THE DIGITAL VIDEO BROADCASTING SYSTEM

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ABSTRACT

Among the five terrestrial digital broadcast systems standardised during the last five years (i.e.: DAB-T, DVB-T, ISDB-T, ATSC-8VSB and the forthcoming DRM), four are based on a variant of the Coded Orthogonal Frequency Division Multiplex modulation (COFDM).

The European DVB-T standard includes a large number of transmission modes to cover a wide variety of broadcast situations :

- ✓ The hierarchical modulation allows to organise a single RF channel in two virtual circuits, each carrying a dedicated multiplex with a dedicated protection, as it has been demonstration during the recent NAB 2000 convention in Las Vegas,
- ✓ The COFDM intrinsic resistance to multi-path propagation allows to operate a network of transmitters on the same Radio Frequency channel, then to constitute a so-called Single Frequency Network (SFN),
- ✓ the incredible robustness offered by some DVB-T transmission modes make possible to broadcast from one to three Digital TV programmes (5 .. 15 Mbps) to Mobile receivers even in motion at several hundreds km/h,

This presentation intends to highlight how these features have been made possible by the DVB-T standard and its COFDM modulation scheme.

Following a tutorial introduction of the DVB-T COFDM signal, SFN operation, Hierarchical Modulation & Mobile capability are presented and commented.

Why so much countries have chosen COFDM based systems ? The author intends to highlight the magic's of the COFDM, which have driven these choices.

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 comes from the possibility given to adjust the modulation parameters, then to implement up to 120 regular modulation modes and up to 1200 hierarchical ones.

The 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.

Furthermore, the possibility given to the DVB-T to operate Single Frequency Network (SFN) provides a tremendous simplification on the RF network planning exercise.

Moreover, even it has not been designed to broadcast TV contents to mobile receivers, the DVB-T has publicly shown (Broadcast Asia 98, IBC 98, NAB 99) its suitably for this particularly difficult propagation environment.

These possibilities are being explored in this paper which, as a tutorial introduction, presents the basic concepts of the COFDM then highlights its assets for such various application fields.

COFDM: THE FOUNDATIONS

Early in the 60's, the US's Bell Laboratories discovered the spread spectrum techniques and the particular Orthogonal Frequency Division Multiplex (OFDM) one, which since have been used for military applications.

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 OFDM" (COFDM).

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

COFDM: WHAT DOES IT MEANS ?

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

To overcome this problem, the first mechanism is to spread the data to transmit over a large number of closely spaced frequency sub-bands. Then, as some data will be lost during the terrestrial propagation, to reconstruct them in the receiver, the data flows are encoded (i.e. : protected) before transmission.

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

COFDM: HOW TO ORGANISE THE CHANNEL?

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, the 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 ».

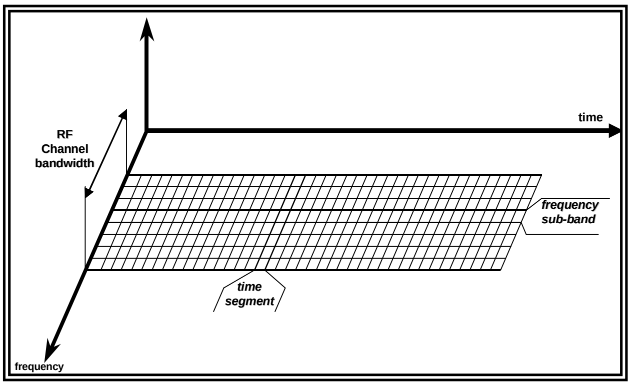

Figure 1 : DVB-T channel partitioning

SUB-CARRIERS INSERTION

Inside each time-segment, named OFDM symbol, one sub-carrier supply 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: then sub-carriers are "orthogonal".

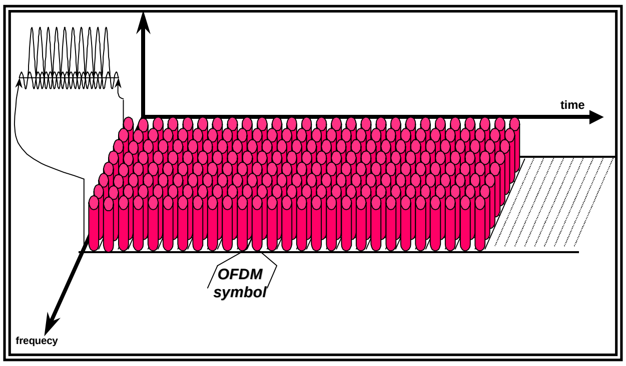

Figure 2 : Sub-carriers insertion

GUARD INTERVAL INSERTION

As « echoes » are constituted with delayed replicas of the original signal, the end of each 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.

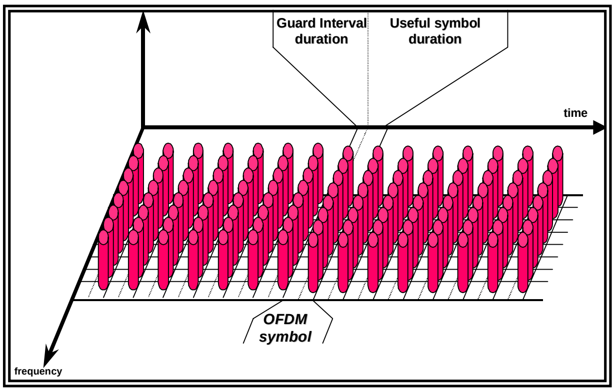

Figure 3 : Guard Interval insertion

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

CHANNEL SYNCHRONISATION

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.

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

This is illustrated in the following figure 4.

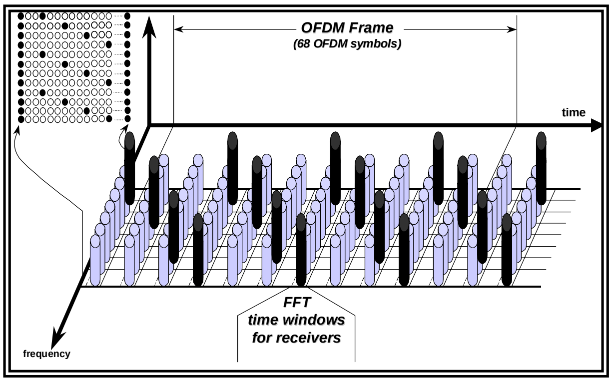

Figure 4 : Synchronisation markers

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

Unfortunately, most of these features imply a lost of the channel payload or a reduction of its useful bitrate. A contrario, they provide channel robustness.

