFN or SFN) and the maximum size of the transmission cells,
- the guard interval choice is driven by the service area type (i.e.: urban vs. rural), as this environment influences the echoes delay dispersion in the Terrestrial channel.

On top of these choices, the hierarchical modulation feature allows a further refinement for planning.

In practice, the choice of hierarchical modes parameters will drive to manage a range of situation between the two extreme ones shown in figure 9.

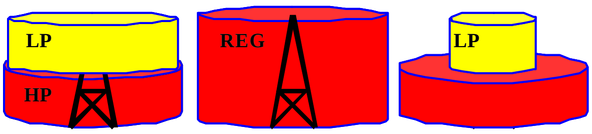

Figure 9: Symbolic coverage for hierarchical modulation

Hierarchical modulation feature represents a new trade-off between bitrate & roughness and, as a result, a new trade-off between bitrate and coverage area.

During the early time of the DVB-T experimentation, the hierarchical modulation has been only viewed has a way to define two coverage areas for a given transmitter.

This is essentially true, but only essentially: the two coverage areas do not seem to be necessary if only one category of Service is envisaged.

But if the objective is to implement two categories of Services, then the hierarchical modulation can heavily facilitate their introductions in a spectrum heavily occupied by the traditional analog ones!

In short, the flexibility offered by the hierarchical modulation can be customized in different ways, which mainly depends on the broadcaster point of view or concerns. Some examples are reported hereafter.

BROADCAST TO FIXED & PORTABLE RECEIVERS

One primary usage of the hierarchical modulation is to slightly modify the modulation parameters to facilitate the indoor reception for portable receivers.

Fixed receivers will take benefit of the roof top antenna gain, whereas the portable receiver will be penalised by the building penetration loss.

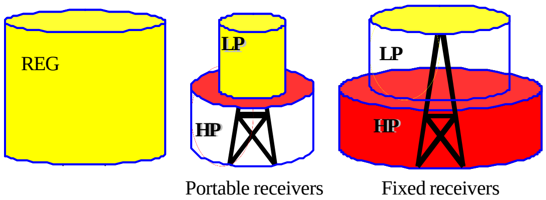

Figure 10: Hierarchical modulation for portable receivers

As figure 10 tries to represent it, in comparison to a regular modulation mode, HP & LP will cover two distinguished areas, as follow:

The more rugged data stream (HP), containing the “core” programmes, would be received both by fixed and portable receivers. But, concerning the portable receivers, the HP coverage area will be slightly larger than it would be in regular modulation modes.

Regarding the fixed receivers, only a small penalty will affect the LP coverage area.

Practically, what will be the trade-off if a regular mode 64QAM 2/3 is converted in a hierarchical one as HP: 4QAM 1/2 and LP: 16QAM 2/3 ?

Bitrate	REG : 24,13 Mbps	HP : 6,03 Mbps LP : 16,09 Mbps
C/N Gaussian	REG : 16,5 dB	HP : 8,9 dB LP : 16,9 dB

Table 1 : Indoor vs Outdoor trade-off

In terms of useful bitrate, the capacity moves from Regular: 24,13 Mbps to a hierarchical one of 22,12 Mbps. The global capacity is then reduced from 2,01Mbps.

But in terms of C/N, in a Gaussian channel, the HP protection is far better, whereas the LP one is identical to the regular transmission mode.

Globally, the overall bitrate is less reduced than the gain obtained in robustness for the HP stream, whereas the LP coverage is quasi-identical.

This constitutes an interesting benefit the case of the penalised portable receivers, as it was verified during field trials performed in UK by the BBC Research Department [3].

INCREASE NET BITRATE CAPACITY OF THE CHANNEL

In this approach, the broadcaster has accepted that the hierarchical modulation will change the overall coverage area, in comparison to the regular mode, as symbolised in figure 11.

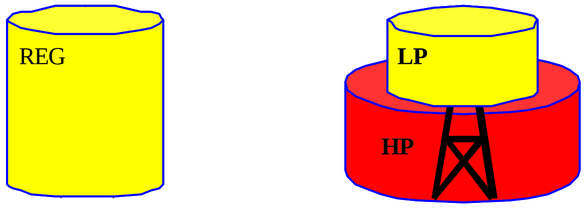

Figure 11: Hierarchical modulation for more bitrate

Accordingly, instead of the regular 64QAM 2/3, the following hierarchical one is used HP: 4QAM 3/4 and LP: 16QAM 3/4.

What will be the penalty in terms of C/N, in Gaussian channel?

Bitrate	REG : 24,13 Mbps	HP : 9,05 Mbps LP : 18,10 Mbps
C/N Gaussian	REG : 16,5 dB	HP : 13,7 dB LP : 18,6 dB

Table 2 : Increase net bitrate trade-off

The HP’s C/N becomes slightly better (+2,8 dB) and the LP’s C/N slightly worse (-2,1 dB) than the regular figure. Then the coverage will be slightly smaller for LP and slightly larger for HP than in regular mode.

But the bitrate capacity moves from 24,13 Mbps to 27,15 Mbps, which represents an appreciable gain of 3,02 Mbps.

Globally, at the expense of a distortion in the overall coverage area (5 dB penalty between HP & LP) and perhaps a larger LP’s sensitivity to the co-channel interferers, the payload capacity of the channel will be enlarged by several Mbps!

BROADCAST TO MOBILE RECEIVERS

The various field trials and laboratory tests performed up to now, by the MOTIVATE European research project, have demonstrated that mobile reception of a DVB-T signal is suitable.

