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**Report ITU-R SM.2304-0**  
(06/2014)

**Application of technical identification and  
analysis of specific digital signals**

**SM Series**  
**Spectrum management**



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*Note: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

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## REPORT ITU-R SM.2304-0

**Application of technical identification and analysis of specific digital signals**

(2014)

**1 Introduction**

The purpose of this Report is to supplement information found in Recommendation ITU-R SM.1600 – Technical identification of digital signals, and in §§ 4.6 and 4.8 of the Spectrum Monitoring Handbook. It is focused on solving specific problems and issues related to signal identification and is intended to provide practical benefits to spectrum administrators and their monitoring services.

The content of the Report is found in Annex 1 that follows. It contains the following elements:

- Signal (or signal class) description and usage
- Definitions and acronym listing (if needed)
- Background and problem statement
- Description of the tools, techniques and methods used in the solution
- Results
- Conclusions

Further studies are expected to be added to this Report to add other examples; each additional Annex is intended to be self-contained following the above format and addressing a specific example related to signal identification.

**Annex 1****Transmitter identification in DVB-T single frequency network****Introduction**

This use case, implemented in Italy, applies to a signal already recognized as DVB-T belonging to a single frequency network (SFN), in order to identify all the transmitters detectable, in a specific receiving location: it allows the user to make a further step in the identification process.

**DVB-T allotment/transmitter identification**

Generally in an identification process for a DVB-T signal, the following steps have to be carried out:

- *Step 1:* Auto-correlation to identify the presence of guard interval (GI), taking into account that the symbol duration can be chosen between 2 (DVB-T) or 3 (DVB-H) values;
- *Step 2:* Channel estimation;
- *Step 3:* I/Q recording;
- *Step 4:* Transmission parameter signalling (TPS) analysis and Cell ID assessment.

The described methods focus on the latter step, the analysis of TPS for the identification of the DVB-T allotment/transmitters.

The DVB-T signal is an orthogonal frequency division multiplex (OFDM) type, composed by three typology of carriers: continuous and scattered pilot carriers, TPS carriers and data carriers. The **pilots carriers** are used for channel estimation and are known as “x-axis phased carriers”; *a priori* knowledge of them is available. The **TPS carriers** contain information on the modulation parameters adopted and a specific field called Cell ID (ETSI EN 300 744 V1.6.1 (2009-01), § 4.6). The modulation scheme adopted for TPS is DBPSK. The **data carriers** modulation is chosen in the range of digital modulation from QPSK to 64 QAM.

Using a vector signal analyser (VSA) or monitoring receiver, the readout of Cell ID permits the user to identify the transmitter in a multifrequency network (MFN), or the allotment in a standard k-SFN (see also Recommendation ITU-R SM.1875, § 3.1.3.2). Even more, it applies when  $k = 1$  and each allotment comprises only one transmitter. In this case, each transmitter has a univocal identifier (Cell ID).

### **Background: SFN Architecture**

All the information/pictures below are drawn from ITU documents from RRC-04 and GE06.

SFN is defined as:

- a) *Network of synchronized transmitting stations radiating identical signals in the same RF channel.*

Similarly, others are defined below:

**Large Area SFN:** *a SFN which contains more than one high-power station together with any associated medium and low-power stations, usually with a composite coverage greater than 10 000 km<sup>2</sup>.*

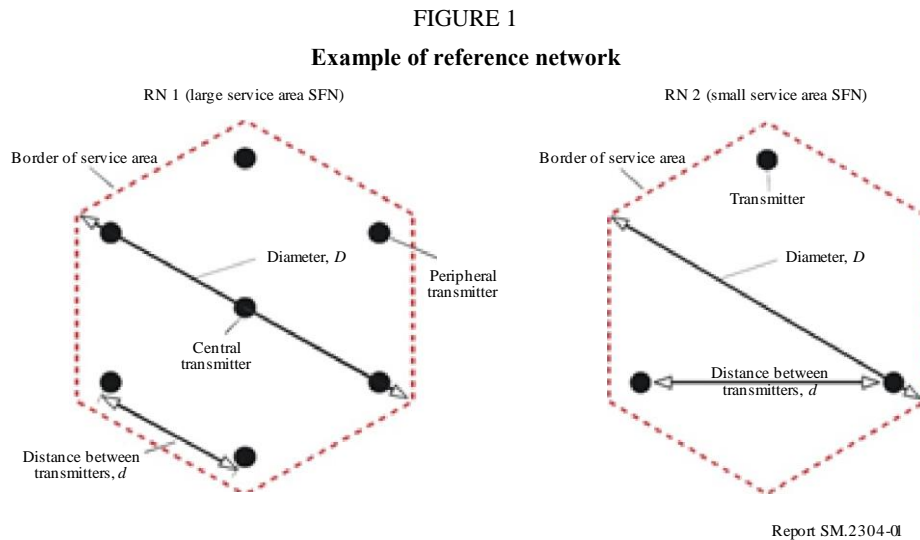
**Mini SFN:** *one high power station together with at least one (and probably several) associated medium or low-power stations.*