Playing with such parameters allow to manage various trade-off between “Bitrate & robustness”.

To give as much liberty as possible to the broadcasters, then to adapt the terrestrial transmission to each specific situation, 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 modulation spreads the transmitted data in the time & frequency domains, after protecting data bits by convolutional 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 5.

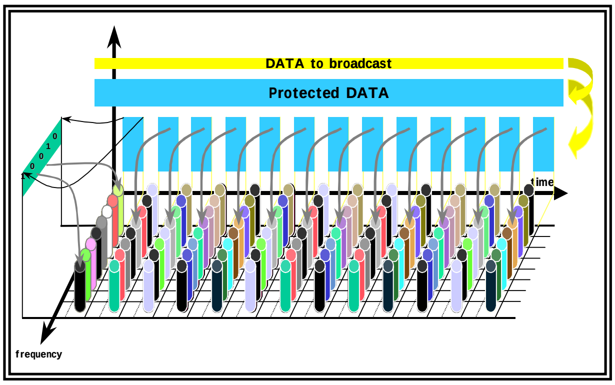

Figure 5 : Map data on OFDM symbols

BASIC CONSTELLATION

To map data onto OFDM symbols means to individually modulate each sub-carrier according to one of the three basic DVB-T complex constellations. The DVB-T’s regular constellations are shown in figure 6.

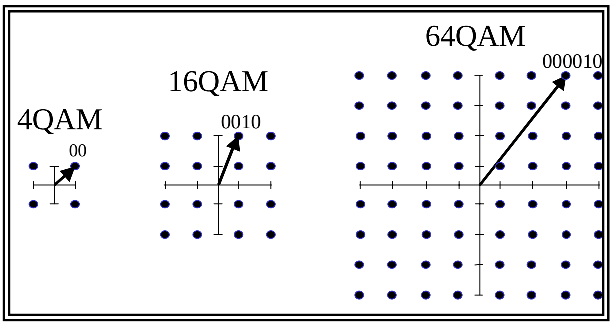

Figure 6 : Basic DVB-T constellations

Depending on the constellation chosen, 2 bits (4QAM), 4 bits (16QAM) or 6 bits (64QAM) are carried at a time on each sub-carrier.

But each constellation has a dedicated robustness, in regard to the minimum C/N tolerated 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 7, 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.

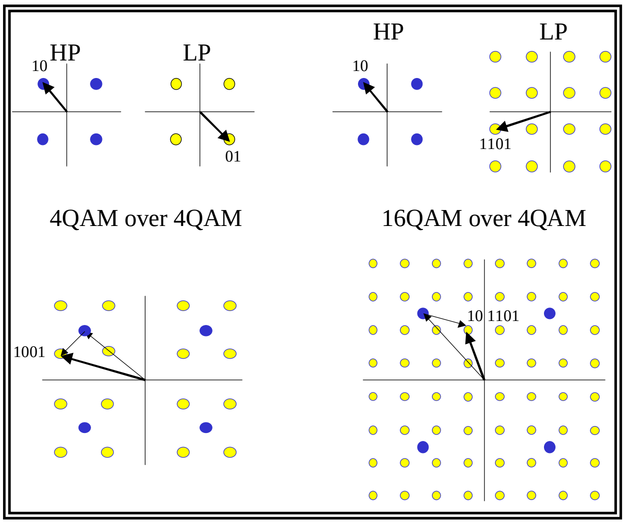

Figure 7 : DVB-T Hierarchical Constellations

HIERARCHICAL MODULATION

The characteristics of the two virtual channels follow the constellation & coding rate combinations applied.

The first data stream will always use a 4QAM modulation, then, 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 HIGH PRIORITY STREAM (HP)

The HP stream, always modulated as a 4QAM, has 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 suffers 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 constellation's alpha factor, the HP penalty can be quasi-cancelled,
- if a small reduction of the HP stream bitrate is admissible, then the HP penalty can be 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).

THE LOW PRIORITY STREAM (LP)

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

As far as robustness is concerned, as the LP's 4QAM or 16QAM modulation is applied over the HP's 4QAM one, the C/N required to demodulate it is far more important than it will be in non-hierarchical 4QAM & 16QAM modes.

In fact, the C/N required for the hierarchical LP is comparable with the one needed for the whole constellation (i.e.: regular 16QAM or 64QAM).

HIERARCHICAL MODULATION: WHY?

In many countries, the introduction of digital TV services is performed sharing the UHF/VHF bands with existing analogue TV services, that means using the so-called “taboo” channels.

This situation drives to introduce digital TV services at an average power of 15..20 dB below the analogue vision carrier one.

The network planning exercise is then focused on the optimisation of the DVB-T channel capacity.

Accordingly, the network planners tend :

- to select a high density modulation scheme,
- to minimise the coding rate,
- to reduce the guard interval as much as possible in regard to the geographical situation of the transmitter (i.e.: urban vs rural).

That's why generally 64QAM constellation and 2/3 coding rate protection are chosen.

The network type and the field coverage topologies drive to the selection of the remaining parameters :

- the 2K/8K system selection is influenced by the network operating mode (MFN or SFN) and the maximum transmission cell size,
- the guard interval value is selected depending on the service area type (i.e.: urban vs. rural), as this environment largely influences the echoes delay dispersion.

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

In practice, the choice of hierarchical modes parameters allows to manage a range of situation between the two extreme ones shown in figure 8.