The 16QAM and 4QAM schemes seem viable if they are supported by a strong protection. As, mobile applications are generally forecast for Urban area (i.e.: public transport) then the channel profile will be characterized by short echoes.

Following that statement, DVB-T modes having high coding rates and offering a transport capacity of 8 to 12 Mbps (2 to 3 programmes) seem suitable to broadcast Services to mobile receivers.

Then how to introduce services to mobile, simultaneously with the DTV services addressed to fixed and portable receivers, in a RF spectrum congested by analog TV services?

If two RF channels can be made available, a primary analysis will drive to allocate one of them to mobile services (roughly 2 programmes) and the other one for traditional receivers (roughly in Europe, 5 to 6 programmes).

A further analysis considering hierarchical modulation will perhaps drive to another conclusion.

Let us choice a hierarchical mode having a 1/16 guard interval and a HP: 4QAM 1/2, LP: 16QAM 3/4. Then, the bitrate capacity of the two hierarchical virtual channels will be HP: 5,85 Mbps and LP: 17,56 Mbps.

for mobile Rx	RF 1 ~	12 Mbps	~ 2 programmes
for fixed Rx	RF 2 ~	24 Mbps	~ 6 programmes
for mobile Rx	HP 1 :	5,85 Mbps	~ 1 programme
for fixed Rx	LP 1 :	17,56 Mbps	~ 4 programmes
for mobile Rx	HP 2 :	5,85 Mbps	~ 1 programme
for fixed Rx	LP 2 :	17,56 Mbps	~ 4 programmes

Table 3 : Fixed vs Mobile trade-off

This setting will give, to each RF channel, the capacity for one strongly protected programme (i.e.: for Mobiles in HP stream) and roughly, four programmes, for static reception, in the LP stream.

As two RF channels are available, if hierarchical modulation is applied on them, the broadcast capacity will be two programmes for mobile and eight programmes for fixed receivers.

The conclusion is crystal clear:

- if RF channels are devoted to a specific usage, then a maximum of 8 programmes (2+6) can be delivered,
- if hierarchical modulation is used instead, making virtual circuit inside each RF channel devoted to a specific service, then a maximum of 10 programmes can be delivered (2 x (1+4)).

Again, it looks like the hierarchical modulation gives a significant advantage to an efficient use of the RF spectrum.

SIMULCAST OF HD AND SD DIGITAL TV FORMATS

Outside Europe, a large number of countries, including Australia, aim to offer High Definition programmes to support the introduction of Digital TV.

This objective is justified by the availability of High Definition screens on the market, at affordable price, in the time scale of the Digital TV deployment.

Nevertheless, in the interim period of the DTV services introduction, all the receivers will not have the High Definition capability.

To speed up the liberation of the analog channels, it will then be necessary to simulcast the digital programmes both in HD and SD formats.

A hierarchical mode using 1/16 guard interval, HP: 4QAM 3/4 and LP: 16QAM 3/4 will offer sufficient bitrate capacities (HP: 8,78 Mbps and LP: 17,56 Mbps) to simulcast DTV programmes in HD and SD formats.

It remains possible to use a non-uniform hierarchical constellation (alpha factor equals 2 instead of 1) to increase the HP stream robustness (C/N: 10,8 dB instead of 13,7 dB) and then to save the LP C/N by increasing its coding rate (2/3 instead of 3/4).

This additional protection given to the LP (C/N: 18,9 dB instead of 21 dB) will unfortunately imply a loss of its payload capacity (15,61 Mbps instead of 17,56 Mbps).

Anew, the hierarchical modulation used for simulcast of SD & HD services, instead of regular mode addressing a dedicated service, allows saving RF channels while keeping the same richness of broadcast deliveries.

RESIDUAL COMMENTS

In all detailed examples, it is clear that the DVB-T hierarchical allows broadcasting two fully independent and self-decodable MPEG-TS multiplexes. That implies for each of them, the needs to include a set of video, audio and service information components, this to provide the user with complete digital TV services.

When simulcast operations are envisaged, either in the portable / fixed or mobile / fixed or HD / SD cases, some duplications of source information is requested, that is to fulfil the multiplexes independence rule.

But this apparent duplication shall not be viewed as a definitive default : In general, the elementary components are really different either in terms of contents (i.e.: HD vs. SD) or quality (i.e.: stereo or multi-channel sound).

Only the Service Information could be viewed as sharable between the two virtual channels offered by the hierarchical modulation, but as their bitrate is relatively modest, their duplication does not imply a great penalty.

In no cases, they can be stated as a “killer” argument against the hierarchical modulation feature.

CONCLUSIONS

In the early days of the DVB-T standard experimentation, the hierarchical modulation feature has not attracted the broadcasters. Currently, things and thoughts evolve to place the hierarchical modulation in an attractive situation.

Hierarchical modulation constitutes one of the numerous assets of the DVB-T standard, allowing another kind of spectrum efficiency usage by addressing various categories of receivers in various situations.

This liberty given to the broadcaster to start digital TV by introducing various categories of services, without demanding additional spectrum, seems to be a definitive advantage for the DVB-T system.

ITIS has designed its reference DVB-T modulator and demodulator products to allow the broadcasters to take benefit of all the standardised functions offered by DVB-T.

Even if its advantages are not trivial to analyse, then to implement: « Hierarchical Modulation is not an engineer's fantasy: it is among others, a clear asset of the DVB-T system».

ACKNOWLEDGEMENTS

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Special thanks shall be addressed to the CCETT engineers who have contributed to bring the ITIS products range to the forefront of the COFDM technology.

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