**Reference Network (RN):** *a generic network structure representing a real network, as yet unknown, for the purposes of the compatibility analysis. The main purpose is to determine the potential for and susceptibility to interference of typical digital broadcasting networks.*

Two kinds of RN should be considered (Fig. 1):

- 1) large service-area SFNs composed by 7 transmitters situated respectively at the centre and at the vertices of an hexagonal lattice;
- 2) small service-area SFNs, dense SFNs, composed by three transmitters situated at the vertices of an equilateral triangle.

The service area is assumed to be a hexagon, as well.



Each hexagon can be seen as an allotment and, in general, adjacent allotments should use different frequencies. The distance between different allotments is called “frequency reuse distance”. The complete frequency band is subdivided into clusters composed by a number of allotments. The number of allotments in one cluster is given by  $N = i^2 + i \cdot j + j^2$  where  $i$  and  $j$  are integers.  $N$  is called the “frequency reuse factor” (FRF). Usually, values for FRF are 3, 4 and 7. For those frequencies that are available on the whole service area, FRF can be assumed as 1 (1-SFN).

### k-SFN features

Allotments using the same frequency can carry the same or different content. In the first case, we have an SFN on the whole service area; otherwise we have a regional SFN. In either case, under specific propagation conditions, the signal emitted by a transmitter situated in a specific allotment can reach any other allotment, working on the same frequency, causing interference. If each allotment is identified by a unique code, it becomes very easy to recognize the source of any interference, anytime and everywhere. If the identification code is implemented at a transmitter level, the recognition of the source of any interference will be even more precise.

The adoption of a unique code for each transmitter in a SFN is possible regardless of the network configuration adopted, allowing for an excellent management of the network under any condition.

### Large scale 1-SFN

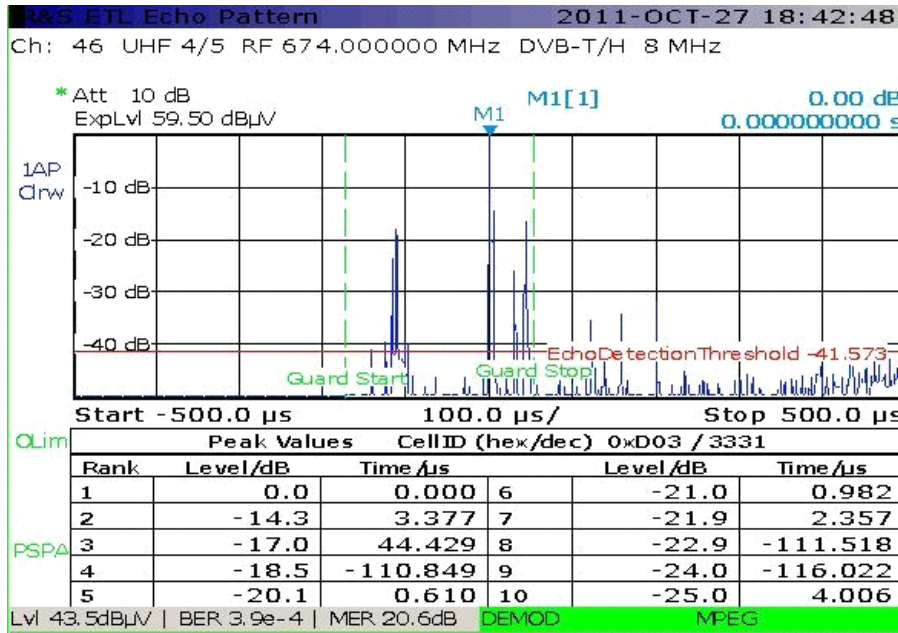
Large scale 1-SFN obtains the best efficiency in spectrum usage, but some drawbacks can arise. The most serious problem affecting large scale 1-SFN’s is the considerable number of echoes at the user end, where two different kinds of echoes, natural and artificial, can be detected. The first category of echoes is originated by reflections or scattering produced from nearby obstacles, the second is originated by the other transmitters of the network operating on the same frequency. Propagation effects further complicate reception in areas surrounded by warm sea.