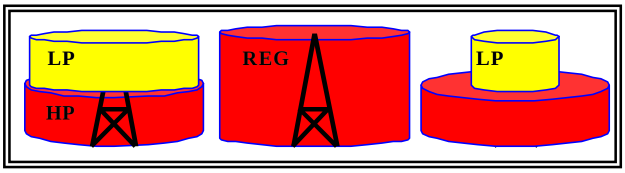

Figure 8 : HP & LP Symbolic coverage

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

That is essentially true, but only essentially : two coverage areas have to be considered only if a single category of Service is envisaged.

But if two categories of Services have to be implemented, then the hierarchical modulation heavily facilitates their introductions in a spectrum already occupied by the traditional analogue ones.

The flexibility offered by the hierarchical modulation can be customised in different ways by the broadcasters, 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 take benefit of the roof top antenna gain, whereas the portable receiver are penalised by the building penetration loss.

As figure 9 symbolised it, in comparison to a regular modulation mode, HP & LP provide two distinguished coverage areas. But, as far as portable & fix receivers are concerned, such coverage areas will not have the same behaviour.

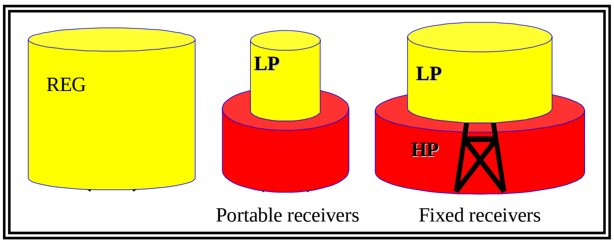

Figure 9 : Fixed vs Portable Receivers

Practically, what appears 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

The useful bitrate capacity moves from 24,13 Mbps to 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 quasi-identical to the regular transmission mode.

Accordingly, the overall bitrate is less reduced than the HP's robustness gain is increased, whereas the LP's robustness (i.e.: coverage) is quasi-identical.

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

INCREASE THE NET BITRATE CAPACITY OF THE CHANNEL

In this approach, the broadcaster has accepted to modify the overall coverage area, but wanted to provide more broadcast capacity. This is symbolised in figure 10.

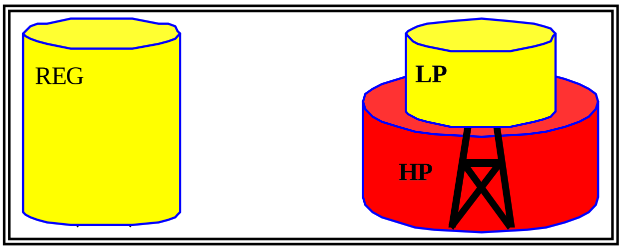

Figure 10 : More bitrate !

Instead of the regular 64QAM-2/3, the hierarchical HP : 4QAM 3/4 and LP : 16QAM 3/4 is used.

What is the penalty in terms of C/N, in a 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

Compared to the regular constellation, the HP's C/N becomes slightly better (+2,8 dB) and the LP's C/N slightly worse (-2,1 dB). Then the LP's coverage will be slightly smaller and HP's coverage slightly larger than in a regular mode.

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

In short, at the expense of a distortion in the overall coverage area (5 dB penalty between HP & LP) and then 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 around the world have demonstrated that mobile reception of a DVB-T signal is suitable.

The 4QAM and 16QAM constellations seem viable if they are supported by a strong protection. Moreover, as mobile applications are generally forecast for Urban area (i.e.: public transport), the propagation will be characterised by short echoes, allowing the use of a short Guard Interval.

Accordingly, DVB-T modes offering a transport capacity of 5 to 15 Mbps (1..3 TV programmes) seem suitable to broadcast Services to Mobile receivers. Then :

" How to introduce DTV services to Mobile receivers, simultaneously with the fixed and portable ones, in a RF spectrum congested by analogue TV services ? "

If two RF channels are available, one can be allocated to the Mobile receivers (roughly 2 programmes) and the other one to the traditional fix & portable receivers (roughly 5 to 6 programmes).

A further analysis, considering the hierarchical modulation will drive to another conclusion…

Let us choice a hierarchical DVB-T mode having a 1/16 guard interval and a HP : 4QAM-1/2, LP : 16QAM-3/4.

The bitrate capacities offered by this hierarchical mode are HP: 5,85 Mbps and LP: 17,56 Mbps, as resumed in Table 3.

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 hierarchical DVB-T mode gives, per 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 two virtual circuits inside each RF channel, 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 deliver High Definition programmes to support the introduction of Digital TV.

This objective is justified by the expectation to have High Definition screens at affordable prices, 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 screen : it is then necessary to simulcast the digital programmes both in the High Definition and the Standard Definition 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 perform such simulcast.

It remains possible to decrease the HP's coding rate to a 4QAM-1/2, at the expanse of its bitrate (HP : 5,85 Mbps) but with a gain in C/N (HP : 8,9 dB) to improve its portable reception even to mobile reception situation.

This possibility has been publicly demonstrated, by the DVB project, during the recent NAB 2000 convention in Las Vegas.

It has shown to the US broadcasters that the transition to the digital TV era, is not necessarily confined to HD receivers, but can address simultaneously two populations of receivers (HD & SD sets), then two ranges of cost for the customers, without demanding additional RF resources !

ANOTHER COFDM MARVEL : THE "SFN"

The advantages of the sophisticated COFDM digital modulation are numerous, but one of the major is its immunity against echoes.

Such echoes can be produced either by reflections on the environment (i.e. : terrestrial channel propagation) or by several transmitters operating in the same RF channel.

In the new broadcast world made possible by the COFDM, the natural echoes produced by reflection or refraction are voluntary reinforced by active echoes sources issued from co-channel transmitters or repeaters.

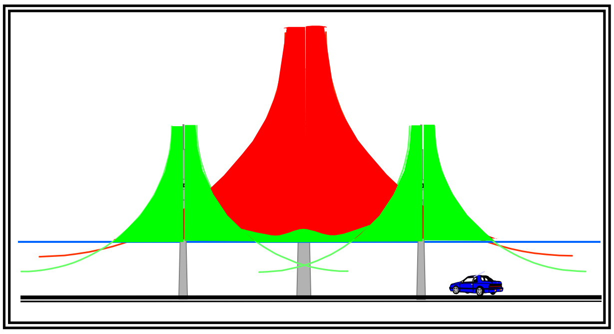

Figure 11 : SFN networks

That's because the COFDM is able to use the « positive echoes » (i.e.: the ones which increase the received power), and is able to bypass the negative effects of the others.

