DELIVERABLE D2.1

REPORT ON DVB-NGH SYSTEM ARCHITECTURE

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EXECUTIVE SUMMARY

In ENGINES work package two (WP2), individual system architecture components are studied, and the results from these studies are forwarded to standardization work (DVB-T2 Lite, DVB-NGH). Additionally there is work on overall architectures, especially issues not covered by direct standardization that are novel access technologies and end-to-end system integration.

WP2 can be further divided into three main directions: system concepts and receiver algorithms for DVB-NGH, novel access technologies such as hybrid networks and cognitive radios and end-to-end system integration.

This deliverable collects the system architectural work performed by ENGINES partners for the DVB-T2 Lite and DVB-NGH. The topics considered here are:

- T2-4-NGH proposal
- Definition of ”T2-Lite”
- “Flexible Time Division Multiplex based on DVB-T2” proposal
- Proposal of a DVB-T2 Future Extension Frame based on 3GPP LTE broadcast mode (E-MBMS) for DVB-NGH
- Proposal of a NGH satellite Super Frame structure
- NGH Hybrid network architectures
- System Architecture Proposals for DVB-NGH Integrating MIMO Schemes

The advanced component techniques that have been devised or refined in order to solve fundamental issues for reaching required capacity and performance for DVB-NGH are presented in deliverable 2.3. “Report on advanced concepts for DVB-NGH”.

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LIST OF CONTRIBUTORS

The following ENGINES members, listed in alphabetical order, have contributed to this deliverable:

- BBC
- CNES
- DiBcom
- Hispasat
- INSA-IETR
- MERCE
- Nokia
- Orange Labs/France Telecom
- Teamcast
- Telecom Bretagne
- Teracom
- Thomson Broadcast
- Universidad Politécnica de Valencia/ iTEAM
- University of Turku (as editor)

1 INTRODUCTION

Most of the early work performed towards the definition of the new DVB-NGH system was dedicated to the definition of an overall architecture for the system. All the devised architectures assume that DVB-NGH services should be deployable on an existing DVB-T2 network infrastructure. In addition to terrestrial network, an optional satellite component for the DVB-NGH is considered. In this deliverable, the architectural studies and proposals made by ENGINES partners are presented.

The T2-4-NGH proposal, described in Chapter 2 is mainly a subset of DVB-T2, suited for mobile reception with an optional satellite component, inspired from the DVB-S2 [1] or DVB-SH [2] standards. This proposal was partly used for the definition of the so-called ”T2-Lite” profile of DVB-T2, intended primarily for reception of broadcast services in mobile environments (see Chapter 3).

The “Flexible Time Division Multiplex based on DVB-T2” system concept described in Chapter 4 takes advantage of the Future Frame Extension (FEF) concept embedded in DVB-T2 to alternate transmissions of several type of waveforms, each optimised for a specific population of receivers. A set of frames is designed to serve efficiently several network structures (broadcast, wireless broadband, mobile telecommunications networks).

Based on the DVB-T2 structure, two particular NGH frame structures have been studied. Chapter 5 deals with embedding a 3GPP E-MBMS frame in a DVB-T2 FEF, which could be seen as the cornerstone of the convergence of the E-MBMS and NGH mobile broadcasting standards. Section 6 presents a super frame structure, compliant with both terrestrial and satellite requirements, and based on a flexible position of NGH frames to address terrestrial mixed T2/NGH transmission and NGH-only transmission.

Hybrid satellite-terrestrial network scenarios for DVB-NGH are presented in Chapter 7. Frame structures envisaged for hybrid networks are considered. Also the concepts of SFN and MFN hybrid network and their constraints are described. Finally, in Chapter 8 MIMO network architectures for DVB-NGH are presented in detail.

2 T2-4-NGH PROPOSAL

This NGH system architecture proposal was elaborated and proposed to the NGH Call for Technology by a group of DVB members, including three ENGINES members, **BBC**, **Nokia**, and **Teracom**.

2.1 General overview

The NGH system proposed here affects the physical and the upper layers. The physical layer part consists of a terrestrial branch and an optional satellite branch. The terrestrial one is widely identical with DVB-T2, but suggests the following restrictions:

The number of constellations has been limited to those useful for mobile reception. The set of code rates was adjusted to those applicable for mobile reception, i.e. a few rates were added, whereas some of the original T2 ones were not adopted. Also the number of FFT sizes was limited following the same approach.

For the optional satellite branch DVB-S2 and DVB-SH were chosen as the reference points.

The upper layer part of this proposal puts emphasis on the IP route with OMA-BCAST applications on the application layer. But also the TS branch is considered and illustrated.

2.2 System architectural model

As a reference for NGH, Figure 1 gives the architectural model defined for DVB-T2 systems. The chain is composed of 5 sub-systems (SS1, SS2, SS3, SS4, SS5), and 4 interfaces (A, B, C, D): SS1, SS2, and SS3 subsystems with interfaces A, B, and C are at the network side, whereas SS4 and SS5 with interface D are located on the receiver side. In the following, we briefly describe the network subsystems and interfaces.

SS1 deals with the encoding and multiplexing of all input program signals plus associated PSI/SI information and other L2 signalling. It performs the main following functions:

1. Encoding of the input signals using A/V codecs.
2. Multiplexing of encoded streams into CBR MPEG-2 TS streams and/or GSE streams.
3. Re-multiplexing of CBR TS and/or GSE streams to form the TS partial streams (TSPS), where each TSPS maps to one data PLP. This also includes the insertion of common data for some groups of TS streams and mapping it into common PLPs.

SS2 (T2-Gateway) receives the TSPS streams from SS1 via the interface A, and generates T2-MI packets that are passed then via the interface B (T2-MI) to SS3 (T2 Modulator). The SS2 T2-Gateway performs pre-analysis of the first stages of the DVB-T2 modulation process, which enables it to create BB frames, signaling and SFN synchronization information, all encapsulated into the sequence of T2-MI packets. The interface B "T2-MI" enables distribution of the packets over legacy DVB-T (TS) or IP distribution networks.

SS3 (T2-Modulator) receives the T2-MI packets via interface B and generates corresponding DVB-T2 frames, which are then sent over the RF channel as DVB-T2 signal through the interface C.

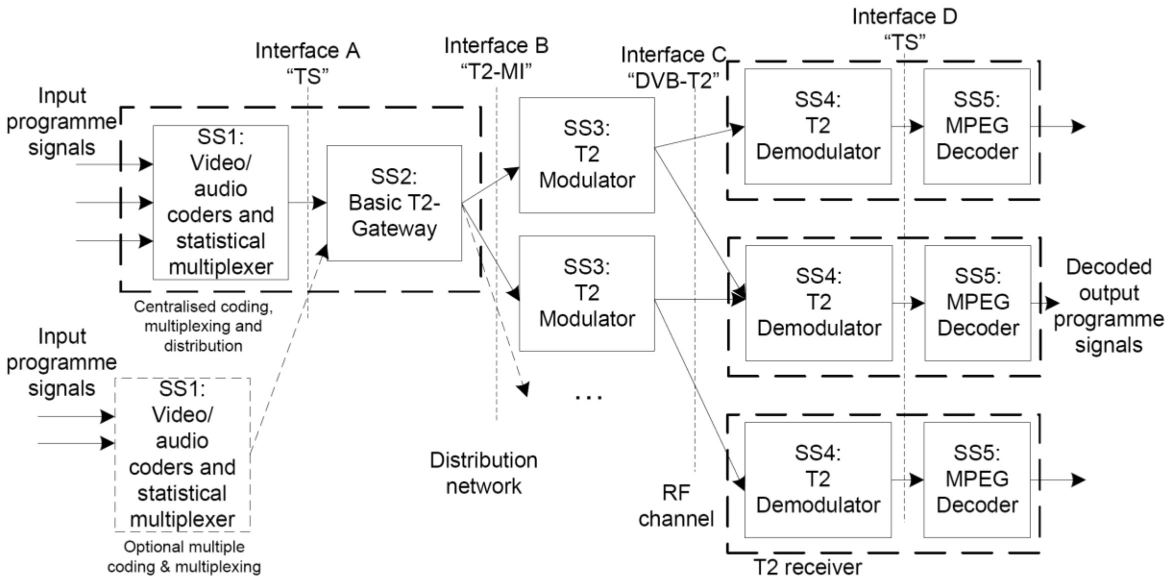

Figure 1: Block diagram of DVB-T2 chain

Figure 2 depicts our NGH system proposal aiming for the maximum reuse of T2 functionalities and infrastructure up to the interface B (i.e. distribution network).

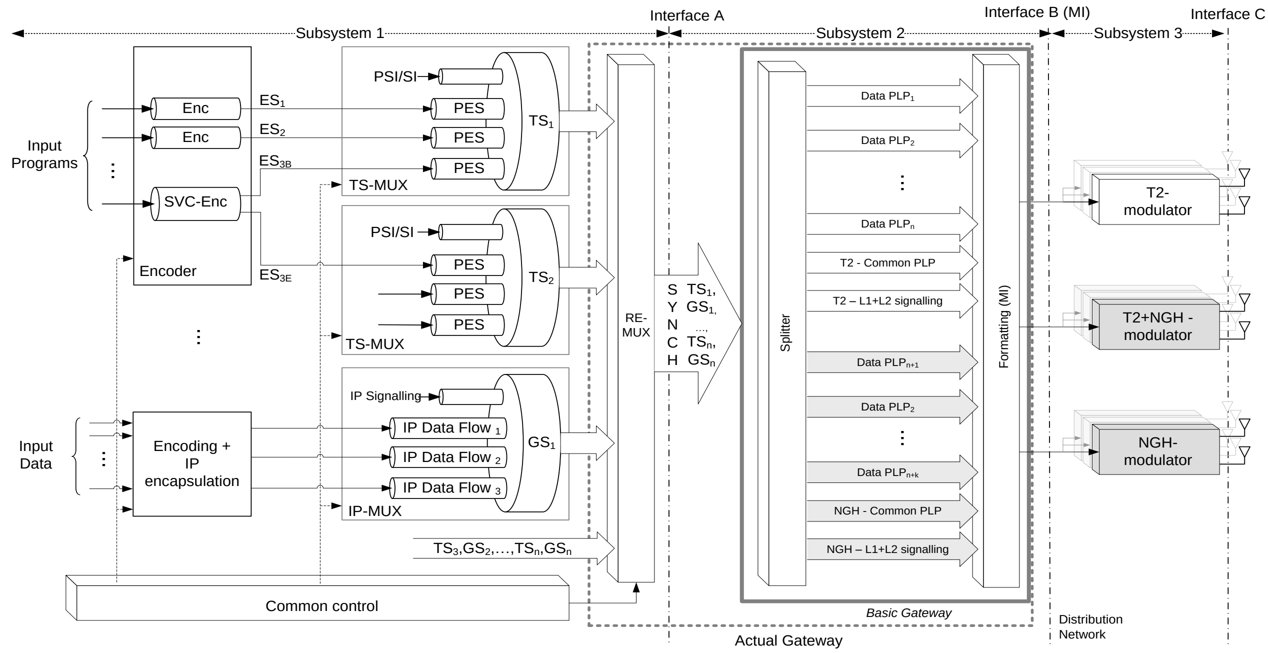

Figure 2: Architectural model for DVB-NGH network.

As observed in Figure 2, current NGH proposal is flexible to transmit both Transport Streams (TS) and Generic Streams (GS). The mapping between TS/GS(s) and PLP(s) is arbitrary. This is explicitly reflected in the previous figure by the Splitter block which separates the T2 and NGH services. Both NGH and T2 mapped PLPs may be combined later to comply with the format expected at the input of the interface B (a.k.a. Modulator Interface – MI). The PLP mapping and MI encapsulation are performed by the Basic Gateway, although actual gateways also perform the service re-multiplexing (as in T2).

Following current proposal, NGH and T2 would share the same interfaces A and B leading to minor modifications to SS1 and SS2. Farther to interface B, the NGH and T2 modulators have the possibility to be the same or different, whilst still using the same RF transmitter (i.e. T2 and NGH operate simultaneously in the same interface C).

Nevertheless, note that only the network side is depicted in Figure 2, since the receiver side follows the same structure as in Figure 1 substituting the SS4 T2 demodulator by an NGH demodulator.

Note that receivers need to decode several PLPs in parallel, e.g. a video-, and an audio-carrying PLP plus the common PLP. If SVC is used, the number of PLPs to be decoded in parallel gets even higher.

From the above architecture, the integration of NGH with T2 appears to be the most natural scenario. The integration refers to when the NGH and T2 services co-exist both on the same network. The FEF integration approach is shown in Figure 3 below:

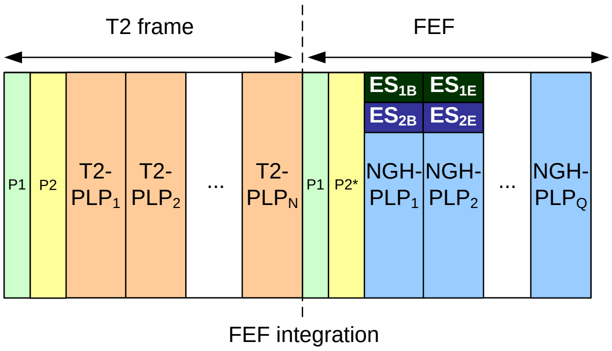

Figure 3: NGH and T2 signal in the same RF channel

FEF integration:

The NGH services are carried within the FEF part of the T2 signal, thus, will map to NGH PLPs. This gives more flexibility for NGH enhancements through specific design and configuration of the data PLP and signalling. The NGH signalling PLP is used in the FEF integration and hence this approach is mutually very close and at the same time fully backwards compatible with DVB-T2.

If SVC is permitted for NGH receivers, the Base (ESB) and Enhanced (ESE) layers of the elementary stream will map to different PLPs. In the context of SVC, it might be possible to achieve an even higher degree of integration between NGH and T2, in which the ESB maps to NGH PLPs, whereas the ESE maps to T2 PLPs. This tighter integration would reduce the amount of bandwidth required when the same service is provided for both, NGH and T2 systems, at different quality levels. However, provided the implications this would have on current T2 receivers, this solution is unlikely to be considered for the current NGH system specification.