Echoes may fall into or outside of the guard interval; some of them arrive in advance of the main signal, others after it (Fig. 2).

The need to accurately deploy and check the behaviour of a large SFN is well known to operators, some of which are therefore using the transmission parameter Cell ID to identify each transmitter.

FIGURE 2

Example of echo spread at the receiver end



note: Genova (GE) 085339 442445 SOpt:FASt;WPos:AUTO; Mux1 M.Beigua

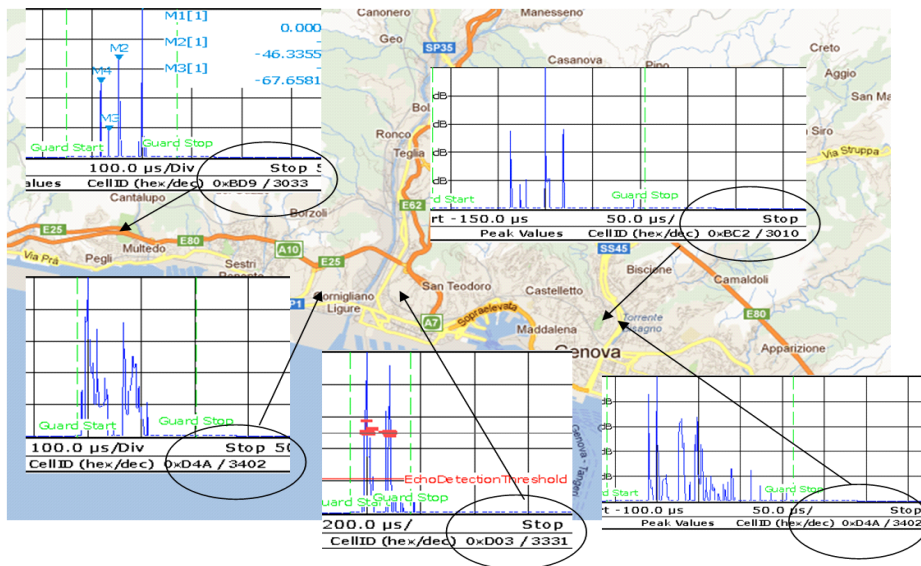
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The adoption of a different Cell ID for each transmitter, in conformity to § 5.2.4 of ETSI TR 101 190 V1.3.2 (2011-05), permits the user to simplify measurements and field monitoring activity.

In this way, it is possible to identify all the transmitters received at a measuring/monitoring point and to record their channel impulse response (CIR) for further comparative analysis (Fig. 3).

FIGURE 3

Identification of the highest received transmitter through Cell ID



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The methods described in the sections that follow allow the user to identify the main signal received as well as all the echoes having levels above  $-30$  dB relative to the main signal.

In addition, the methods permit the user to discriminate the signals belonging to two distinct SFNs (with different content) having the same network delay and synchronized at super frame level, which are seen inside the CIR as part of the same network.

### Identification by matching measured delays with planned delays database

The use of a different Cell ID for each transmitter in a SFN enables rapid identification of the transmitter with highest received level and to compute all the delays of echoes related to it.

In fact, it is possible to draw up two tables of the overall delay for each signal received at a given measurement point:

- **Overall calculated delays table:** generated from transmitters planned delays table (local delay) taking into account transmitters and receiving point coordinates (Fig. 4).
- **Overall measured delays table:** readout from VSA or monitoring receiver.

By comparing measured delays to their expected delays, it is possible to identify all transmitters belonging to the same network and received at a given measurement point.