Accordingly, COFDM offers to the broadcasters a new way to operate their terrestrial networks : to increase the number of co-channel signal sources to improve the quality of services, inside the transmission cell.

With COFDM, it becomes more efficient to use several low power transmitters or repeaters than using a highly powered single transmitter, as this last will never be able to avoid shadowed zones in the service area.

SFN HOW ?

Single Frequency Network operation is obtained when all transmitters operate as co-channel transmitters : that means they radiate an identical on-air signal, on any point of the service area.

To summarise such conditions, the following « SFN Golden Rules » can be used :

Each transmitter involved in an SFN shall radiate:

- ➔ *on the same frequency,*
- ➔ *at the same time,*
- ➔ *the same data bits.*

These constraints have a direct consequence on the way to setup the primary distribution network and the transmitters, as presented in the following chapters.

FREQUENCY DOMAIN CONTRAINSTS

As it was already the case in conventional frequency planned networks, the working frequency of each SFN transmitter shall be accurately managed and monitored.

But, in the case of COFDM SFN operations, the stability and the accuracy of the working frequency shall ensure that each radiated sub-carrier has an absolute position whatever the RF channel frequency one.

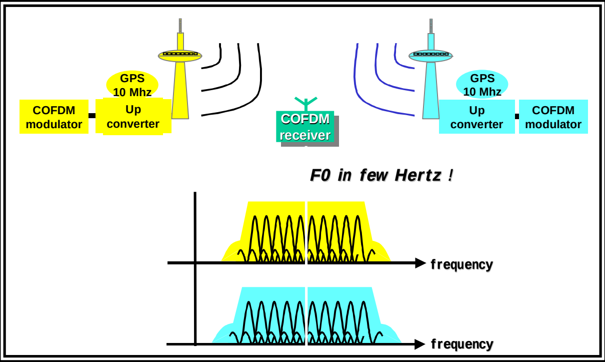

Figure 12 : Frequency domain synchronisation

Practically, a global frequency reference issued from GPS receivers is used to synchronise the SFN networks.

This case is illustrated in the figure 12.

TIME DOMAIN CONTRAINSTS

The time domain constraint constitutes a new challenge for the broadcasters: it is required from each transmitter to radiate the same OFDM symbol at the same time, then the transmitters shall be synchronised in the time domain.

The guard interval value chosen to operate SFN has a major implication on the network topology : as its duration governs the maximum echoes delay admissible by the system, the guard interval value influences the maximum distance between SFN transmitters.

This is illustrated in figure 13.

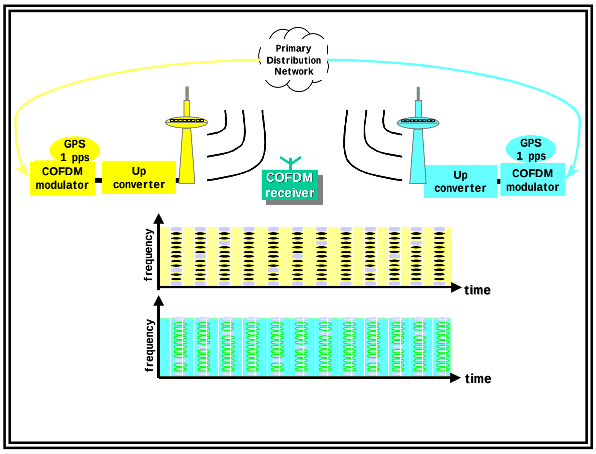

Figure 13 : Time domain synchronisation

The receiver has to setup a time window to sample the on-air signal only during its useful period. That allows excluding the guard interval period during which the signal is made of a mixture of two consecutive COFDM symbols.

Accordingly, the guard interval has to be considered as a budget : it has to be consumed on-air and not used to compensate a wrong time synchronisation of the SFN transmitters.

Practically, network operators use the one pulse per second signal (1 pps) issued from a GPS receiver, as an Universal time reference available in any point of the SFN network.

This common time reference is used, at the front-end of the primary distribution network, to insert “time-stamps” in the multiplex. As it is common, such time reference is used, in each transmission site, by the COFDM processor to delay the incoming multiplex until a common launching time instant occurs.

ANOTHER COFDM MARVEL : BROADCAST TO MOBILE

To investigate the practical and theoretical performance limits of the DVB-T standard for mobile reception, a consortium lead by T-NOVA, and grouping 17 broadcasters, network operators, equipment manufacturers and research centres, founded the Motivate project.

Few Motivate's results are reported here-after.

MOBILE DVB-T : THE RECEIVERS POINT(S) OF VIEW

Among all the parameters characterising the Service delivered to mobile receivers the maximum speed, corresponding to a given Doppler frequency value, is considered as the main one.

The Motivate's laboratory tests have demonstrated that, until a given Doppler limit (or inter-carrier interference level), the receivers are able to perform sufficient channel equalisation to demodulate the DVB-T signal.

When the Doppler (i.e. : the speed of the mobile) further increases, the recovery performance decreases drastically until a point where no demodulation remains possible. This receiver behaviour is illustrated in figure 14.

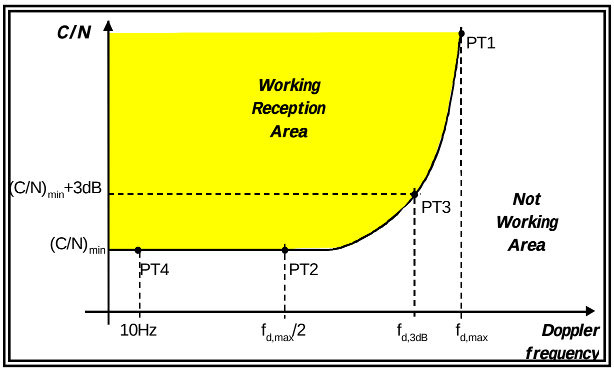

Figure 14 : DVB-T Mobile Receiver behaviour

The Mobile behaviour curve is then characterised by a « C/N floor », $(C/N)_{min}$, giving information about the minimum signal requirement for a good mobile reception, and by an upper Doppler limit, giving information on the « maximum speed » reachable by the receiver.