Finally, the particular context, where the NGH system is standalone on an independent RF network, is illustrated in Figure 4 below, where the NGH frame structure is equivalent to the T2 frame structure with P1 and P2 symbols.

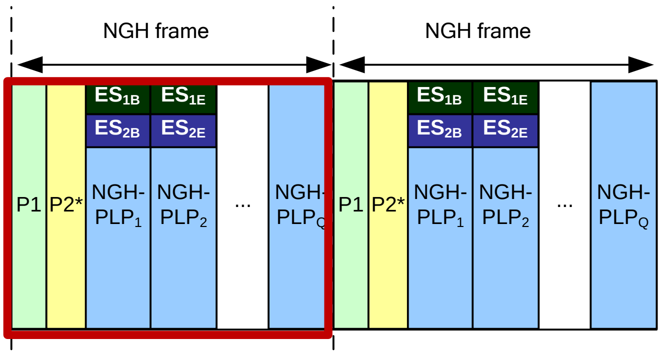

Figure 4: NGH signal occupying its own RF channel (standalone case)

In such context, the degrees of freedom for the design of the NGH signal remain similar and the degree of freedom for the selection of parameters is even higher than in the combined T2/NGH case, though a T2-like design is likely to be the most viable approach.

2.3 Overview of the NGH protocol stack

The NGH protocol stack is split into two core parts, i.e., the Upper layer and the DVB-NGH bearer, where the IP layer behaves as an interface. The Figure 5 illustrates the generic protocol stack of the end-to-end

NGH system where OMA-BCAST is carried over IP on the top of NGH bearer. The NGH bearer consists of the encapsulation&multiplexing layer, signaling within the L1 and L2 layers and of the physical layer. The header compression layer is located below the IP layer and it affects RTP/RTSP, UDP, IP and L2 encapsulation protocols.

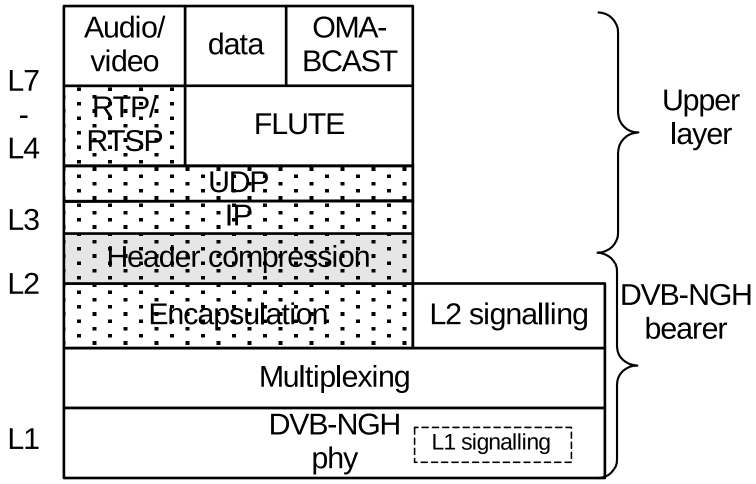

Figure 5: The IP protocol stack of the entire NGH system.

2.3.1 OMA-BCAST

OMA-BCAST is the application layer on top of the IP layers and it is transparent to the NGH bearer for other than some enhanced functionality, such as device management objects similar to those defined in the DVB-H context. OMA-BCAST used for NGH is the same as is used e.g. for DVB-H, FLO and ATSC M/H.

2.3.2 Encapsulation and multiplexing

The encapsulation is needed for IP datagrams and the multiplexing is needed for the encapsulated IP datagrams and L2 signalling which are carried over the NGH bearer.

2.3.3 Signalling

The signalling is split into the L2 and L1 part. The OMA-BCAST-specific signalling, including legacy and NGH specific amendments is not fully in the scope of this document.

2.3.3.1 L2 signalling

The purpose of the L2 signalling is to associate the IP streams with the physical layer pipes and with the network information. Also the bootstrap functionality of the ESG is enabled by the L2 signalling.

2.3.3.2 L1 signalling

The L1 signalling structure in its widest extent is adopted from DVB-T2. However, new signalling elements were defined to meet the NGH-specific needs e.g. related to mobility and handover. This new L1 signalling is carried within the dedicated NGH signaling PLP. The new L1 signalling provides information e.g. about the neighbouring frequencies, i.e. handover candidates, for each cell.

2.3.4 DVB-NGH physical layer

The DVB-NGH physical layer is based on the DVB-T2 physical layer, except for the removal of code rates, FFT sizes and other OFDM parameters which are not applicable to NGH.

2.4 Network elements and interfaces

In T2, a T2-GW carries out scheduling and allocation of BB frames to the T2 frame. T2-MI is the interface that carries this information from the T2-GW to a T2 modulator or set of T2 modulators which can be used to form a synchronised SFN. The T2-MI carries complete BB frames and therefore has no knowledge of their contents. It would therefore most likely be suitable for carrying NGH BB frames containing L2-encapsulated IP packets.

T2-MI is packet based and a number of different packet types are defined for T2. For the use with NGH, the existing packet type for BB frames could be re-used. If a change is made to the L1 signalling, a new packet type could be defined specifically for NGH L1. A new timestamp packet could also be defined to support bandwidths and fundamental time periods different from those defined for T2.

The T2-MI packets are always carried over conventional TS to ensure compatibility with existing DVB-T distribution networks. The overhead associated with this is small (typically 2%). Optionally RTP can be used to in turn carry this conventional TS over an IP network according to the DVB specification for TS transport over IP. For NGH, if the link based on the TS should be replaced, a direct T2-MI to UDP/RTP mapping could be defined.

3 Definition of ”T2-Lite”

The ad-hoc group TM-H chaired by Frank Herrmann (Panasonic) has been working on the standardisation of the DVB-NGH and it has been decided that it should consist of a ‘T2-Lite’ profile. ENGINES members, such as **BBC** and **Teracom**, actively participated to its definition. This profile is also added to the DVB-T2 specification [3] in Annex I and the relationship between T2, T2-Lite and NGH is shown in Figure 6 below:

- DVB-T2 forms the basis for both the DVB-NGH and the DVB-T2-Lite
- DVB-T2-Lite is a subset of DVB-T2 with a few additions and it is the entire subset of DVB-NGH

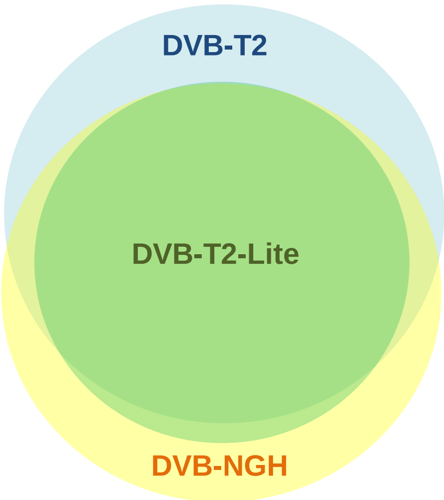

Figure 6: Relationship between DVB-T2, DVB-NGH and DVB-T2-Lite.

T2-Lite was previously known as T2-mobile and the new name has been adopted since 13th July 2011. All the work and documents leading to that have been using T2-mobile as the working name.

The T2-Lite profile is intended primarily for reception of broadcast services in mobile environments, although conventional stationary receivers may also receive these services. To aid the implementation of mobile receivers, the T2-Lite is based on a limited subset of the modes in the original T2 (now referred to as ‘T2-base’) profile and the key changes are:

i) The FFT sizes are restricted to 2k, 4k, 8k and 16k, meaning 1k and 32k FFT sizes removed
ii) Scattered pilot patterns allowed are PP1 to PP7, meaning PP8 removed
iii) Three combinations of FFT size, guard interval and scattered pilot pattern removed. Refer to Table I.5 and Table I.6 in Annex I for the allowed combinations
iv) Long FEC blocks removed
v) Time-interleaving memory halved - this is acceptable due to low data rates
vi) In-band signalling type B made mandatory to help receiver acquisition
vii) Code rates & rotated constellation changes
   - Code rates 1/3 and 2/5 taken from DVB-S2 are added to improve mobile performance
   - Code rates 5/4 and 5/6 removed
   - Code rates 2/3 and 3/4 not used with 256-QAM (refer to Table I.4 in Annex I)
   - Rotated constellations not used with 256-QAM (refer to Table I.4 in Annex I)
viii) Maximum data rate reduced to 4 Mbits/s
ix) Assuming processing rate for FEC decoder to be reduced by limiting rate at which cells are processed in Receiver Buffer Model
x) FEF length of up to 1 second allowed – this is to allow for low ratio of T2-Lite to T2-base frames

The complete description of this profile can be found in the Annex I of the DVB-T2 specification [3].

Due to the addition of the T2-Lite profile in DVB-T2, the specification needs to be revised to V1.3.1 and the proposed changes were presented to the Technical Module (TM) of the DVB Project. During the 88th TM meeting on the 8th and 9th of June 2011 in Geneva, the proposed revision to the draft DVB-T2 standard was approved.

This specification was later presented to the DVB Steering Board (SB) on the 7th July 2011 for their 68th meeting and it was approved with the request of changing the original 'T2-mobile' name to 'T2-Lite' before proceeding through ETSI.

The new name avoids the misconception that DVB-T2 was not designed to work in the mobile environment. In fact the original DVB-T2 (specification V1.2.1) can be configured to work in fixed, portable or mobile reception. A DVB-T2 network targeting stationary receivers with rooftop reception can be configured to maximise the data rate but the penalty is poor mobile reception. Hence the T2-Lite profile allows a more robust OFDM mode to be transmitted alongside with a high data rate service within the same channel of T2.

4 Flexible Time Division Multiplex based on DVB-T2

The "Flexible Time Division Multiplex based on DVB-T2" system concept for DVB-NGH, has been elaborated by a group of 7 ENGINES partners: **CNES**, **DiBcom**, **Teamcast**, **INSA-IETR**, **MERCE**, **Orange Labs/France telecom** and **Telecom Bretagne** with the aim to fulfil the Commercial Requirements elaborated by the DVB forum for the DVB "Next Generation to Handheld terminals" system.

Three main ideas have driven the works:

- DVB-NGH services shall be deployable on an existing DVB-T2 network infrastructure,
- DVB-NGH systems might be tailored to address various populations of nomadic/mobile receivers over a whole country and/or over cities and/or inside buildings,
- DVB-NGH shall anticipate the future landscape of "Mobile Multi Media" services resulting from the

"Digital Dividend" (790-862 MHz), the forthcoming 4G-LTE deployment and the technical evolutions of the handheld devices.

4.1 Rationale of the system concept

Even if the DVB-NGH Commercial requirements constituted our reference framework, some additional considerations emerged from our works:

- Mobile TV services still look for an adequate "Business Model": the translation of the classical broadcast business models (i.e. "Free-to-air" and "PayTV") do not exhibit nowadays a noticeable commercial success story,
- Successful deployment of Mobile TV services seems to be linked to the capability of the broadcast infrastructure to provide several services simultaneously.

Accordingly, it seems mandatory to design the DVB-NGH system in order to allow – as an initial step – the deployment of DVB-NGH services over an existing broadcast platform (similarly to the "One-Seg" scheme introduced on the Japanese Digital TV broadcast system ISDB-T).

But, following the introduction phase, which essentially aims to build up a park of receiving terminals, the DVB-NGH system should be able to be extended in order to offer more services to more users, in other words to extend its capacity and coverage to address more receiving situations (thus to avoid the impasse noticed by some broadcast systems in some countries).

On another hand, interestingly, "broadcast modes" are announced in the new generation of bidirectional wireless networks (i.e. WiMax, B3G-LTE and 4G-LTE-A) showing the strong asset of the "broadcast topology" to provide wireless terminals with high-bitrates Multi-Media contents.

This also lets anticipate that future handhelds terminals will be equipped with "broadcast mode" demodulators and that it should be adequate to ease the apparition of silicon performing universal broadcast demodulation, instead of using a "multi-modems" approach which characterises, nowadays, the "Smart-Phones".

As far as receiving terminals are concerned, it should be also noticed that the recent technological evolutions make "handheld TV" not only restricted to access uniquely a broadcast network, but embed means to become "connected devices" to either a wireless broadband network or a mobile telecom networks.

This suggested that the Hybrid Broadcast Broadband TV (HbbTV) services organisation, which uses the connected capability of stationary set top boxes, should constitute a suitable basis for the definition of Mobile DVB-NGH services.

The broadcast market trends observed at the terminal level seems to show a clear path to the harmonisation of the "broadcast mode" used in wireless access networks: the work engaged by DVB-NGH should be an excellent opportunity to provide to the forthcoming intelligent terminals a way to insure the continuity of Mobile TV services and to make DVB-NGH service network agnostic!

Based on these considerations, came our conclusions:

- DVB-T2 shall be the starting point of the DVB-NGH system design,
- DVB-NGH system shall offer capability of evolution to a range of network architectures (i.e. broadcast, cellular, hybrid),
- DVB-NGH shall offer paths for convergence with other categories of networks.

4.2 NGH as a flexible "Time Division Multiplex"

By construction, DVB-T2 offers three ways to transmit broadcast services having different physical layer characteristics: multi-PLP, auxiliary streams and Future Extended Frame.

The two first features require that all services share the same waveform (one FFT size, one guard interval, one time interleaver…). With this definition, it should be difficult to serve efficiently & simultaneously various topologies of network contributing to serve nomadic/mobile handheld devices.

On the contrary, the Future Frame Extension (FEF) concept embedded in DVB-T2, allows to alternate transmission of several type of waveforms, each optimised for a specific population of receivers (i.e. Fixed / Portable / Mobile), each population accessing to a given service (i.e. HDTV / SDTV / LDTV).