FIGURE 4  
Cell ID and overall delay calculation

Channel	Transmitter	Cell ID		Distance (Km)	Azimut	Tx	Delays (µsec.)		
		Dec	Hex				Path	Tot	Rel
30	BUSALLA	3003	BBB	18,587	35	720	62	782	-22,7
30	GENOVA CAMALDOLI	3035	BDB	9,857	86	760	32,9	792,9	-11,8
30	M.BEIGUA	3331	D03	24,028	274	720	80,1	800,1	-4,6
30	M.FASCE	3402	D4A	13,399	93	760	44,7	804,7	0
30	GENOVA RIGHI	3010	BC2	5,875	86	800	19,6	819,6	14,9
30	COGORNO	3019	BCB	41,65	104	720	138,8	858,8	54,1
30	SESTRI PONENTE	3041	BE1	2,713	316	860	9	869	64,3
30	OREGINA	3043	BE3	3,254	113	860	10,8	870,8	66,1
30	GENOVA BRANEGA	3011	BC3	6,89	282	860	23	883	78,3
30	GENOVA PORTOFINO	3033	BD9	25,971	111	800	86,6	886,6	81,9
30	POLCEVERA	3009	BC1	8,007	357	860	26,7	886,7	82
30	QUEZZI	3085	C0D	8,295	90	860	27,7	887,7	83
30	CAMPOMORONE	3092	C14	8,796	24	860	29,3	889,3	84,6

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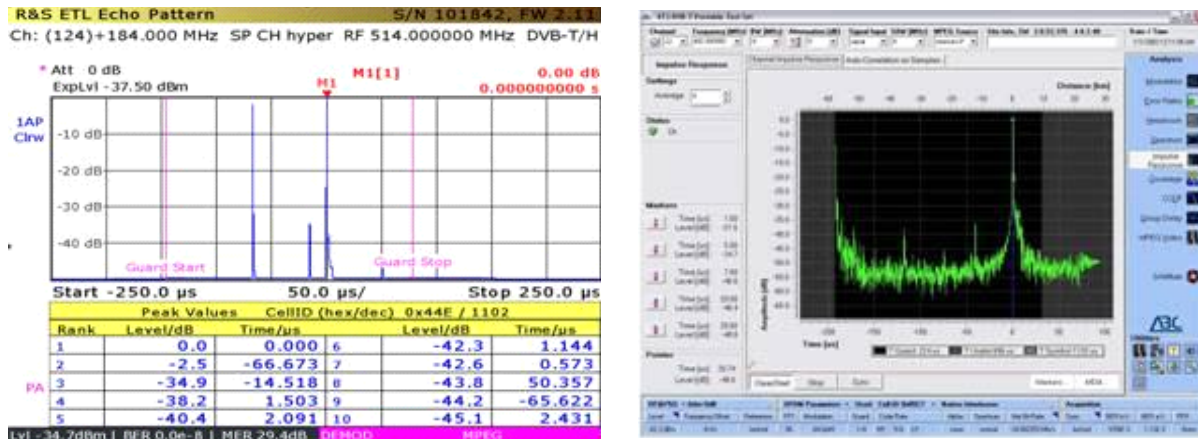
### Identification with VSA software package

A new method of DVB-T transmitter identification has been developed, suitable to be implemented as an upgrade in a typical measurement receiver or in a VSA. By using this method, the user can effectively identify all received signals from transmitters of a DVB-T SFN, at a receiving point.

Measurement instruments currently available do not allow a user to obtain information on the origin of all signals of an SFN. For example, in Fig. 5, the shown Cell ID value, 0x44E, is relative to the strongest signal (Time = 0, level = 0 dB).