LABORATORY TEST CAMPAIGNS

Motivate performed two laboratory test campaigns in November 98 and in October 99, kindly hosted by T-NOVA and organised by ITIS.

Up to eight receivers have been evaluated. These receivers are representative of three generations of design (using Discrete components, 1st chipset generation and 2nd chipset generation) and three application domains (consumer, professional products and experimental receivers).

The following figure 15 shows, as a representative example, the C/N vs Doppler characteristics obtained from the various receivers when using the "2K - 16QAM - CR : 1/2 - GI : 1/4" DVB-T mode.

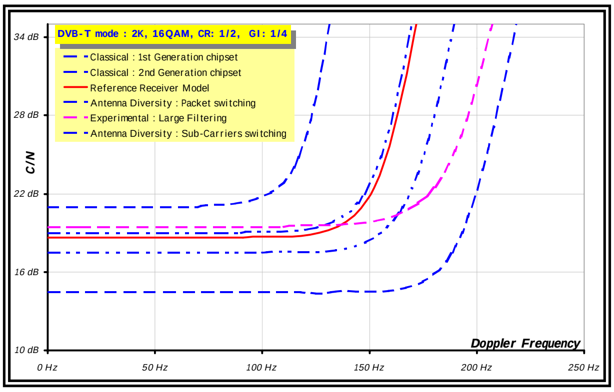

Figure 15 : Receivers behaviour dispersion

The dispersion of characteristics comes essentially from two factors :

- The generation of the chipset used in the receivers,
- The architecture of the receiver (i.e. : using or not antenna diversity and the type of diversity technique used).

Inside the group of single front-end receivers, the second generation showed better results than the first one, but an experimental receiver, which makes use of a deep time domain filtering to perform the channel estimation, shows also excellent results.

In the group of receivers using "antenna diversity" techniques, two different methods have been tried. Nevertheless, whatever the method, the diversity receivers are using two synchronised front-ends supplied by two distinct antennas.

- Method one : the received signals are combined at the level of the sub-carriers. This method is called "Maximum Ratio Combining" (MRC),
- Method Two : a selection is realised at the level of the MPEG-TS packets, after a full demodulation. This method is called "Packet Selection".

Even the "antenna diversity" receivers tested were at an early stage of design, they shown better results than the single front-end receivers.

Furthermore, the "carrier combining" technique obtained noticeable better results than the "packet selection", even if it has been penalised by the use of a first generation chipset.

The work accomplished on receivers, during the last years reveals that considerable improvements have been achieved in the channel estimation and channel correction techniques; nevertheless room remains to further enhance the synchronisation algorithms.

Moreover, the performance dispersion between receivers strongly highlights the room for reception improvements offered, by the DVB-T standard, to the manufacturers.

MOBILE DVB-T : THE NETWORK POINT OF VIEW

Following a positive response to the first question "Is DVB-T able to deliver digital TV to mobile receivers ?" an immediate second question arises : "Which bitrate at which speed ?".

The response to this second question is not immediate : "Mobile reception of a DVB-T signal is influenced by the characteristics of the terrestrial propagation channel, which itself depends on the geographical environment and on the robustness of the DVB-T modes used".

The combination of these factors will allow the reception of various numbers of programmes at various maximum speeds !

DVB-T MODES

It is clear that many of the standardised DVB-T modes are not suitable for mobile reception. Six non-hierarchical modes and four hierarchical modes have been selected for the Motivate laboratory tests, which cover both the 2K & 8K cases.

FFT SIZE INFLUENCE

The FFT size has a direct impact, for a given network C/N, on the maximum reachable speed of the receiver. This has been systematically verified for the modes experienced, as illustrated in the following figures 16A & 16B.

Roughly, 2K modes can cope with 4 times higher Doppler shift than 8K modes, due to the 4 times larger carrier-spacing it produces.

As the DVB-T 2K & 8K modes offer exactly the same bitrate ranges, it is expected that the choice of the FFT size will be mainly driven by the network planning criteria.

Then, it is anticipated that broadcasters will firstly identify the nature of the mobile Service area (ie : rural / urban / SFN), will then deduce the maximum speed in this area and will choose finally the 8K or 2K mode as a function of the transmission cell size (in MFN or SFN cases).

But, whatever the broadcaster choices, the receivers will have to provide a hand-over function to deal with transmission cell hopping.

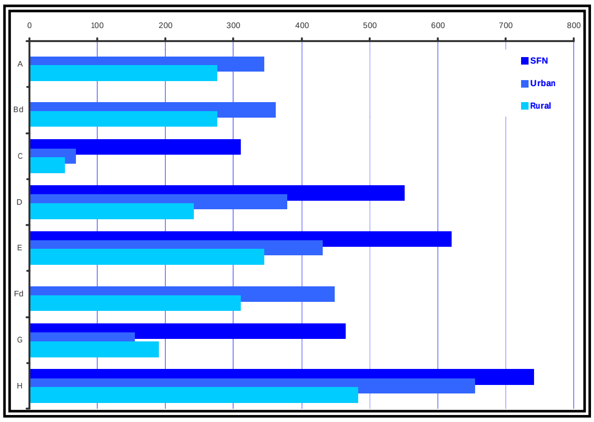

Figure 16A : "Maximum Speed" using 2K Modes

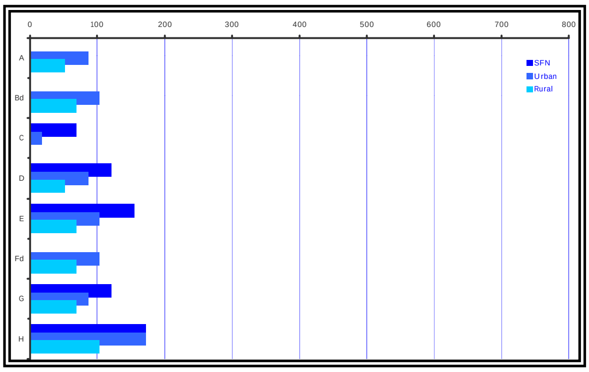

Figure 16B : "Maximum Speed" using 8K modes

GUARD INTERVAL INFLUENCE

For DVB-T Services addressing fixed and portable receivers, the guard interval is generally viewed as a "necessary evil", because it consumes channel bitrate capacity, but remains necessary to make the DVB-T receivers able to cope with delayed replicas of the original signal : the echoes.