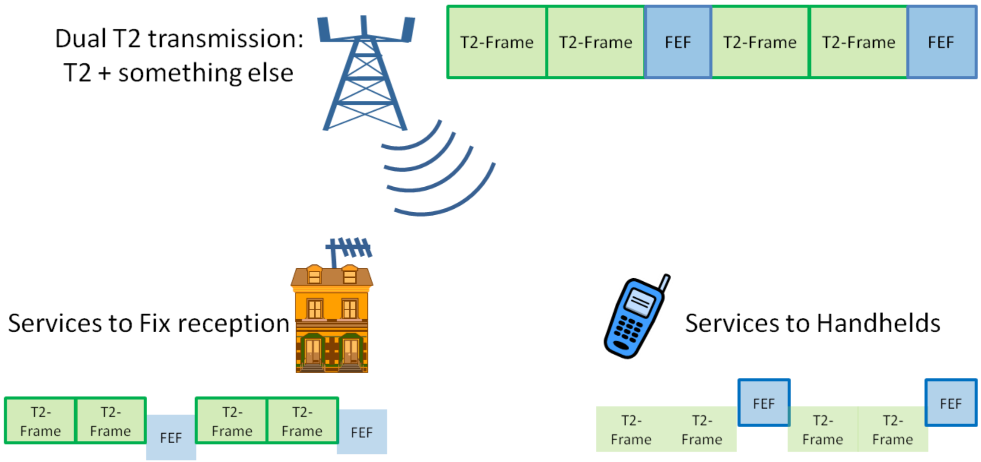

Figure 7: Dual transmissions "T2 & something else"

In its current definition, DVB-T2 allows two sets of services, as illustrated in Figure 7:

1. The CORE T2 service carried in one category of DVB-T2 frame,
2. "*Something else*" carried in the "Future Extension Frame" (FEF).

With this definition, it is somehow difficult to address simultaneously various kinds of requests, especially if it is needed to tune the transmission parameters – and not only the BICM ones - to optimally deliver a service over a unique network of transmitters...

For instance, some broadcasters should wish to use a pure DVB-T2 waveform but to use alternatively three sets of DVB-T2 parameters to specifically target three dedicated population of receivers:

a. Those using a roof top antenna → HDTV over Fixed receivers,
b. Those using a set top antenna → SDTV over Portable receivers,
c. Those using a built-in antenna → LDTV over Mobile receivers.

The difficulty with the current DVB-T2 definition is to signal three independent DVB-T2 multiplexes (of PLPs) broadcasted in a single RF channel, but carried by a dedicated waveform having specific physical properties (i.e. FFT/GI/MIMO/Pilot Pattern).

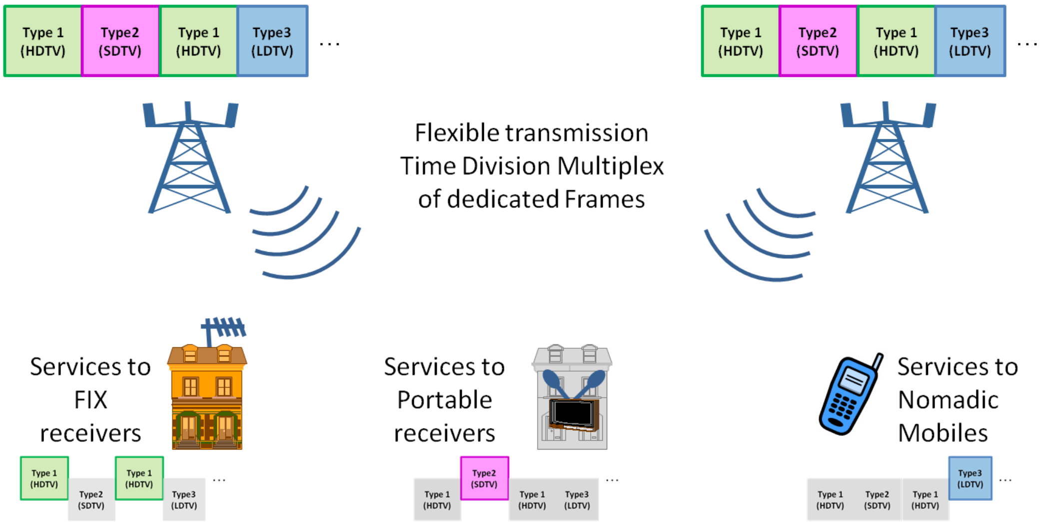

Figure 8: DVB-NGH as a flexible TDM of "frames starting with P1"

The conclusion of our analysis is that the definitions of the DVB-T2-FEF and the related P1 signalling messages must be "relaxed" in order to allow a free organisation of the sequential transmission of any type of "frames starting with the P1 preamble", as illustrated in Figure 8.

The purpose of making DVB-NGH a free multiplex of frames, based on the underlining structure specified in DVB-T2, is clearly to offer to the DVB-NGH network operator a full flexibility in the transmission resources allocation. This "flexibility in Broadcast Services" should furthermore be managed either statically (i.e. fixed organisation of the TDM) or dynamically (i.e. variable organisation of the TDM along day/week/month to face special demands/events).

4.3 Is a unique "DVB-NGH frame" able to satisfy every CR needs?

If the "in-band Mobile TV" scenario is foreseen to ease the introduction of Mobile TV services over an existing DVB-T2 transmission infrastructure, it is also foreseen that the initial network coverage will have to be improved and to be extended.

In this progressive scenario, it should be noted that everything performed to improve coverage will benefit to all services. Also, if the broadcast service to Handheld is commercially successful, it should be anticipated that new networks/new transmission capacities will be required using not only the broadcast UHF spectrum, but also other bands made available for Mobile Multimedia services.

Globally, it seems that the number of scenarios should be of extreme variety and accordingly the topology of the DVB-NGH broadcast network should be able to evolve in various directions.

Ultimately, high performance DVB-NGH networks could include three categories of transmission cells, each having a specific purpose and accordingly implementing a specific waveform.

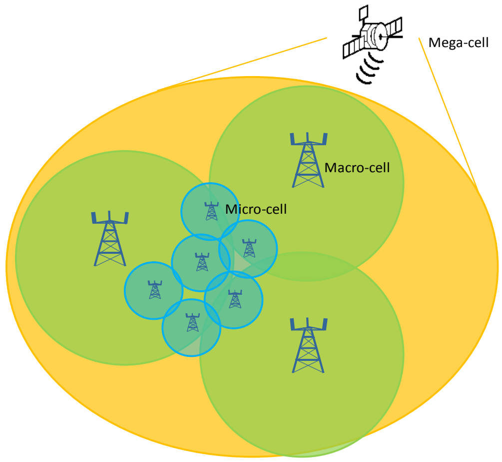

Figure 9: DVB-NGH network topology involving 3 categories of transmission cells

As tentatively pictured in Figure 9, three types of broadcast components are co-operating to contribute to a universal availability of DVB-NGH services over a wide area:

1) **<u>Macro cells</u>**: are served by traditional Digital TV broadcast sites, characterised by high power (x KW) / high elevation (x00 m). These sites would insure essentially the **urban outdoor coverage,**
2) **<u>Mini cells</u>:** which use "cellular" sites, characterised by low power (xW) / low elevation (x0 m). These would be used mainly to deliver the DVB-NGH services for **urban indoor receivers,**
3) **<u>Mega cells</u>**: will be served by geostationary satellite (or possibly by constellation of satellites with inclined orbits offering permanently a high elevation angle), which will produce a broadcast signal characterised by high power (xKW) / very high elevation (x000 km) which turns out to offer low power density at the ground level perfectly adapted to serve **rural/countryside outdoor receivers.**

Due to the richness of foreseen network topologies, notably in terms of cell sizes and channel characteristics (indoor/outdoor/satellite), it seems difficult to determine a unique frame structure which possesses adequate characteristics to cover efficiently every transmission cell case.

Our system concept proposes then to define a set of frames designed to serve efficiently all network structures. A set of NGH-frames can be freely combined to constitute the NGH-TDM and even, each NGH-Frame being introduced by the regular DVB-T2-P1 preamble, they could be embedded in a regular DVB-T2 transmission, as shown in Figure 10, without disturbing classical DVB-T2 receivers.

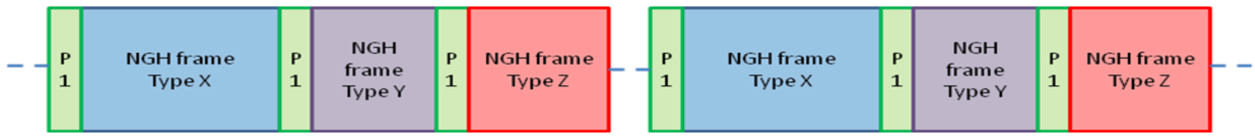

Figure 10: DVB-NGH transmission based on a flexible time multiplex

The conclusion of our analysis is that a unique type of NGH-frame cannot satisfy the wide diversity of network topologies which will be needed to address the wide variety of demands/constraints the future DVB-NGH-system will be faced on the markets. We proposed a DVB-NGH system offering a wide variety of "NGH-Frames" to cover optimally several deployment scenarios.

4.4 A set of NGH-Frame to optimise NGH-Services

In order to provide optimal "Flexibility of Services" and "Flexibility of Network Topologies" we have identified seven frame types which could be assembled to constitute a Time Division Multiplex articulated in compliance with the architecture previously described:

- NGH01 – Full DVB-T2: Targeting fixed reception through roof-top antenna,
- NGH02 – Modified DVB-T2: same target but proposing enhanced P2 format,
- NGH03 – Enhanced DVB-T2: introducing enhanced BICM and MIMO component,
- NGH04 – NGH Hybrid: reusing DVB-SH elements,
- NGH05 – SC-OFDM: optimised satellite component for hybrid network,
- NGH06 – OFDM/OQAM: optimising cellular coverage,
- NGH07 – LTE Broadcast (E-MBMS): optimising convergence of networks.

The main technical features of these frames are summarised in Table 1.

	Chanel Coding			SSS			Modulation	
	FEC	Constellation	Time Interleaving	Sync.	Signalling	Sounding	MISO MIMO	Waveform
NGH01 Full T2	T2	T2	T2	T2	T2	T2	T2	T2
NGH02 T2 with P2'	T2	T2	T2	T2	**Compressed & Scrambled L1 messages**	T2	T2	T2
NGH03 Enhanced T2	**LDPC w All DVB-S2 code rate**	T2	T2	T2	**Compressed & Scrambled L1 messages**	**Subset of T2**	**STBC 3D- MIMO**	**CP-OFDM 1K 2K 4K 8K**
NGH04 NGH Hybrid	**TC-3GPP2 (or LDPC)**	**QPSK 16QAM (64QAM) Rotated)**	**Long Convolut. TI**	T1	**T1**	T1 **Joint PAPR/CS I**	**STBC 3D- MIMO**	**CP-OFDM 1K 2K 4K 8K**
NGH05 NGH Satellite	**TC or LDPC**	**QPSK 16QAM (64QAM)**	**Possibly Longer than T2**	T2	**Compressed & Scrambled L1 messages**	See MERCE doc	**STBC / SFBC or SDMA or Both**	**SC-OFDM 1K 2K 4K 8K**
NGH06 NGH Cellular	**TC or LDPC**	**QPSK 16QAM 64QAM**	T2	T2	T2	T2	**Spatial Multiplexing Like**	**OFDM-OQAM 1K 2K 4K 8K (16K)**
NGH07 NGH LTE	**Turbo Codes**	**QPSK 16QAM 64QAM**	**E-MBMS**	**E-MBMS**	**E-MBMS**	**E-MBMS**	**LTE (i.e. none)**	**CP-OFDM 128 256 512 1K 2K**

Table 1: Proposed DVB-NGH Frame Set

4.5 Conclusion

This system concept proposal was intended to provide a "Flexible Time Division Multiplex based on DVB-T2" with the following suggestions:

- **relax the definition of the Future Extension Frame (T2-FEF)** of DVB-T2 in order to allow transmission of any combination of frames "*starting with preamble P1*";

- **define a set of specific “NGHxx” frames** each specifically optimised for a component of the DVB-NGH transmission network or population of receivers.

We were convinced that DVB-NGH should offer extended flexibility to address efficiently a forthcoming market (i.e. Mobile Multi Media) which will involve a wide variety of actors / business models themselves involving various topology & cooperation of networks... and it seems the commercial success of DVB-NGH is strongly linked to its ability to satisfy a wide variety of demands.

5 Proposal of a DVB-T2 Future Extension Frame based on 3GPP LTE broadcast mode (E-MBMS) for DVB-NGH

This NGH frame structure was studied and proposed by **Orange Labs/ France Telecom**. It is based on the following rationale: both DVB and 3GPP standardization bodies aim to define new standards for mobile TV broadcast. On DVB side, the DVB-NGH standardization phase is open and ETSI standard is expected to be published in 2011 in order to reach the market in 2013. On 3GPP side, LTE will be launched in the next couple of years, including the so-called E-MBMS, LTE embedded broadcast mode. Both standard organizations target the same timing for devices availability and market launch. Both organizations work tightly with ETSI to deliver successful standards.

So, in order to avoid market fragmentation while enlarging the ecosystem on mobile broadcasting, it is studied here in which extent DVB and 3GPP mobile broadcasting standards could be merged.

5.1 Use cases

Two use cases must be clearly separated here: on the one side the networks and operators use cases, for which networks rolling out and related costs, spectral efficiency and robustness, covered areas and density of users are parameters to take into account while dealing with specific national regulation rules; on the other side the end-user use cases, which is mainly service-driven.

Mobile broadcasting is **a "point to area unidirectional wireless access"** for massively pushed mobile services (continuously or not), with a controlled QoS over a given area, regardless of the number of active end-users. **Broadcast dedicated frequencies** in the UHF-VHF spectrum insure good indoor reception and good coverage performance (i.e. over large or medium-sized cells). An overlay broadcasting mode may allow the optimization of the networks instant loading (e.g. at peak time) and could offer "catch-up" access, by downloading popular contents into the **terminal cache memory** (somehow a hidden network), prior to the user's real-time demand. Mobile operators could complement the broadcast capacities of their own mobile networks, by using a **native optimized broadcast access,** mainly in highly populated areas.

A mix of linear and non-linear services could benefit from this optimized system: live TV or live radio could always be delivered even if this is not a sufficient service to roll out a new network; pre-download of contents (stock market updates, weather/traffic information, music games, e-books ...) before the users would wish to see it could also be a valuable service.