FIGURE 5

## Cell ID identification for the strongest signal



a)

b)

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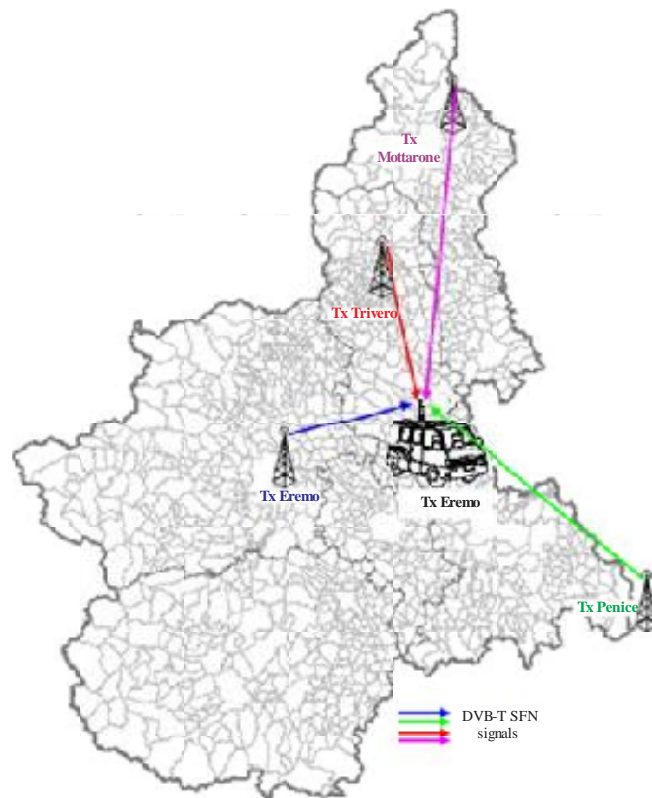
The method assumes to insert in TPS carriers a unique transmitter identification code, in the Cell ID field, as explained above.

The fact that, in given time-frequency positions, *different* signals are sent from different transmitters can be seen from two interesting perspectives. From one hand, this can be considered a “collision”, a phenomenon with negative connotation. On the other hand, this is similar to what happens in systems with multiple-antenna, like MISO (multiple inputs single output) (ETSI EN 302 755 V1.2.1 (2010-10), § 9.1), where the band reuse is possible through transmission of different signals, on the same frequency, from multiple antennas. Thanks to the spatial diversity, every individual channel frequency response could be estimated, where “channel” is considered to be the propagation path between each transmitter and the receiver.

At a specific receiving point, it is desirable to know the intensity of all the signals detected. For example, in Fig. 6, a geographic area covered by a group of DVB-T SFN transmitters is shown.



FIGURE 6  
Example of measurement in coverage area



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In the figure, the transmitters are called “Mottarone”, “Trivero”, “Eremo” and “Penice”. It would be useful to know the contribution of each transmitter at the receiving point.

The identification code adopted, the Cell ID, is transmitted in the S40-S47 symbols of the TPS carriers.

The symbols S0-S39 are transmitted identically, bit by bit, from each transmitter of the SFN, so the received OFDM signal is perfectly coherent (without conflicts). Whereas, Cell ID symbols S40-S47, carry different code identifiers; related to different transmitters, thus the received signal could contain collisions only on TPS carriers. The same situation occurs for the bits S48-S67, which contain the fields “reserved for future use” and “error protection”, due to the adopted differential encoding system.

However, as already mentioned, the OFDM signal **is always perfectly coherent in cells that carry pilots and payload data** (video, audio, etc.), thus ensuring a perfect reception.

Let us consider a measurement receiver, placed at a specific receiving point, which receives the signals from transmitters in service area. Let  $x(t)$  and  $y(t)$  be, respectively, the signal transmitted by a generic transmitter and the signal received, represented in time domain. The  $x(t)$  and  $y(t)$  signals can be represented in the frequency domain, by applying the Fourier transform, respectively as  $X(\omega)$  and  $Y(\omega)$ .

As the transmission channel, on which signals  $x(t)$  propagate from the generic transmitter to the receiver, is affected by multi-path propagation, it can be described by its CIR,  $h(t)$ , or by the Fourier transform  $H(\omega)$  of the latter, also known as channel frequency response (CFR).

This applies to each of the  $N$  transmitters. In this way, it is possible to define  $N$  different “transmission channels” between each transmitter and the receiver ( $H_1(\omega)$ ,  $H_2(\omega)$ , ...  $H_n(\omega)$ ), each one affected by its own parameters due to the individual, peculiar multi-path propagation.

Each “transmission channel” will have a different delay, phase shift and attenuation. In general, the transmission path has the relationship:

$$Y_i(\omega) = X_i(\omega) \cdot H_i(\omega)$$

where variables  $X_i$ ,  $Y_i$  and  $H_i$  are complex quantities, and the operator “ $\cdot$ ” is the complex product.