In the mobile situation, where the receivers have to cope with fast variations of the transmission channel characteristics, the guard interval constitutes another disadvantage : it stifles the receiver's channel estimation with the information needed for tracking the fast channel variations.

This constitutes an additional argument in regard to the 2K vs 8K choice : as 8K modes provides symbol having four times the duration of the 2K modes, the channel estimation is performed less often in 8K modes, making it difficult for the receivers to compensate the fast channel variations… but 8K modes allow greater transmission cells.

Motivate choose to focus laboratory tests on a single value of the guard interval : 1/4. As this value is the most stringent one, the results obtained have to be considered as the worst possible case.

In other words, networks using a shorter guard interval will enjoy an increase of available channel bitrate whilst the receivers will achieve slightly better mobile performance.

CODING RATE OR PROTECTION INFLUENCE

As can easily be anticipated, the amount of protection bits embedded in the DVB-T signal has a direct influence on the receivers performance in mobile situation.

Even if it consumes useful bitrate, a strong protection is definitively required to help the receivers to cope with the degradation experienced in a time varying multipath channel, as is the mobile one.

This clearly means that code rates 1/2 and 2/3 are the most suitable for mobile Services, as illustrated in the figures 17A & 17B, extracted from the 2K-4QAM cases.

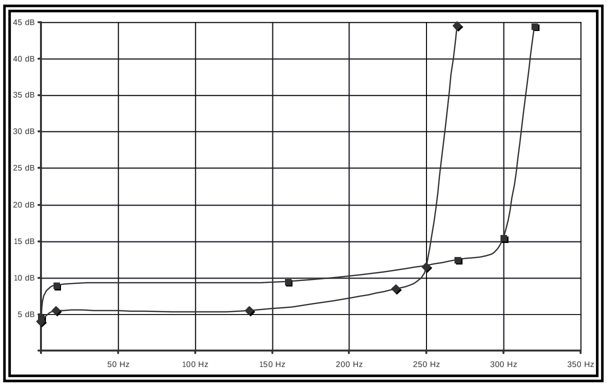

Figure 17A : Performance with CR 1/2

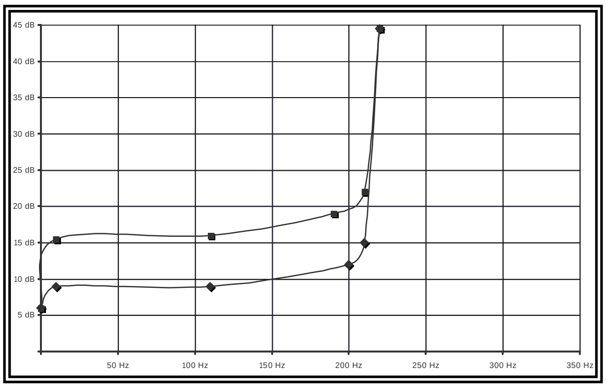

Figure 17B : Performance with CR = 2/3

This example shows that decreasing the coding rate from 1/2 to 2/3 brings two penalties both in terms of maximum admissible Doppler (~50 Hz) and minimum C/N required (~5 dB)… but it provides a 1.7 Mbps bitrate capacity gain !

Accordingly, as usual the network planners will be faced with a trade-off between robustness and bitrate, but in the case of the Services to mobile receivers, this trade-off needs to be carefully weighed-up because it will make the difference between an operational and a non-operational system.

REGULAR CONSTELLATION INFLUENCE

Clearly, the more dense the modulation scheme is, the more bitrate is available on air, but also the more difficult it will be for a receiver to demodulate the DVB-T signal.

Accordingly, 4QAM and 16QAM modulations will give better mobile reception performance than 64QAM which provides high bitrate capacity. Nevertheless, with improved receivers, the use of 64QAM constellation remains possible.

The figures 18A, 18B and 18C illustrate, in the CR:1/2 cases, the behaviour of three receivers faced with the 4QAM, 16QAM and 64QAM constellations.