An optimized system, embedding both broadcasters’ and mobile operators’ requirements, and based on 3GPP existing standard for ease of integration in smart phones, could also lead to cooperation in terms of coverage.

5.2 E-MBMS overview

E-MBMS stands for Evolved Multimedia Broadcast and Multicast System and is the broadcast mode of

3GPP LTE.

5.2.1 Spectrum allocations

E-MBMS system is defined for the following bandwidths: 1.4 MHz, 3 MHz, 5MHz, 10MHz, 15MHz and 20MHz, which covers 15 & 20MHZ cases as required by DVB-NGH commercial requirements.

5.2.2 Duplex modes

Both FDD (Frequency Division Duplex) and TDD (Time Division Duplex) are defined in 3GPP standards; TDD could be preferred in order not to reserve unused UL (uplink) spectrum. As TDD does not define a 100% DL (downlink) mode, this study will focus on FDD physical layer.

5.2.3 Frame structure

In LTE, unicast and broadcast signals can be multiplexed in time in the same frame (shared carrier between both transmission types). It is also possible to use a dedicated carrier for broadcast (even if not defined for all ISO layers in the standard). This case will be presented here as it is more comparable with conventional DVB standards.

Basic time unit in LTE is Ts = 1/(15000*2048) seconds (inverse of maximum sampling frequency Fs = 30.72MHz). A radio frame has a duration Tf = 307200.Ts = 10ms. A radio frame contains 20 slots of length Tslot = 15360.Ts = 0.5ms, numbered from 0 to 19.

Two consecutive slots are parts of a sub-frame: sub-frame i is composed of slot 2i and slot 2i+1.

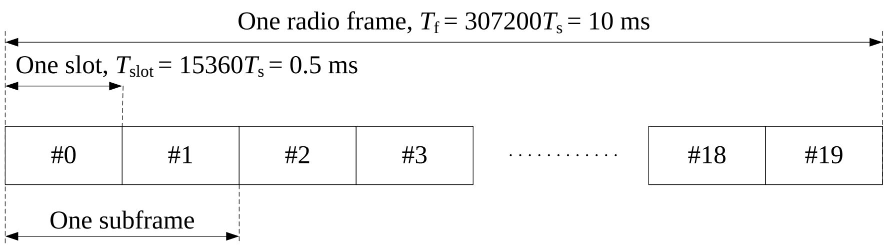

Figure 11: Frame structure.

Sub-carrier spacing is fixed and equal to 15kHz, whatever the bandwidth (value used either in unicast or when multiplexing unicast and broadcast in time); a 7.5kHz spacing is available only for dedicated MBSFN (Multimedia Broadcast Single frequency Network) carriers.

5.2.4 Downlink parameters, resource definition and allocation

Downlink transmission is based on OFDMA (Orthogonal Frequency Division Multiple Access), leading to high flexibility in resource allocation in frequency domain and scalability in bandwidths management.

Several sub-carriers are grouped together to form resource blocks in frequency. The minimum resource size in frequency is equal to 180 KHz (either 12*15kHz or 24*7.5kHz according to sub-carriers spacing).

Several different lengths of the cyclic prefix have been defined in order to compensate the delay spread of the multi-path channel for different environments and cell sizes. The long cyclic prefix (16.67µs) is especially needed for multi-cell transmission in a synchronised network. For large cells and especially for multi-cell transmission (for MBMS service for instance), an alternative parameter set was added allowing for a guard interval up to 33.3µs. Here, the sub-carrier spacing has been reduced to 7.5 kHz in order to keep the overhead to a reasonable level. Note that a longer cyclic prefix increases the overhead and reduces the number of data symbols transmitted within a sub-frame and thus the throughput, if the sub-carrier spacing is kept constant.

Spectrum allocation	1.4MHz	3MHz	5MHz	10MHz	15MHz	20MHz
Sub-frame duration	1ms (= 2 sub-frame of 0.5ms)					
Subcarrier spacing	15kHz (7.5kHz can be used for dedicated MBSFN carriers)					
Sampling Frequency	1.92MHz	3.84MHz	7.68MHz	15.36MHz	23.04MHz	30.72MHz
FFT size	128	256	512	1024	1536	2048
Number of occupied subcarriers	76	181	301	601	901	1201
Number of OFDM symbols per slot versus CP length for normal CP	7 symbols / 4.69us for symbols 1 to 6 and 5.21us for symbol 0					
Number of OFDM symbols per slot versus CP length for extended CP	6 symbols / 16.67us (3 symbols / 33.3us extended CP for 7.5kHz spacing)					
Physical Resource Block	180kHz = 12 subcarriers (24 subcarriers for 7.5kHz spacing)					
Typical VRB size (depending on amount of control signals)	14 OFDM symbols x 12 sub-carriers = 168 symbols Typical overhead: 3x12 symbols of control + 12 add. reference symbols Total number of payload symbols for normal CP: 120					
Number of available physical resource blocks for transmission	6	15	25	50	75	100

The transmitted signal in each slot is described by a resource grid of sub-carriers and OFDM symbols. A subcarrier and an OFDM symbol constitute a Resource Element. So for frame structure type 1 (FDD), a physical resource block is constituted of 12x7 resource elements The resource grid is illustrated in Figure 12 in the FDD case.

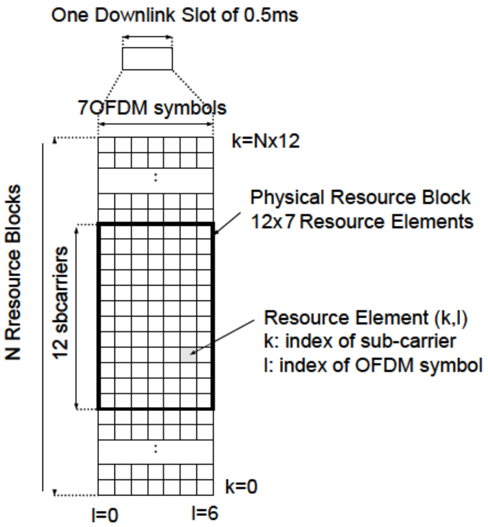

Figure 12: DL resource grid FDD frame structure and normal CP.

5.2.5 Channel coding

UMTS Rel6 Turbo Codes are used for channel coding with a mother code rate of 1/3. A new contention-free internal interleaver (quadratic permutation polynomial or QPP) was specified in order to allow parallel processing and higher throughputs. Typical code rates may range from 1/3 to 8/9 and are obtained using rate matching; for very low rates, repetition coding can also be applied. Trellis termination is used for the turbo coding. Before the turbo coding, transport blocks are segmented into byte aligned segments with a maximum information block size of 6144 bits. Error detection is supported by the use of 24 bit CRC (Cyclic redundancy Check).

5.2.6 Constellations

Data can be modulated using QPSK, 16QAM or 64QAM constellations.

5.2.7 Synchronisation, sounding and signalling

Mapping of reference signals (used for channel estimation for instance) are depicted in the two following figures.

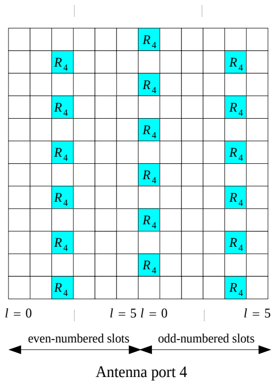

Figure 13: Mapping of MBSFN reference signals (extended cyclic prefix $\Delta f = 15\,\mathrm{kHz}$).

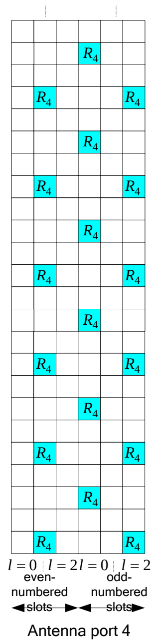

Figure 14: Mapping of MBSFN reference signals (extended cyclic prefix $\Delta f = 7.5\,\mathrm{kHz}$).

Synchronisation process in a LTE network is called cell search. This consists of a series of synchronization stages by which the receiver determines time and frequency parameters that are necessary to demodulate the downlink and to transmit uplink signals with the correct timing. The receiver also acquires some critical system parameters. Cell search is based on DL cell specific signals: the Primary and Secondary Synchronization CHannels (P-SCH and S-SCH), and the Downlink Reference Signals (see previous subsection). The P-SCH and the S-SCH used in any cell are two sequences that belong to a set of sequences known by both the transmitter and the receiver. The receiver detects the pair of P-SCH and S-SCH sequences in use in the cell by trying several hypotheses among all the possibilities and by performing correlation products between the received signal and candidate sequences: i.e. the receiver performs a search of the actual sequences in use among all the possibilities. The P-SCH and the S-SCH use a fixed transmission bandwidth corresponding to 72 sub-carriers independent of the system bandwidth, which may not be known during the cell search procedure, and are sent every 5ms, on the last and second last OFDM symbols of the slot, as shown in Figure 15 below. The P-SCH is utilized for timing detection, frequency offset estimation and channel estimation for coherent detection of the S-SCH index.

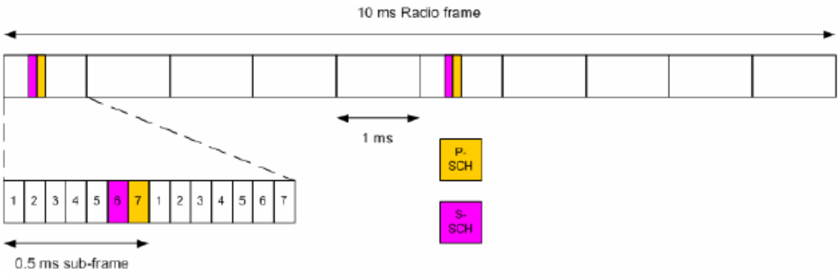

Figure 15: P-SCH and S-SCH.

This initial synchronisation procedure also gives information on cyclic prefix length and mode used (FDD or TDD). Primary Synchronisation Sequence is based on Zadoff-Chu sequences.

The following figure gives a summary of the mapping of logical channels on transport and then physical channels.

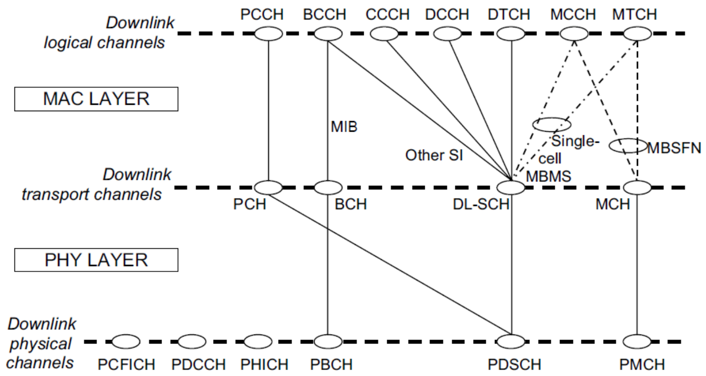

Figure 16: Summary of downlink physical channels and mapping to higher layers.

After synchronisation, a receiver decodes the data embedded in Physical Broadcast Channel (BCH). This channel carries MIB (Master Information Block), parameters required for initial access to the cell, and SIB (other System Information Blocks). MIB contains transmission bandwidth configuration (N_{RB} in downlink) while SIB gives information on MBMS frame allocation. Once BCH is decoded, there is still control information coming from MCCH (Multicast Control Channel), mapped on MCH (Multicast CHannel) transport channel (in MBSFN mode). MCCH gives information about mapping and coding rate used for transmission. Data can then be decoded thanks to all these information; data from MTCH (Multicast Traffic Channel) are mapped also to MCH in MBSFN.

5.3 Performance overview and comparison with DVB systems

5.3.1 Coverage

In a typical mobile DVB configuration, following parameters could be selected: GI = 1/8; FFT=8K in an 8MHz bandwidth. In such a case the typical coverage radius can reach 33.6kms.

With e-MBMS and maximum GI equal to 33.3us, maximum radius is “only” 10kms (typical: 5kms).

This significant difference can be explained by the different origins of both systems (small cells in 3GPP case).

5.3.2 Time interleaving

Maximum interleaving depth in DVB-T2 reaches 250ms while in E-MBMS case it is only 1ms. Latency constraint of unicast mode is clearly a limit for time interleaving here.

5.3.3 Doppler resistance

Sub-carrier spacing is clearly higher in 3GPP case (typically 15kHz versus 1.116kHz in DVB case); then it leads to a greater resistance to Doppler for DVB system (3kHz for 3GPP system versus about 220Hz for DVB).

5.3.4 Channel estimation limits

Nyquist limits in terms of Doppler and SFN can be defined with the following equations:

$$D_{Nyquist} = \frac{0.8 * F_s}{2 * (FFT * (1 + CP) * X)} \text{ and } T_{Nyquist} = 0.8 * \frac{FFT}{F_s} \frac{X}{Y}$$

Where:

- Fs: sampling frequency
- FFT: FFT size
- CP: CP value
- X: spacing between 2 pilot tones in time direction
- Y: spacing between 2 pilot tones in frequency direction

Comparison between DVB and 3GPP systems then gives following results:

BW=5MHz	**DVB-NGH (PP2)**	**E-MBMS (15kHz case)**
F_s (MHz)	5.71	7.68
FFT	8192	512
CP	1/8 (~180us)	¼ (16.67us)
Y	12	2
X	2	8
$D_{Nyquist}$ (Hz)	124	600
$T_{Nyquist}$ (us)	191	213

For the DVB case, pilot patterns are optimized in terms of SFN and delay spread but lead to quite "low" resistance to Doppler; for 3GPP case pilot pattern is over dimensioned (at least in frequency) and then density could be decreased.

5.3.5 Throughput

For this throughput comparison, the following configurations have been assumed (as many common parameters as possible even if scenarios are not realistic for network roll out):

BW=10 MHz	DVB-NGH	E-MBMS
Fs (MHz)	11.42	15.36
FFT	1K	1K
CP	1/4 (22.4us)	1/4 (16.67us)
Tu	89.6us	66.67us
MCS	QPSK 1/2	QPSK 1/2

In DVB case with PP1, 16 P2 symbols, a frame closing symbol, frame duration reaches 99.904ms (L_{data} = 874). Assuming 16K codewords, 83 LDPC blocks can be mapped on the frame, leading to a throughput of **5.57Mbps**. In a more realistic situation for DVB (8K, GI = 1/8, BW = 8MHz, PP2, frame size still ~100ms), throughput is slightly more than 5Mbps.