Furthermore, since in the OFDM modulation sampled data processing is used, with a fast Fourier transform (FFT) in the demodulator, and its inverse (IFFT) in the modulator, the above mentioned variables are expressed using  $n$  index for the symbol position within the frame, and  $k$  index for the frequency position.

Thus, for an OFDM signal, the previous formula can be rewritten as:

$$Y_i(n, k) = X_i(n, k) \cdot H_i(n, k)$$

Moreover, due to the superposition effects, the total received signal  $Y(n, k)$  is the sum of all  $N$  partial signals  $Y_i(n, k)$ , with  $i = 1, \dots, N$ .

Due to the superposition of all the signals relating to the  $N$  transmitters of the SFN, which cover the reception area, the “Total” signals  $Y(40, k) \dots Y(47, k)$ , are the summation of signal received on the TPS cells with  $k$  index during the symbols S40-S47.

The signal coming from each transmitter is multiplied by its channel frequency response. In mathematical terms, therefore, we have:

$$\begin{cases} Y(40, k) = X_1(40, k) \cdot H_1(40, k) + X_2(40, k) \cdot H_2(40, k) + \dots + X_8(40, k) \cdot H_8(40, k) \\ Y(41, k) = X_1(41, k) \cdot H_1(41, k) + X_2(41, k) \cdot H_2(41, k) + \dots + X_8(41, k) \cdot H_8(41, k) \\ \dots \\ Y(47, k) = X_1(47, k) \cdot H_1(47, k) + X_2(47, k) \cdot H_2(47, k) + \dots + X_8(47, k) \cdot H_8(47, k) \end{cases}$$

For each  $k$  value, the above equations define a linear system:

$$\underline{Y} = \underline{X} \cdot \underline{H}$$

where:

- $Y$ : vector of 8 elements in which an element  $Y_j$  represents a signal acquired by the receiver and related to the  $j$ -th symbol (with  $j = 40, \dots, 47$ ) of the DVB-T frame signal;
- $X$ :  $8 \times 8$  size matrix in which an  $X_{j,i}$  element represents a signal contribution that the receiver would receive if the  $i$ -th transmitter was the only one to broadcast, on an ideal transmission channel, the signal of the  $j$ -th symbol;
- $H$ : unknown, is an 8 element vector in which  $H_i$  element represents the frequency response of the “transmission channel” related to the  $i$ -th transmitter.

The linear system  $\underline{Y} = \underline{X} \cdot \underline{H}$  produces a unique solution, provided the determinant of  $\underline{X}$  matrix is different from zero; in practice this is almost always verified. Otherwise, it can be easily worked around with a suitable choice of the identification codes values assigned to the transmitters.

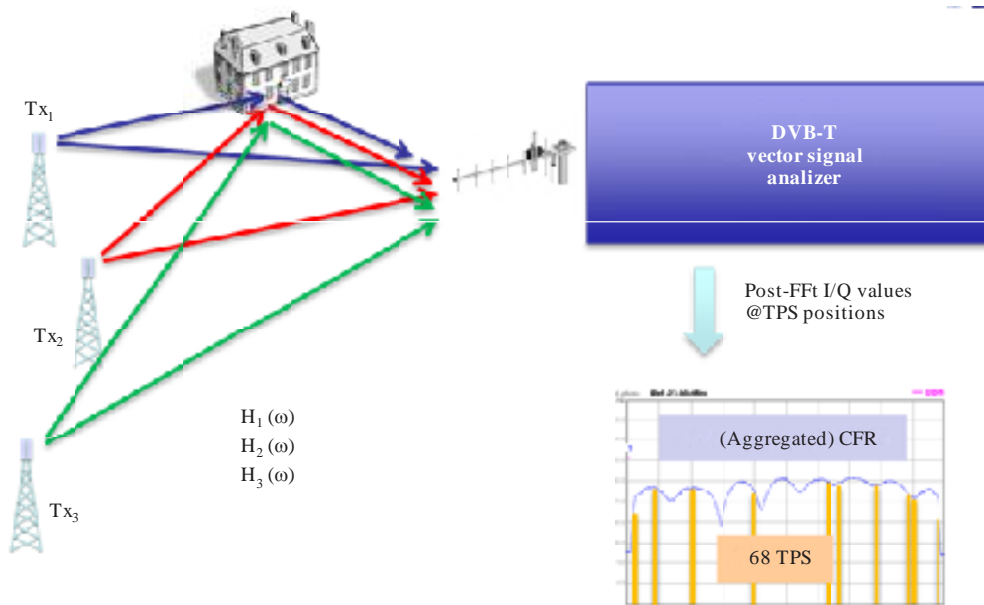
Once the above linear system is solved, we obtain the vector  $\underline{H}$ , which represents the frequency responses of each of the  $N$  transmission channels. The value of each component of vector  $H$ , normalized to the strongest signal, gives information on the signal level received from each transmitter.