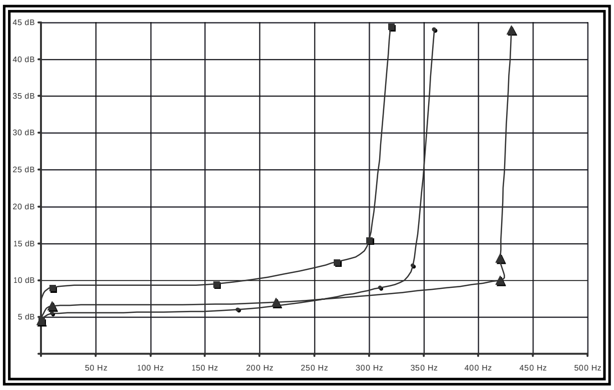

Figure 18A : Performance with 4QAM

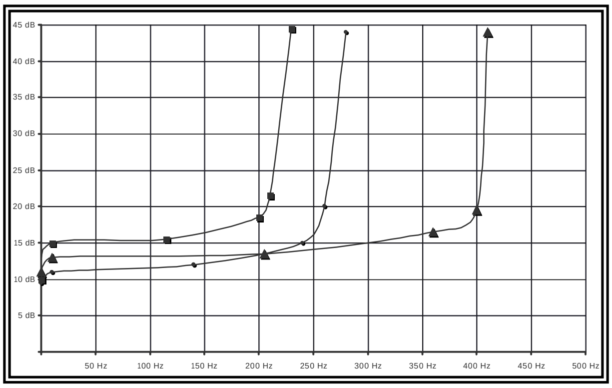

Figure 18B : Performance with 16QAM

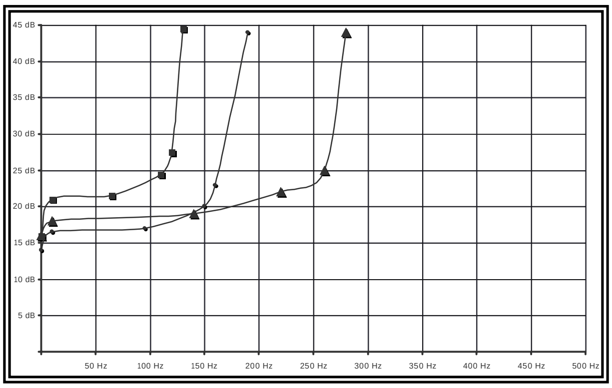

Figure 18C : Performance with 64QAM

These figures clearly show that a ~5 dB C/N floor penalty, accompanied by a ~100 Hz loss in the maximum admissible Doppler frequency, occurs when constellation density is increased.

Nevertheless, the inadequacy of the regular 16QAM or 64QAM constellations for the mobile situation can be mitigated somewhat by the introduction of the hierarchical modulation schemes.

HIERARCHICAL CONSTELLATION INFLUENCE

As previously presented, in the hierarchical modes the on-air signal is either a 16QAM or 64QAM but it is constituted by a basic 4QAM (HP) “over-modulated” by a 4QAM (LP) or 16QAM (LP).

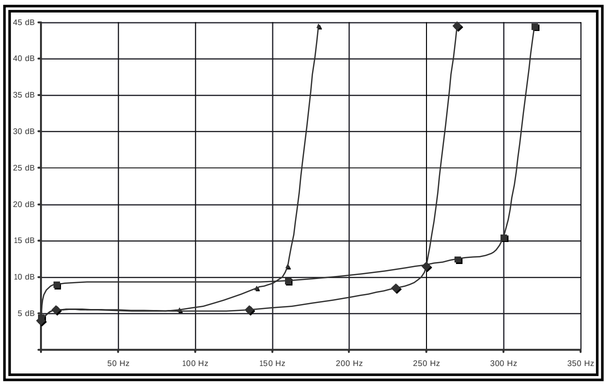

Figure 19A : Regular 4QAM

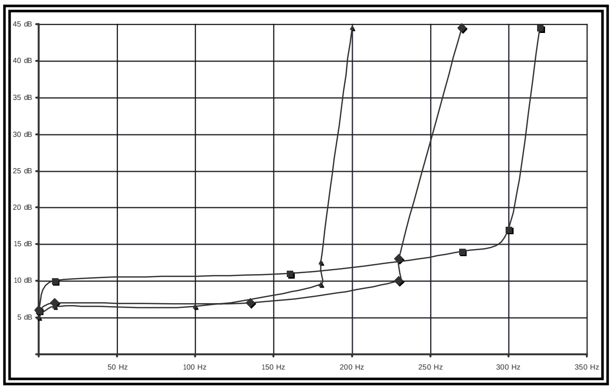

Figure 19B : 4QAM in a 16QAM

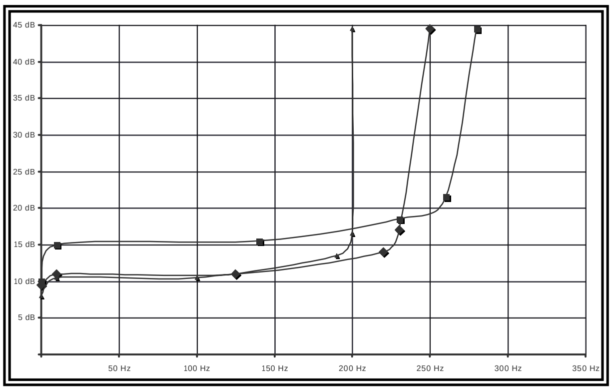

Figure 19C : 4QAM in 64QAM

In other words, using hierarchical modulation, a single RF channel carries two transport streams (i.e. : two MPEG-TS) having dedicated properties and different robustness.

That means the hierarchical modes can offer the way to introduce simultaneously Digital TV Services for static receivers and for mobile receivers. It can also be considered to improve the delivery to portable indoor ones.

Moreover, as soon as the HP delivery is guaranteed, the LP bitrate delivery capability can be viewed as a gift to the network planners.

This point is illustrated in the figures 19A, 19B & 19C, for three mode using a CR:1/2 cases which offer the same bitrate capacity, but are respectively obtained with a regular 4QAM, a 4QAM-HP in 16QAM and a 4QAM-HP in 64QAM.

It clearly appears that the use of hierarchical constellations retains the basic property of the regular 4QAM constellation, with the exception of a small C/N penalty, whilst a remaining LP stream for fixed / portable Services is offered.

RF CHANNEL INFLUENCE

As the impairments occurring in the mobile environment are related to the Doppler effect and because the “Doppler distortion” evolves proportionally both with the speed of the vehicle and the DVB-T signal centre-frequency, the RF channel used to deliver Digital TV to mobiles is of major importance on the Service reception performance.

The following figure 20 gives a view of the variation of the speed limit (i.e. : at C/N floor+3dB) as a function of the RF frequency channel, in the different DVB-T modes experienced.

Figures related to the DAB (Digital Audio Broadcasting – ETS 300 401) have been included as this system also takes advantage of the COFDM modulation scheme.

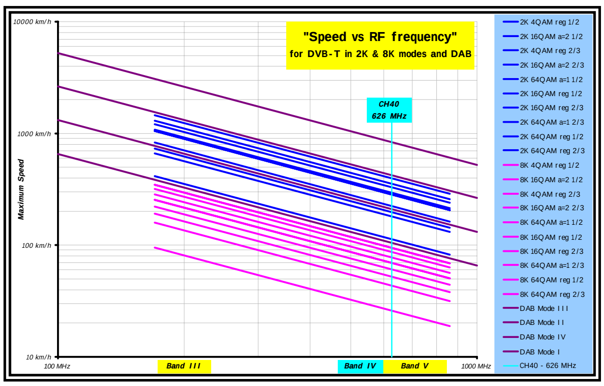

Figure 20 : Effect of RF channel used

The laboratory tests made use of the UHF channel 40 (626 MHz). This channel is roughly situated in the middle of the DVB-T Services band. This implies that the C/N performances reported in this document are average in regard to the various usable RF channels.