In 3GPP case, assuming an overhead of about 30%, throughput can be estimated to 4.8Mbps (5.49Mbps if only 20% overhead is considered).

Reachable throughputs are then comparable, even if the required signal to noise ratio is different due to far different time interleaver depths.

5.4 E-MBMS embedded in DVB-T2 FEF

5.4.1 Bandwidths

E-MBMS is not defined in usual DVB bandwidths 6, 7 and 8MHz. In order to cover these cases in an easy way, it is possible to start from 10MHz case, while modulating fewer carriers than in the original 10MHz case. The following figures can be derived:

FFT	1024						
BW (MHz)	Fe (MHz)	Symbols per Slots (Ext CP)	ExtCP (us)	Tsymb (us) Nfft/Fe	Delta_f (kHz)	Modulated sub-carriers	Transmission BW (MHz)
10	15.36	6	16.67	66.67	15	600	9
8	15.36	6	16.67	66.67	15	480	7.2
7	15.36	6	16.67	66.67	15	420	6.3
6	15.36	6	16.67	66.67	15	360	5.4

5.4.2 Frame size

An LTE radio frame has duration of 10 ms. DVB-T2 Future Extension Frame, likely to embed DVB-NGH standard, can have duration up to 250 ms. So it is possible to include multiple E-MBMS frame in a DVB-T2 FEF.

6 PROPOSAL OF A NGH SATELLITE SUPER FRAME STRUCTURE

Based on the DVB-T2 structure, **CNES** studied and proposed an architecture based on a flexible position of NGH frames in the Super Frame to address terrestrial mixed T2/NGH transmission and NGH-only (or standalone) transmission. This super frame structure is compatible with both terrestrial and satellite requirements.

6.1 Future extension frame for the satellite component

First of all, satellite will not transmit DVB-T2 frames because they may not be used (because of either potential interference of the terrestrial network caused by a small guard interval or of degradation of satellite transmission spectral efficiency if T2 frames are not transmitted on the satellite).

Satellite will transmit only “future extension frames” or FEF. So we need to define a configuration of the FEF in order that they could be self-sufficient, allowing the transmission of FEF without DVB-T2 frames.

6.2 DVB-T2 Super Frame structure

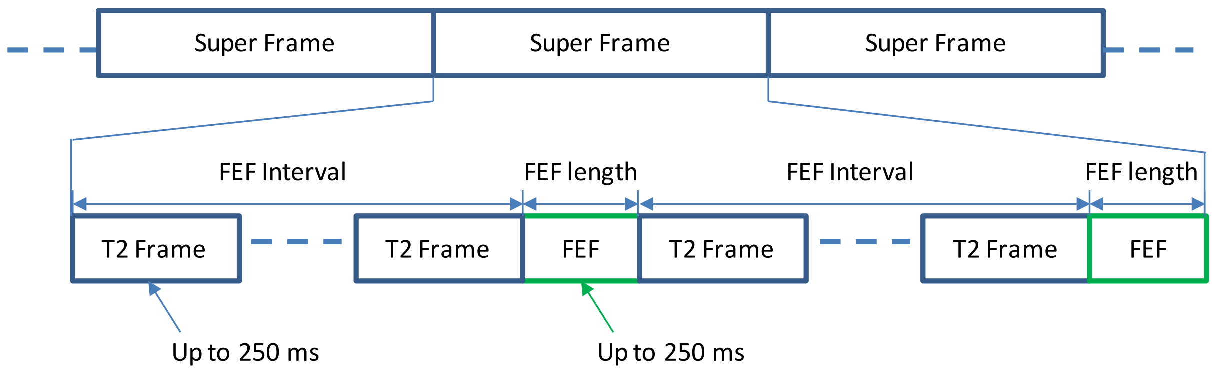

Figure 17: DVB-T2 Super Frame structure

DVB-T2 Super Frame structure is depicted in Figure 17.

The DVB-T2 Super Frame is composed of N_{T2} T2 frames and optionally N_{FEF} FEF, with N_{FEF} a divisor of NT2. T2 frames and FEF last each 250ms maximum. When present, FEF are “equidistributed” in the Super Frame and as there is less FEF than T2 frames, there is so never two consecutive FEF. Thus 2 T2 frames are at worst separate from 250ms. Besides, a mixed Super Frame always begins with a T2 frame and finishes with a FEF.

The DVB-T2 frame structure was used as starting point to build the proposal for NGH Super Frame structure.

6.3 Description of the proposed NGH Super Frame structure

The proposed NGH Super Frame structure is based on 3 criteria:

- one NGH frame lasts 250 ms maximum,
- the delay between two consecutive NGH frames is constant over one Super Frame and lasts 250ms maximum,
- the positions of NGH frames in the Super Frame are flexible.

First criterion guarantees that NGH frames may be included inside a FEF[1]. The goal of the second criterion is to limit zapping time (the longer the delay between two useful frames, the longer can be the zapping time). Finally, the third criterion allows addressing both terrestrial and satellite paths with a same Super Frame structure.

The proposed solution introduced the concept of segment which is the key element to enable terrestrial and hybrid scenario and to ensure the compatibility between DVB-T2 and NGH Super Frame structure. As depicted on Figure 18, the proposed Super Frame is composed of N_{NGH} segments that all have the same length and contain each one NGH frame. Position of the NGH Frame inside the segment is free but constant over all segment of the Super Frame. As a NGH frame lasts 250 ms and is separated from the next NGH frame from 250 ms at worst, a NGH segment lasts so 500 ms maximum. Apart from a maximum duration of 25 0ms, there is no constraint on the signal between two NGH frames (when present).

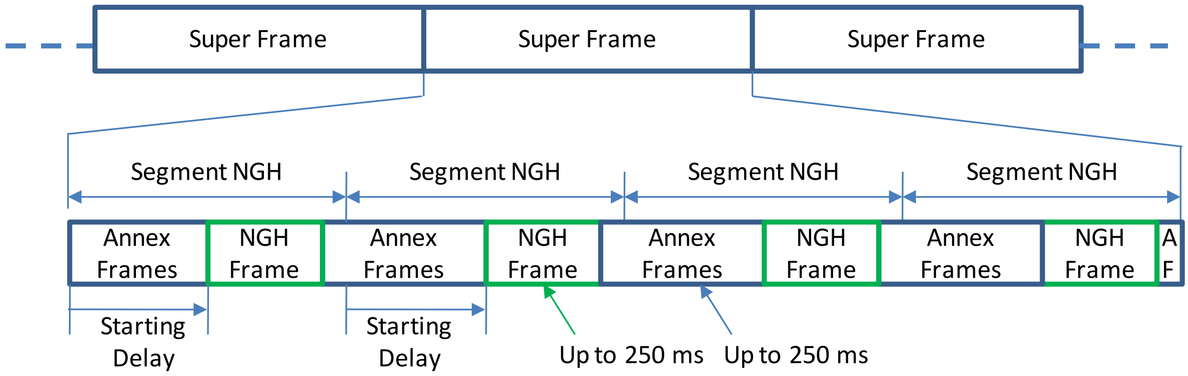

Figure 18 : proposed NGH Super Frame structure

In order to determine the positions of NGH frames, signalling should include the number N_{NGH} of NGH frames (equal to the number of segment), the length of a segment (or in an equivalent way, the delay between two NGH Frames) and the position (starting delay) of NGH frames in the segment.

The signal between two consecutives NGH frames (when present) is depicted as “annex frame” in Figure 18. These annex frames may have different definitions depending whether the NGH super frame structure is used for satellite or terrestrial transmission.

6.4 Mixed T2/NGH terrestrial Super Frame

Figure 19 depicts the super frame structure for a mixed T2/NGH transmission. One segment is composed of a T2 frame (or more if the total T2 part represents less than 250 ms) and a NGH frame. Due to the DVB-T2 Super Frame structure, NGH frames are necessarily inserted at the end of each segment.

[1] We consider here that NGH frames are introduced by a P1 preamble

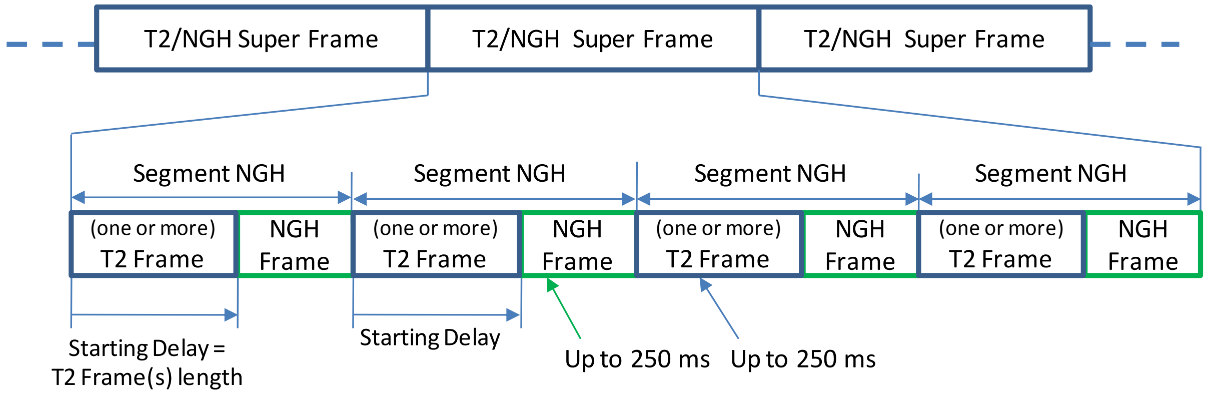

Figure 19: Mixed T2/NGH Super Frame

This example shows that T2 Frames insertion is considered by the proposed Super Frame structure but the solution is not restricted to mixed terrestrial transmission and we may consider a stand-alone NGH transmission.

6.5 NGH satellite Super Frame

Figure 20 depicts an NGH satellite Super Frame associated to a terrestrial T2/NGH Super Frame. On the satellite path, no T2 transmission is assured and all transmission time is allocated to NGH. In order to obtain the equivalence between both satellite and terrestrial Super Frame structures, we propose to enlarge the maximum Satellite NGH frame length to 500 ms. Besides, obtaining the same segment length on both paths may require some padding insertion at the end of each satellite segment. Consequently, the annex frame is reduced to these stuffing samples between two NGH frames.

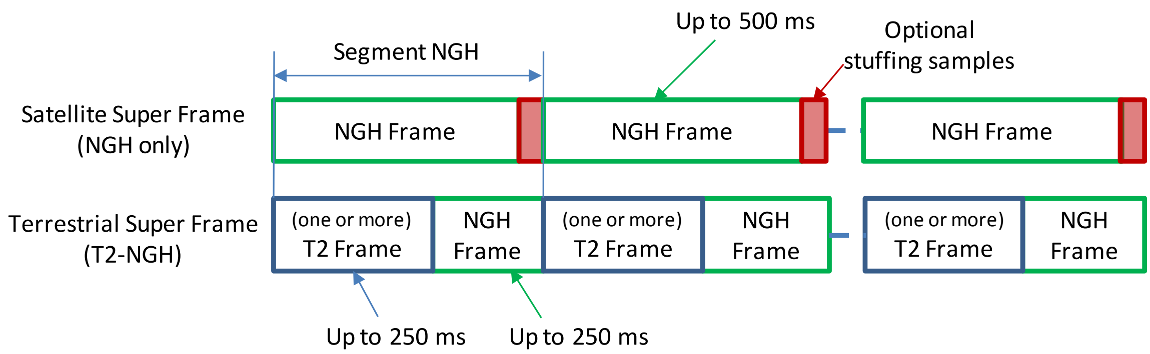

Figure 20: Terrestrial and satellite Super Frame for hybrid MFN transmission

Thus, the proposed Super Frame structure and the three associated signalling elements allow defining both satellite and terrestrial paths of a hybrid transmission. Here again, we may also consider a hybrid transmission that does not include T2 Frames.

6.6 Super Frame modification management

As described before, NGH segment parameters are fixed during the total duration of the Super Frame. We have however to consider the case of a modification of the configuration from one Super Frame to another and make sure that the NGH frame positions will always be known.

If NGH frames are inserted at the beginning of each segment, the determination of the position of the first NGH frame of the Super Frame N+1 requires only parameters of the Super Frame N as illustrated in Figure 21.

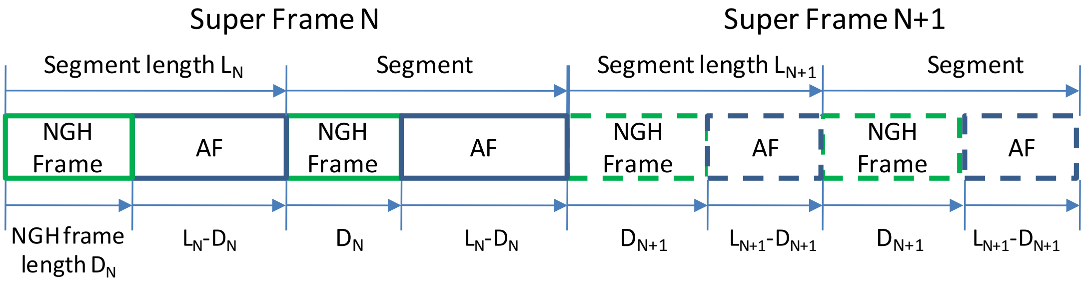

Figure 21: Super Frame modification, example 1

If NGH frames are not placed at the beginning of each segment, parameters of the Super Frame N are not sufficient to detect the position of the first NGH frame of the Super Frame N+1 (Figure 22). Thus, signalling of Super Frame N must also include parameters of Super Frame N+1.