The linear system, as indicated above, is composed of eight equations with eight unknowns. Upon solving such system, it is then possible to identify, via the appropriate identification code, up to eight transmitters which cover the selected geographic point. However, for practical use, the linear system will be extended including the equations associated to the symbols of the frames that carry the other eight out of the sixteen bits of which is composed the identification code of each

transmitter. In this way, it is possible to extend to sixteen the number of transmitter codes resolved in a single matrix operation. Moreover, since the Cell ID consists of a 16-bit binary word, and produces 65 535 values and the zero, it is possible to proceed by attempts: at every attempt the  $\underline{X}$  matrix is built, using the method described above, assuming each time a new set of sixteen different values of identification code, different from the previous case.

Since the calculations for every attempt are always performed on the same  $\underline{Y}$  vector, it is not necessary to repeat the signal acquisition every time, so the speed of the algorithm can be very high.

FIGURE 7  
Superposition of signals at the receiving antenna. Each transmitter-to-receiver (multi)path defines a “channel” with relevant channel frequency response



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Above described operations are performed only on TPS carriers. In principle, since in a given DVB-T OFDM symbol, all TPS carriers are modulated with the *same* bit, it would be possible to use only one TPS carrier to apply the method. However, in the presence of multipath propagation, an estimate based on a single TPS position would be quite inaccurate. Therefore, the process is repeated for all TPS positions. In other words, 68 linear equation systems are solved. Assuming that a set of sixty-eight  $16 \times 16$  linear equations systems are solved, we get 16 arrays of 68 values. Each array represents the CFR of each one of the 16 involved transmitters. Such CFR arrays are composed by just 68 values: they are the frequency response (of that individual transmitter-to-receiver channel) sampled at the TPS frequency positions.

For each one of the sixteen arrays (i.e. of the sixteen transmitters) two operations are performed:

- 1) the magnitude of the 68 frequency values are averaged: this cancels the multipath frequency-selective effect, and further increases the (already high) robustness of the method against Gaussian noise. The obtained value is the normalized level of the signal received from the relevant transmitter.

- 2) by the IFFT, the individual CIR is obtained. The present procedure is more complicated than a simple IFFT, since the TPS density is very low, about 1% of the total OFDM active carriers. In normal periodic-sampled systems this would result in a very strong time aliasing that would reduce the effective time span by a factor 100, thus resulting in a useless estimate of the CIR. Fortunately, the TPS frequency positions, by design, are not periodic, so the aliasing effect is not involved. Being indeed a “sparse sampling” case, the Compressive Sensing concept has been applied. The algorithm is iterative and provides an estimation of CIR reconstructed by principal peaks.

**Operation 1** above allows the user to build a table where the normalized levels of the signals received from the relevant transmitters can be ordered in a list and associated to the code identifiers of transmitters (Cell ID), taken from a predefined table that associates each Cell ID to the name (or geographical site) of the transmitter.