Better performances are generally obtained when the lower part of the broadcast bands is used, whilst worse performance occurs when the upper part of the broadcast bands is used.

DVB-T MOBILE RECEPTION PERFORMANCE AT A GLANCE

The two following figures clearly illustrate the major conclusions arising from the study of the DVB-T mobile capability. They highlight :

- the respective merits of the 2K & 8K modes,
- the penalties brought by the coding rate used,
- the acceptability of the hierarchical modulation schemes,
- the strong effect of the channel profile on the Service delivery performance.

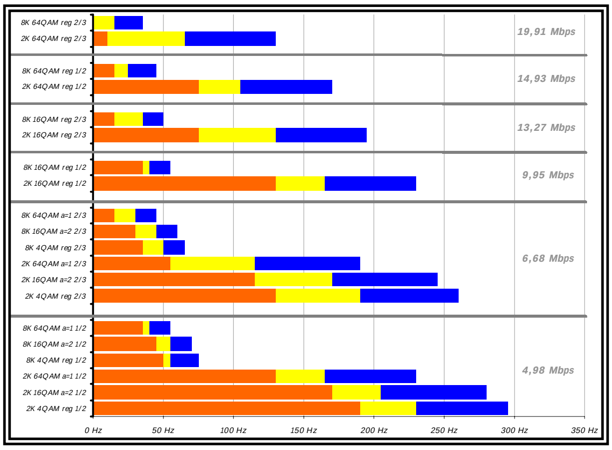

Figure 21 : Mobile performance at a glance

The figure 21 shows the maximum Doppler frequency, for the three channel profiles, in each DVB-T mode. The values have been sorted by bitrate ranges, to highlight the various possibilities (i.e. : DVB-T modes) offered by the standard. For a given bitrate, it is then possible to comprehend the merit of each DVB-T mode in regard to the maximum Doppler (that means maximum speed) the receivers will be able to accept, in the environments modelled by the channel profiles.

The figure 22 shows the maximum speed, as it will be when using CH40 (626 MHz), for the three profiles, in each DVB-T mode. The histogram shows the various bitrate values, in a given range, as a function of the Guard Interval chosen (N.B. : the GI:1/4 is the worst case both for the receiver and for the channel bitrate capacity).

The superimposed segment gives the indication of the maximum speed as a function of the three channel profiles, when GI:1/4 is used.

The higher speed value referred to the "two echoes" profile whilst the lower one is related to the typical rural area one; the point shows the maximum speed obtained for the typical urban profile.

This last figure allows to compare the relative merit of each DVB-T mode, in terms of maximum mobile speed and allows to weight-up the acceptable speed range, in relation with the geographical environment where the mobile digital TV Service is delivered.

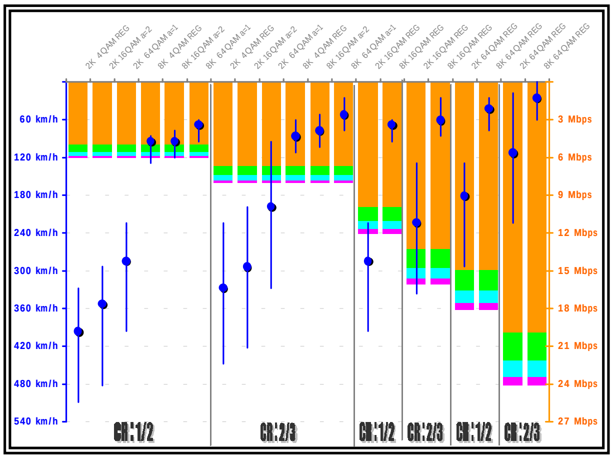

Figure 22 : Mobile trade-off at a glance

At the end of the Motivate's project life-time, the following conclusions can be drawn :

- ✓ On the receiver side, the new chipset generation improves spectacularly the mobile DVB-T usability. In addition, the receivers using antennas diversity techniques bring further capabilities to DVB-T reception, both in the Mobile & the Portable situations.
- ✓ On the network side, the usability limits of the DVB-T modes have been evaluated : providing a strong coding rate (i.e. : 1/2, 2/3) a wide range of bitrates (i.e. : 5 to 20 Mbps) can be broadcast to receivers in motion at various speeds (i.e. : from 50 to 500 km/h). Then broadcasters have to consider a global trade-off between bitrate, robustness and speed.

CONCLUSIONS

In the early days of the DVB-T standard deployment around the world, the hierarchical modulation feature has not very much 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, without demanding additional RF resources.

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

SFN operations of COFDM have been performed in many countries either using the DAB or DVB-T systems. Commercial digital TV networks as deployed in UK, Sweden, Spain, France and Australia use the DVB-T's SFN capabilities to optimise coverage and transmission cell size.

SFN operation is definitively not a laboratory-interesting feature; it is an efficient way to operate broadcast networks on the field.

Motivate did not intend to prove that the DVB-T standard is today the only international system able to broadcast digital TV to mobile receivers – obviousness has not to be demonstrated (!) – but evaluated the limit of the DVB-T standard to deliver Digital TV to mobile receivers.

It appears clearly today that the new generation of receivers improves spectacularly the mobile DVB-T usability. In addition, the receivers using antennas diversity techniques bring further capability to DVB-T mobile reception.

On the network side, the usability limits of the DVB-T modes have been characterised : providing a strong coding rate (i.e. : 1/2, 2/3) a wide range of bitrates (i.e. : 5 to 15 Mbps) can be broadcast to receivers in motion at various speeds (i.e. : from 50 to 500 km/h). The traditional trade-off between "robustness and bitrate" must now include "robustness, bitrate, area type and speed".

At least, the author hopes that this presentation has definitively convinced the broadcasters that using the DVB-T standard allows a tremendous variety of Digital TV applications to be delivered to a large range of receivers in a wide range of situations.

ACKNOWLEDGEMENTS

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