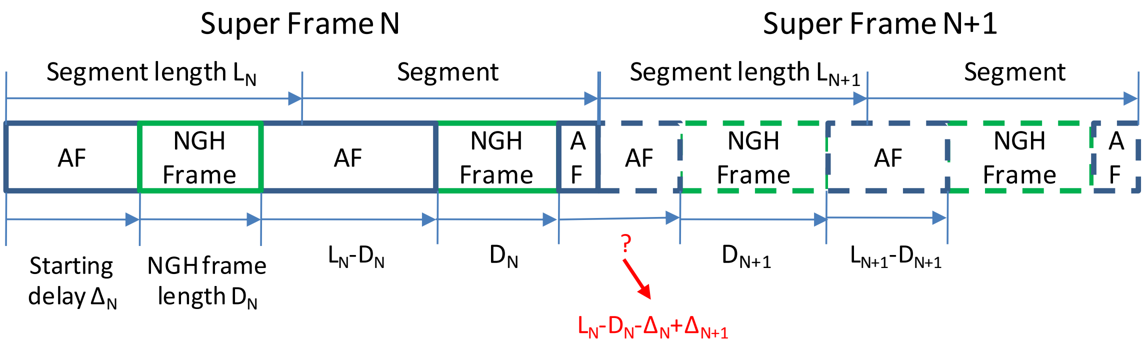

Figure 22: Super Frame modification, example 2

Consequently, in example 2, the signalling has to be aligned with the NGH Super Frame structure to enable the configuration changes in the Super Frame. New fields have to be defined to give information on the next frame (*i. e.* next frame start delay and next annex frame length). These additional signalling fields for the next frame are not required in example 1 when the NGH frames are located at the beginning or the end of the segment.

6.7 Conclusion

The solution proposed by CNES, based on DVB-T2 Super Frame, allows transmitting NGH frames and other signals (like DVB-T2 frames) inside a same Super Frame. More flexibility is offered for the position of NGH frames to address different kind of Super Frame sharing. In a DVB-T2/NGH Super Frame, NGH frames would always be transmitted after T2 Frames. In a stand-alone NGH frame, NGH frames will initiate the Super Frame. To facilitate NGH frames position management, the concept of NGH segment was introduced and specific signalling parameters were proposed.

7 NGH Hybrid network architectures

This section is dedicated to the description of hybrid satellite-terrestrial network scenarios considering DVB-NGH. The DVB-T2 and DVB-NGH standards are indeed specific as they allow time multiplex of frames with different formats. In a first part, we will so evaluate what frame structure we can envisage for hybrid networks in this context. In a second part, we will briefly describe the mechanisms of SFN and MFN hybrid network and their constraints.

7.1 Hybrid network frame structure

Reminder on the T2/NGH frame structure

The DVB-T2 standard [3] has been defined with keeping in mind that the transmission channel maybe shared with other signals dedicated to others services. Thus, the DVB-T2 Super Frame is constituted of T2 Frames but may also integrated FEFs (Future Extension Frame) for the transport of these other signals, as depicted in Figure 23 below. In other terms, T2 Frames and FEFs are multiplexed in time inside a Super Frame.

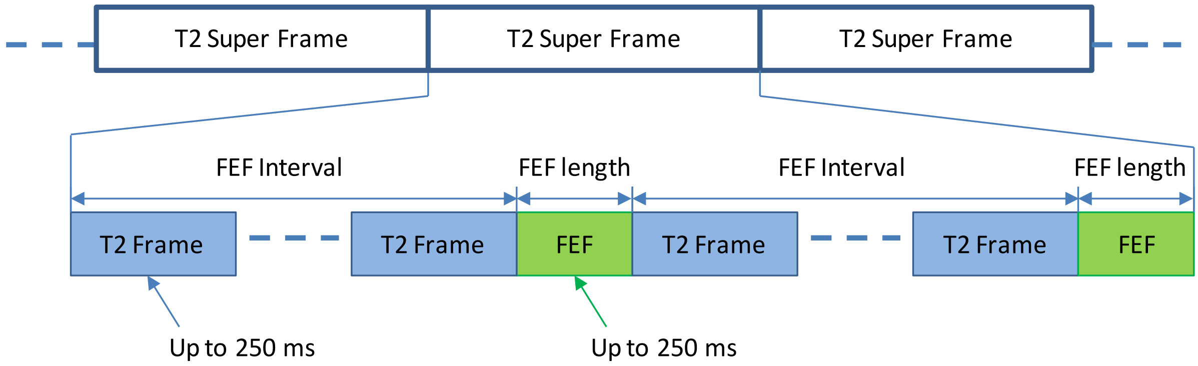

Figure 23: Super Frame structure in DVB-T2.

The concept of FEF offers a real opportunity to launch DVB-NGH services through a DVB-T2 network. We can easily construct a mixed T2/NGH Super Frame constituting of a multiplex of T2 Frames and NGH Frames (See Figure 24). NGH Frames may also be transmitted without T2 signal inside a stand-alone NGH Super Frame that may eventually contain other FEFs dedicated to other services (See Figure 24).
The transmission of DVB-NGH frames into FEF can reduce the cost for the first deployment of the Mobile TV service, thanks to the use of the TV fixed service network to transmit Mobile TV service on the same frequency channels.

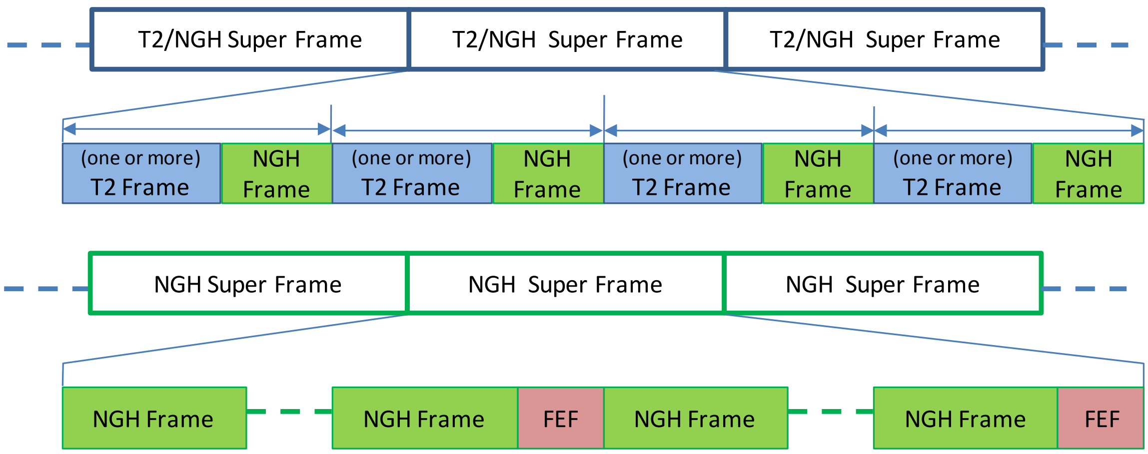

Figure 24: Possible Super Frame structure considering DVB-NGH signal.

Possible frame combinations for Hybrid Network

If TV Mobile service is deployed through TV fixed facilities, TV Mobile Service will use first UHF bands; most probably on a cautious basis with only part of a channel used for mobile services. If TV mobile network operators intend to extend their deployment to support a mass market offer and to ensure a global coverage, TV mobile network operators will make use of hybrid integrated networks (associating satellite and terrestrial transmitters). The satellite component can use S Bands and terrestrial component S or UHF bands.

Thanks to the FEF concept, NGH Frames may be transmitted alone or multiplexed with a T2 signal. This assumption leads us to 5 hybrid frame structures presented in Figure 25. The three first scenarios consider the same signal on the satellite and the terrestrial path and are so mainly dedicated to SFN network if terrestrial and satellite component are in S band. The two last consider different signals on each path and are so exclusively dedicated to MFN networks.

In Scenario 1, both the satellite and the terrestrial path transmit T2 and NGH Frames. If it is interesting to multiplex T2 and NGH in the terrestrial part to limit the cost of the NGH deployment, it seems to be non useful transmitting the T2 signal on the satellite path. No performance benefit can effectively be obtained by transmitting T2 on the satellite (amplification of very high modulation is complex on satellite). Moreover, this SFN scenario would induce a transmission on the S band to be applicable to both path and DVB-T2 has not been defined for these frequencies. This scenario can so not be considered for a real integration.

In Scenario 2, to avoid the transmission of the T2 signal on the satellite, the signal is turned off during T2 signal time. During NGH time, both components are emitting. This scenario is also very unlikely as it is very difficult to manage the switch off and on of the satellite and it will induce a suboptimal use of the satellite component.

Scenario 3 seems so to be the only scenario applicable to SFN network. Both components transmit only NGH signal. Signals transmitted on both paths must here be strictly the same.

Scenario 4 considers only NGH on the satellite whereas the terrestrial component contains T2 and NGH frames. This scenario seems to be really interesting for a hybrid MFN network. On the terrestrial path the NGH signal is transmitted with a T2 signal to reduce deployment cost. On the satellite the NGH is transmitted alone and may then benefit from more robustness.

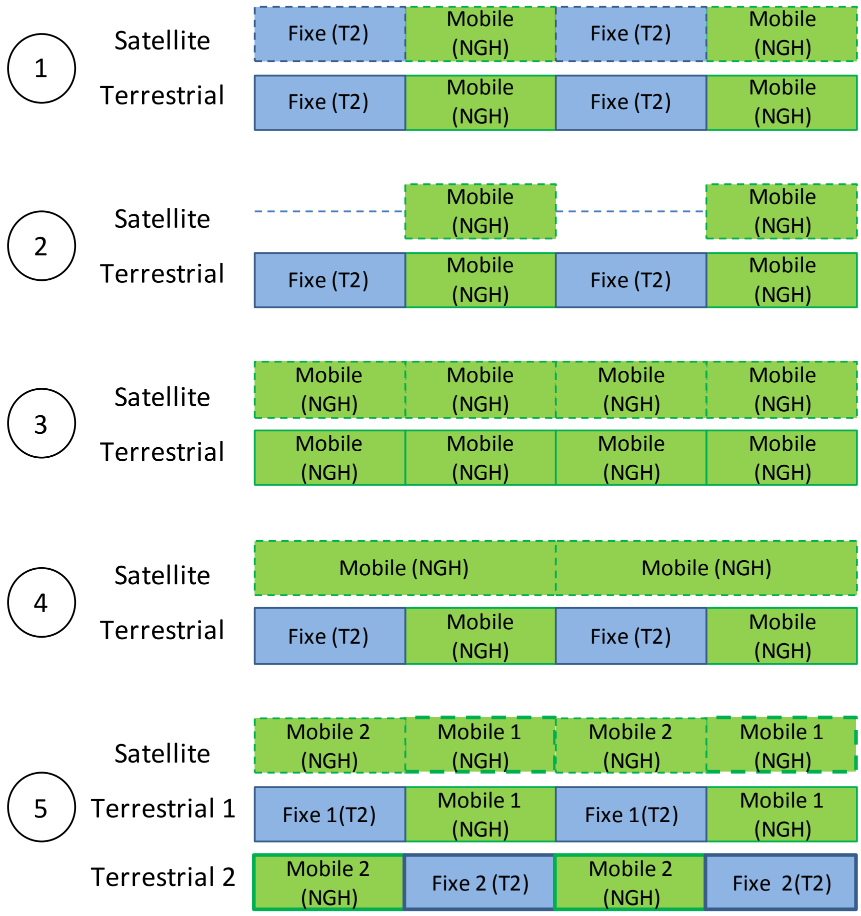

Figure 25: Possible Frame structures for a DVB-NGH Hybrid network.

Finally, as the T2 signal has not to be transmitted by the satellite, the satellite may have the possibility to transmit multiple NGH services that may correspond to different terrestrial transmission. Scenario 5 presents so a case where the satellite component contains NGH frames from two different terrestrial components.

The second generation of DVB standard has introduced the concept of Physical Layer Pipe (PLP) that allows transmitting multiple streams with different robustness inside a unique frame. One frame may transport multiple independent PLP relative to different services. There are thus two ways to define Scenario 5 (See Figure 26). We can either define one satellite frame for each terrestrial component, as depicted in Scenario 5a; or we can also define a unique satellite frame that may transports data corresponding to the different terrestrial component inside different PLP, as depicted in Scenario 5b.

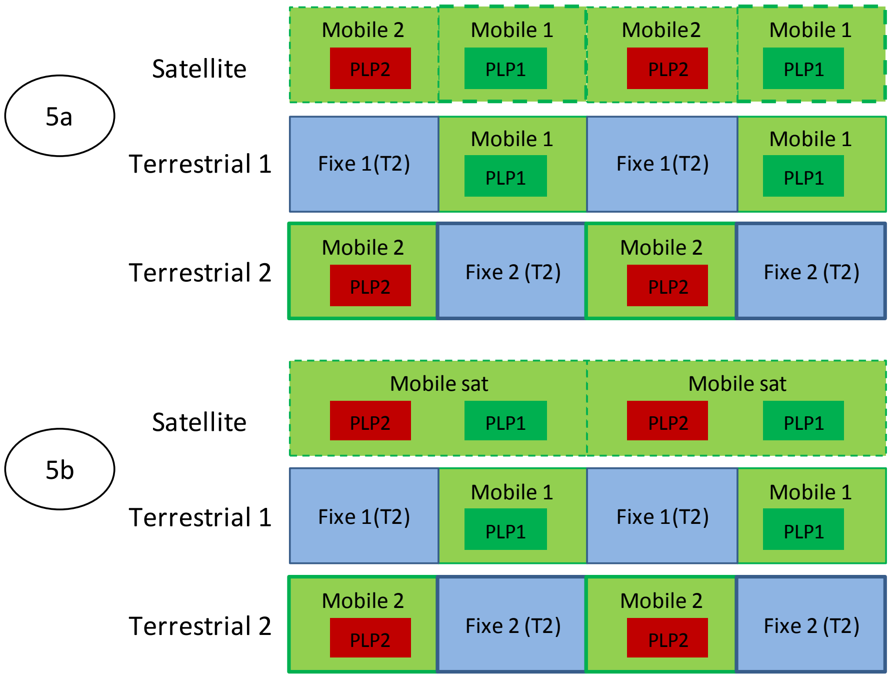

Figure 26: Solutions to multiplex two streams inside a unique Satellite path.