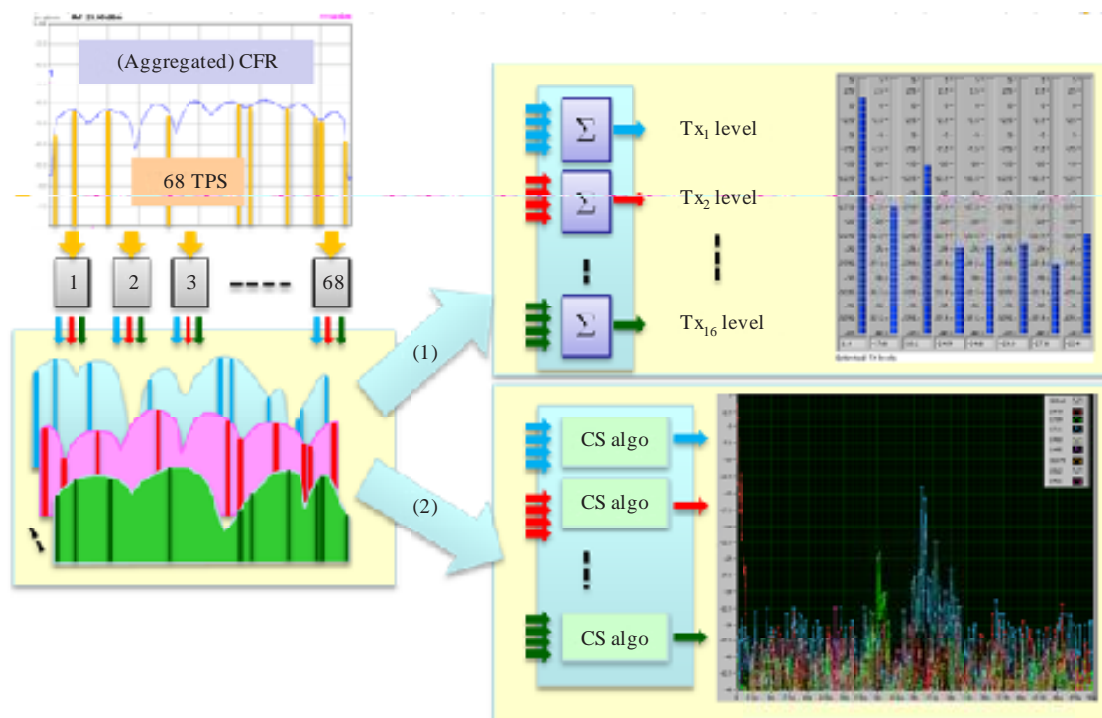
**Operation 2** above allows the user to obtain the time components of the global CIR, disaggregated in the individual CIRs relevant to each transmitter.

### Confirmation

The software package which implements the above method permits measurement receivers or VSAs to add a high value function able to display the labels of the various components of the impulse response on the current graphical video format. The early tests done in laboratory with real SFN signals indicate the system is able to estimate the individual levels of the transmitters, and to disaggregate the CIR into the individual ones. The CIR disaggregation method, although less precise than the classic one based on the scattered pilot tones, has proven to be useful to visualize signals components with differential delays up to two times the guard interval.

FIGURE 8

**Disaggregation by MISO-like technique solving sixty-eight  $16 \times 16$  linear eqn. systems. Sixteen disaggregated CFRs are obtained. Such CFRs are sampled at the TPS freq. positions. The results allow (1) calculation of individual transmitters levels; (2) Reconstruction of the 16 disaggregated CIRs from sparse-sampled CFR, using Compressive Sensing algorithm**



## Results

### **Drawbacks of the use of different Cell IDs for each transmitter in a large scale 1-SFN**

Minor problems caused by the use of different Cell IDs for each transmitter has been detected on a few old-generation consumer receivers. In order to study the real impact, tests in Laboratory have been performed by different organizations.

The method could be easily implemented in the measurement receivers or VSA, requiring limited processing power. The method and test device (“SFN Scope”) was patented by RAI Research and Technological Innovation Centre. Any use is regulated by the Common Patent Policy for ITU-T/ITU-R/ISO/IEC and the associated “Guidelines for implementation of the Common Patent Policy for ITU-T/ITU-R/ISO/IEC”<sup>1</sup>.

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<sup>1</sup> The “Guidelines for Implementation of the Common Patent Policy for ITU-T/ITU-R/ISO/IEC” can be found at [http://www.itu.int/dms\\_pub/itu-t/oth/04/04/T04040000010003PDFE.pdf](http://www.itu.int/dms_pub/itu-t/oth/04/04/T04040000010003PDFE.pdf). To use the patent, contact Research Centre RAI (RAI-CRIT) at <http://www.crit.rai.it/IT/contatti/contatti.htm> and subscribe to the Commitment of Use.