In order to allow the good working of the 3 cases (3, 4 and 5), the following improvements are necessary:

- To introduce DVB-NGH frames, using DVB-SH functionalities helpful for satellite transmission, into DVB-T2 frames through « Future extension Frames » defined in the DVB-T2 standard:
  A great work was done in the DVB-SH to define functionalities allowing satellite transmission, as:
  - ⇨ Extended interleaver in order to compensate fading of satellite transmission channel,
  - ⇨ Synchronization mechanism allowing the combining of terrestrial (OFDM) and satellite (OFDM or TDM) signals in order to benefit from hybrid SFN gain or from MFN combining gain.

- To define a configuration of the « Future extension Frames » in order that they could be self-sufficient:
  DVB-T2 standard allows transmission in UHF and L bands and the ITU regulation allows Satellite transmission in S band.
  If the configuration « Future extension Frames » transmitted between DVB-T2 frames is adopted, satellite will not transmit DVB-T2 frames and it will transmit only « Future extension Frames ».

- To allow a time multiplexing of the « Future extension Frames » :
  To enhance the integration of the satellite component into a Mobile/fixed integrated terrestrial network, a same frame length will be required between terrestrial and satellite frames. Since the terrestrial component may transmit T2 frames between FEF frames, contrary to the satellite component, time multiplexing of different NGH frames on the satellite component would avoid time gaps in the usage of the satellite frequency and therefore maximise satellite transmission spectral efficiency.

7.2 Hybrid SFN network

SFN network principle

In a SFN network, all modulators transmit the same signal at the same frequency on the same time. When considering hybrid SFN, we must so have the same signal on the satellite and on the terrestrial components.

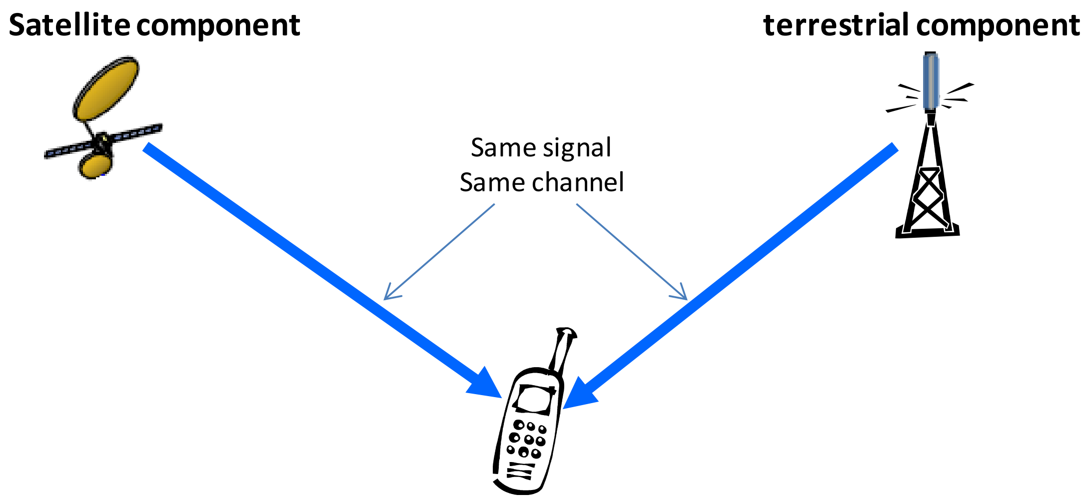

Figure 27 : Hybrid SFN network Principle.

Streams Combining and Handover

As the signals are transmitted on the same channel, the demodulator receives only one signal that corresponds to the sum of the two transmitted signals. The combining between the two components is so performed “over the air”. The receiver will then have only one signal to demodulate and contains so one demodulation chain. In a SISO SFN, the receiver is unable to distinguish which signal comes from which component and may successfully demodulate the signal when receiving only the terrestrial component or the satellite component or both. Due to the fact that both components transmit the same information, no reception failure will append during a handover.

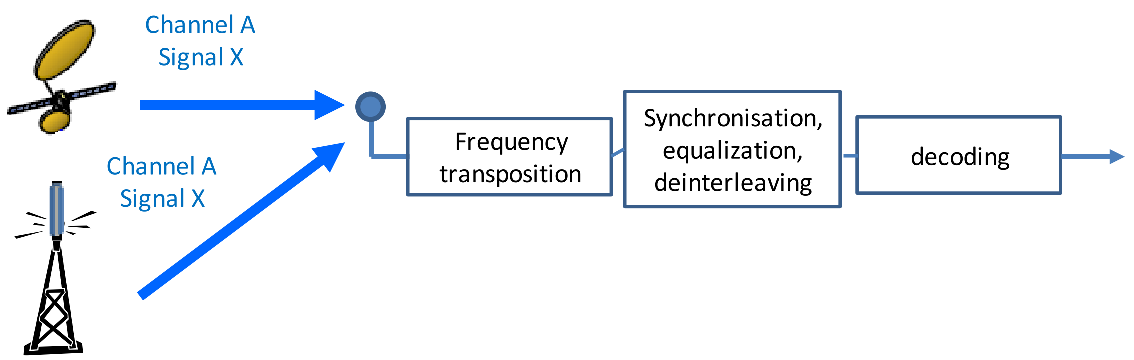

Figure 28: Hybrid SFN network reception process.

Synchronization issues

As they transmit the same signal at the exact same time, transmitter inside a SFN network have some synchronization constraints recalled below:

- All transmitters must be synchronized in frequency. For example, according to DVB-SH hybrid network implementation guidelines, each transmitter should broadcast modulated carriers with an accuracy of $\Delta f/1000$ with Δf the inter-carrier space;
- All transmitters must be synchronized in time. Here again, according to DVB-SH hybrid network implementation guidelines, the maximum delay between two transmitters should be of 10% of the guard interval.

To manage these different constraints, an absolute time reference like the GPS must be given to all transmitters. Besides, each transmitter must know exactly when starting to modulate each Frame thanks to a ”top” signal broadcasted to all transmitters.

Synchronization of a hybrid SFN network imposes also more constraints due to the position and the movement of the satellite. As the satellite covers a large area, it will be associated with multiple terrestrial transmitters. Due the position of the satellite, the transmission time of the satellite signal to reach each terrestrial transmitter may differ and each terrestrial transmitter must so be synchronized individually with the satellite. Moreover, the position of the satellite will vary in time and the transmission time of the satellite signal will also vary. Thus the synchronization of all terrestrial transmitters must be corrected with the movement of the satellite.

Compatible Frame structures

As seen in the previous section, hybrid SFN transmission seems not to be efficient with a signal containing both T2 and NGH services but only if NGH frames are transmitted on both components. This kind of scenario can so be seen as a second phase of deployment of NGH services (the first phase would consist in deployment of NGH on the T2 network).

Concerning the waveform, the terrestrial component in DVB-NGH standard must be constructed with OFDM. Consequently an SFN network will inevitably be performed with OFDM. More precisely, the satellite must transmit exactly the same frame than terrestrial component (same time interleaver, same constellation order…).

Besides, DVB-T2 has introduced the possibility to perform transmission in MISO based on the Alamouti code. This MISO scheme that allows benefiting from the channel diversity of two distinct components may be very interesting in a hybrid SFN network. We can effectively associate one MISO antenna to all terrestrial transmitters and the other MISO antenna to the satellite. As the satellite and the terrestrial channel are particularly different, we may certainly benefit from channel diversity.

7.3 Hybrid MFN network

MFN network principle

In an MFN network, the different components emit signal at different frequencies. As there is no interaction between the signals “over the air”, each component may transmit a different signal. We may then optimize the signal format independently on the satellite and the terrestrial component.

According to the structure of the network and the configuration of each signal, the receiver may combine the received signals or only select one of them to demodulate. Three configurations of MFN hybrid network will be discussed here.

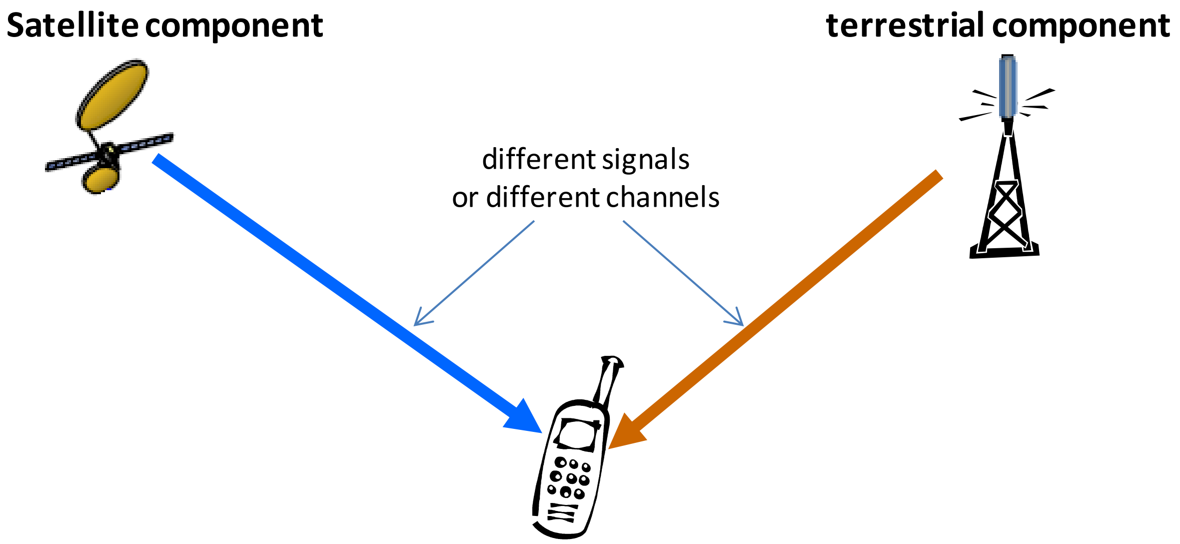

Figure 29: Hybrid MFN network principle.

Hybrid MFN network A: Code combining

In this first configuration, the receiver recovers two different signals from the satellite and the terrestrial transmitter. Synchronization, equalization and de-interleaving are processed independently on each received stream. To benefit from the diversity, estimated bits (or QAM symbols) are then combined before channel decoding.

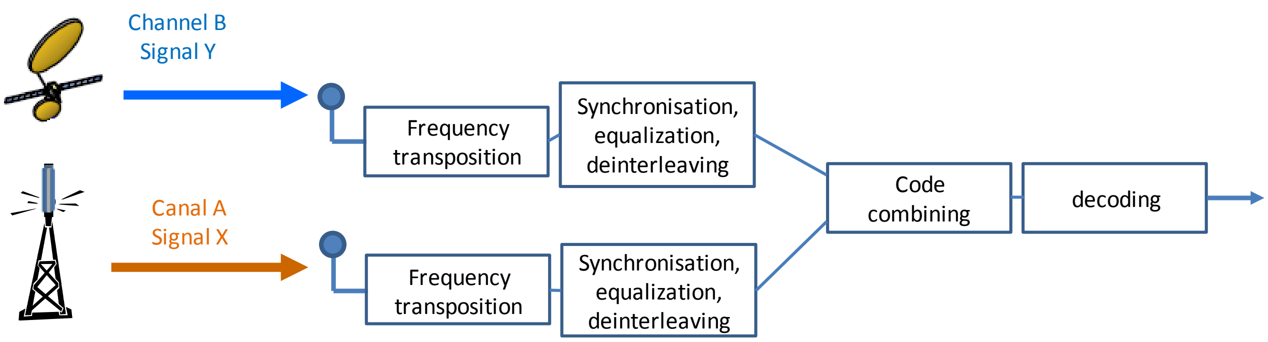

Figure 30: Hybrid MFN network A, reception process.

Code combining represents an efficient way to combine two streams from a hybrid network. As the combining is performed on estimated coded bits, only the channel coding has to be defined conjointly between the satellite and the terrestrial components. Each stream may then have its own waveform, pilot pattern, interleaving, and constellation and may so be optimized relatively to its own constraints of transmission. Thus, even if these parameters are unavailable for the terrestrial component, the satellite component may consider an OFDM, SC-OFDM or TDM waveform, a long time interleaving and potentially a constellation of a lower order.

Concerning channel coding, the configuration is more sensitive. As there is a combining before the decoding, coded packets from both paths must be “compatible”. If the same code with the same code rate is used on both paths, combining will be possible without difficulties. However, if code rates are different, LDPC codes considered in DVB-T2 and potentially DVB-NGH does not allow the combining at the LLR level. With these LDPC codes, the only way to allow code combining with different code rate is to consider incremental redundancy on the path with the smaller code rate. In that case, the two coded packets will be based on the same codeword and combining will be obvious. Thus, to consider code combining in DVB-NGH, it will be necessary either to impose the same code rate (and code size) on the satellite and the terrestrial path, either to introduce new codes with incremental redundancy.

Concerning the synchronization, the constraints are largely lighter than for SFN network. Each component is synchronized independently by the receiver and no frequency synchronization has so to be performed between the two paths. Thanks to the independent synchronization of the two paths, the time synchronization is also largely relaxed. The two streams need however to be synchronized to allow the combining in front of the channel decoder. This time synchronization will have to take into account differences between the two streams that may induce difference in the reception process time (longer interleaver, waveform with larger FFT size). For example, a satellite path with a large time interleaving will so be transmitted slightly before the terrestrial path to be sure that the two streams will be synchronized after their own de-interleaving in the receiver.

Hybrid MFN network B: packet selection

As seen in the previous paragraph, LDPC coding configuration may make complex code combining. Another way to benefit from a combining of the two streams is to combine data after channel decoding as depicted in the following figure. In that case, according to the receiver, a combining or a selection may be realized on the decoded packets. If soft decision is available, combining may be performed before deciding on the value of each bit of the packet. If only hard decision is available, a selection (based on a CRC) may be performed on each packet between the two paths to decrease the packet error rate of the received information.

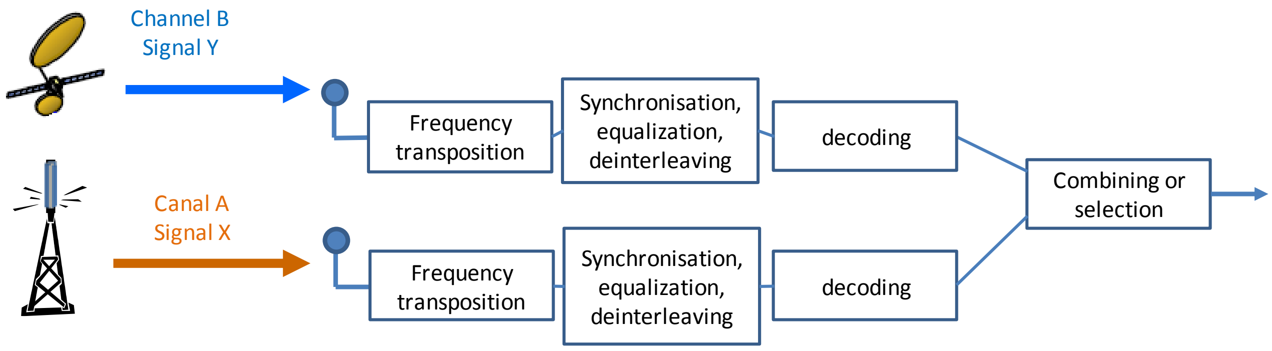

Figure 31: Hybrid MFN network B, reception process.

This solution is less efficient than the previous one as the combining after decoding gives worse results. Besides, this solution imposes to integrate two channel decoders in the receiver. There is however here more flexibility regarding the channel coding configuration of each stream.
Concerning synchronization, the constraints are equivalent to those of previous MFN configuration.

Hybrid MFN network C: received stream selection

In the last configuration, no combining is performed between the two streams. The receiver analyzes the two components individually and demodulates only the better one.

In that case, the two components may be completely different, provided that the receiver is able to demodulate the two waveforms. Moreover, no synchronization in time or frequency is required between the two components as only one is demodulated. This is so a low cost solution for both the transmission part (no synchronization between the satellite and the terrestrial transmitter) and the reception part (as only one reception chain is required).

However this solution does not combine the two streams and provides so worse performance. This is also the only solution that induces necessarily a failure of reception when a handover is required.

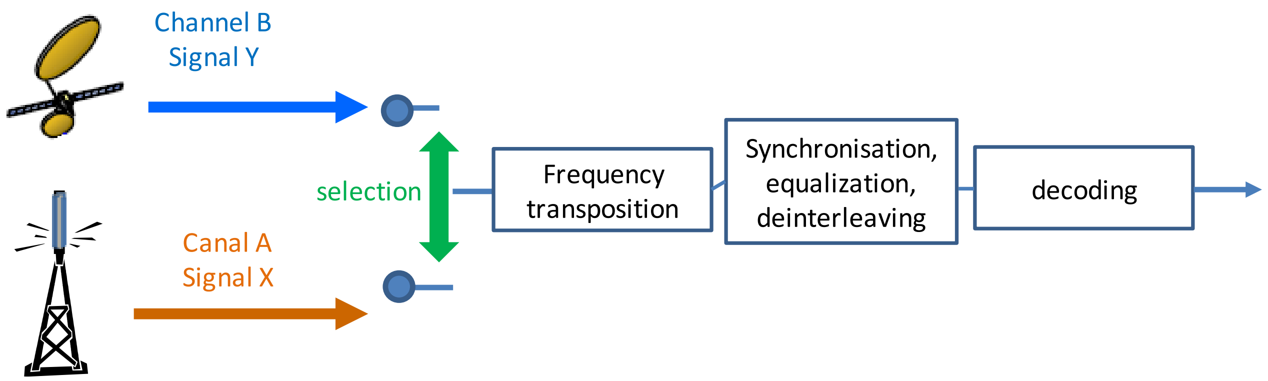

Figure 32: hybrid MFN network C, reception process.

7.4 Hybrid network configurations

Table 2 summarizes the different characteristics of the 4 hybrid network described previously. The SFN network is strongly constrained, whether for the signal waveform or for the synchronization between the transmitters. Concerning the MFN networks, more flexibility is available; however the more the satellite and terrestrial component are independent, the worse the performance are.

Network topology	*SFN*	*MFN A*	*MFN B*	*MFN C*
Frame structure scenario	*3*	*3,4 or 5*	*3,4 or 5*	*3,4 or 5*
Receiver Front-end	*1*	*2*	*2*	*1*
Frequency synchronization	*High accuracy*	*No synchronization required*	*No synchronization required*	*No synchronization required*
Time synchronization	*High accuracy*	*Low accuracy*	*Low accuracy*	*No synchronization required*
Handover	*No reception failure*	*No reception failure*	*No reception failure*	*Reception failure*
Combining	*"channel" combining*	*Code combining*	*Packet selection*	*No combining*
Waveform	*Equivalent to terrestrial (OFDM)*	*Independent (OFDM or SC-OFDM)*	*Independent (OFDM or SC-OFDM)*	*Independent (OFDM or SC-OFDM)*
Interleaving	*Equivalent to terrestrial*	*Independent*	*Independent*	*Independent*
LDPC code	*Equivalent to terrestrial*	*Equivalent to terrestrial or incremental redundancy*	*Independent*	*Independent*

Table 2: Comparison of the hybrid networks.

8 System Architecture Proposals for DVB-NGH Integrating MIMO Schemes

The MIMO transmission can be deployed in several different ways depending on the locations of the transmit antennas. More precisely, in the context of broadcasting, MIMO transmission can be realized by multiple transmit antennas mounted in a single transmitter tower. Several transmitter towers can form a Single Frequency Network (SFN), in which the MIMO transmission can also be applied. Moreover, additional satellite broadcast link(s) can be involved in the transmission network, which forms a hybrid satellite/terrestrial MIMO transmission architecture. Different MIMO system architectures will be presented in detail in the following part of this section.

8.1 Single-tower MIMO Transmission

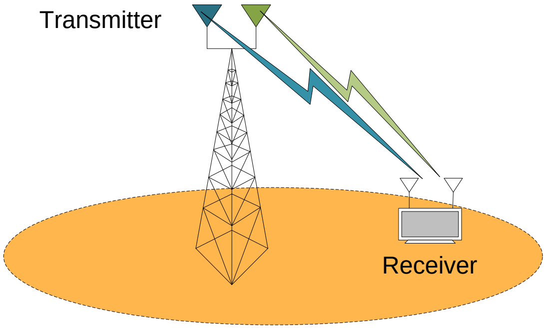

Figure 33 Single-tower MIMO transmission scheme.

In the typical MIMO transmission, as demonstrated in Figure 33, multiple transmit antennas are installed in one transmitter tower. The space-time coded signals are transmitted by the multiple antennas. This scheme can be adopted in the Multi-Frequency Network deployment.

The transmit antennas are commonly cross-polarized in order to de-correlate the channel links to achieve higher MIMO channel capacity. According to the field measurements [4] carried out in Helsinki in the framework of ENGINES project, the cross-polarized pair of antennas can provide sufficient uncorrelated channel links that enables higher transmission throughput using MIMO technique.

8.2 Distributed MISO Transmission

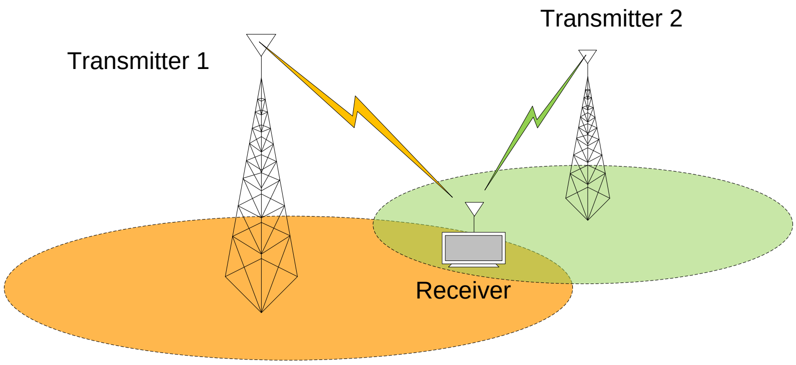

Figure 34 Distributed MISO transmission scheme

In the SFN deployment, several transmitters simultaneously broadcast the same programs in the same frequency bands. The coverage of the broadcast services can be significantly enlarged without the need of more frequency bands. However, there are also some challenges to face in SFN. Traditionally, same signals are transmitted from transmitters situated in different locations. The superposition of signals from different transmitters can lead to severe degradations of signal strength in some spots in the landscape.

The SFN coverage can be improved by introducing distributed MISO transmission. A presentation of the distributed MISO transmission is given in Figure 34. Signal is first space-time coded and then fed to different transmit sites (towers). Space-time coding de-correlates the signals transmitted from different sites and therefore mitigates the signal strength degradation problem in the traditional SFN. In addition, compared to SISO case, MISO transmission lowers the requirement of the minimum signal power to decode the transmitted program. In other words, it improves the coverage of SFN. Another important advantage of the MISO transmission is that it does not require additional transmit antennas and feeds on each transmit site. It means that the implementation of distributed MISO transmission does not need very high hardware update costs. In addition, single antenna is required by the receiver, which helps minimizing the user cost.

A distributed MISO transmission scheme using Alamouti code [5] is specified in the DVB-T2 standard [3]. Although it is initially proposed for two transmit sites case, it can also be used with more sites by dividing them into two groups.

8.3 Two-tower MIMO Transmission

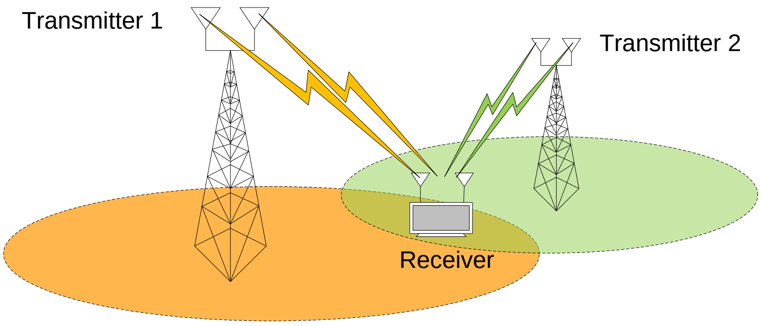

Figure 35 Two-tower MIMO transmission scheme

Another MIMO transmission architecture can be obtained by applying space-time coding on two transmit sites, each of them equipping multiple antennas. This scheme can be viewed as a combination of the previous two schemes. An illustration of this MIMO architecture is shown in Figure 35. Since the transmit antennas are located in geographically separated positions, the different channel links are uncorrelated, which brings inherent transmit diversity. Multiple receive antennas are also adopted at the receiver side to exploit the receive diversity.

8.4 MIMO Architecture including Satellite Link

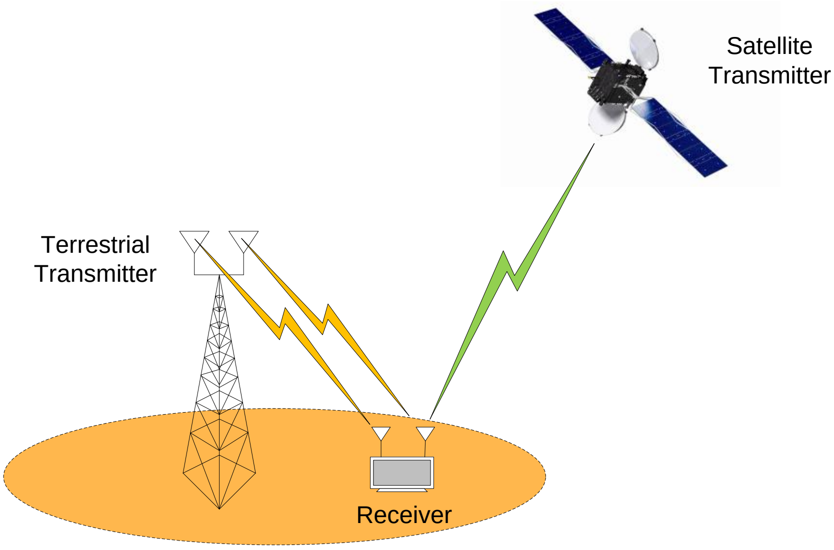

Figure 36 MIMO transmission including Satellite Link

As shown in Figure 36, the hybrid satellite/terrestrial architecture incorporates the infrastructures of both terrestrial and satellite broadcastings. It achieves nationwide satellite coverage. Meanwhile, the terrestrial broadcasting complements the coverage in urban areas where dense buildings and can block traditional satellite signal. Therefore, it can effectively deliver broadcasting services in a large area.

The use of both satellite and terrestrial transmitters provides inherent transmit diversity which can be exploit by applying appropriate MIMO schemes. The satellite transmitter can work in the same frequency as the terrestrial one(s) to form a SFN. In this case, all receive antennas can receive signals from both satellite and terrestrial transmitters, which forms a distributed MIMO transmission. Alternatively, the satellite and terrestrial transmitters can work in different frequency bands. In this case, one or more additional receive antenna(s) should be dedicated to receiving the satellite signal, which provides an independent, cooperative transmission link. Diversities can be extracted by combining the received signals from different sources.

9 Summary

In this deliverable, the architectural studies and proposals made by ENGINES partners were presented. Two system concept proposals were presented. These are called “T2-4-NGH” and “Flexible Time Division Multiplex based on DVB-T2”. What T2-4-NGH mainly proposes is a subset of DVB-T2, suited for mobile reception with an optional satellite component. This proposal was partly used for the definition of the so-called ”T2-Lite” profile of DVB-T2, intended primarily for reception of broadcast services in mobile environments. The properties of T2-lite were also presented in this deliverable. “Flexible Time Division Multiplex based on DVB-T2” proposal takes advantage of the Future Frame Extension (FEF) concept embedded in DVB-T2 to alternate transmissions of several type of waveforms, each optimised for a specific population of receivers.

Further, based on the DVB-T2 structure two particular NGH frames were studied. One was for embedding a 3GPP E-MBMS frame in a DVB-T2 FEF and the other was a superframe structure for NGH that is compliant with both terrestrial and satellite requirements.

From the network architecture side, hybrid satellite-terrestrial network scenarios for DVB-NGH were presented together with frame structures envisaged for hybrid networks. Also the concepts of SFN and MFN hybrid network and their constraints were described. Finally, MIMO network architectures for DVB-NGH were presented in detail.

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