DVB-NGH Channel Models (Revised 9 November 2010)

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1 Introduction

This document describes the channel models which are intended to be used in the development process of the DVB-NGH digital broadcasting standard. The target is to give common definitions of channel models for all who will use them in simulations and laboratory measurements. A variety of models are included to cover a wide range of reception conditions. Also included are specific channel definitions for testing receiver synchronisation issues in SFN-conditions.

The models are intended to be representative of UHF band reception (approximately 500-1000MHz).

The MIMO section of this document includes revisions resulting from the 2010 Helsinki channel sounding campaign.

2 Single-Input-Single-Output (SISO) Channel models

2.1 Stationary reception

2.1.1 Gaussian channel

In this channel model only white Gaussian noise (AWGN) is added to the signal, and there is only one time-invariant path.

2.1.2 Simple two path profile, 0dB echo

This profile only includes two paths. Each path, '*i*', is defined by α_i, τ_i, Δf_i which denote the amplitude, delay and frequency shift of the particular path '*i*', respectively. The profile parameters are given in table 1.

Table 1: 0 dB Echo profile

i	α_i (dB)	τ_i (µs)	Δf_i (Hz)
1	0	0	0
2	0	0.9Δ	1

For a system based on COFDM with a guard interval, the parameter 'Δ' denotes the guard interval duration in µs. For other systems, it is the stated maximum delay tolerance of the system.

2.2 Portable reception

2.2.1 MIMO-model based

For simulation of portable SISO reception, the path h_{11} taken from the MIMO portable channel definitions below in paragraphs **Error! Reference source not found. -Error! Reference source not found.** shall be used.

2.3 Mobile Reception

Two SISO models are defined, one based on the MIMO model described below and the other based on the TU6 model

2.3.1 MIMO-model based

In this case mobile SISO reception is defined as the path h_{11} taken from the MIMO mobile channel definition below in paragraph **Error! Reference source not found.**.

2.3.2 TU6 Model

This profile reproduces the terrestrial propagation in an urban area. It has been defined by COST 207 as a typical urban (TU6) profile and is made of 6 paths having wide dispersion in delay and relatively strong power. The profile parameters are given in table 2.

Table2: Typical Urban profile (TU6)

Tap number	Delay (µs)	Power (dB)	Doppler Spectrum
1	0.0	-3	Classical
2	0.2	0	Classical
3	0.5	-2	Classical
4	1.6	-6	Classical
5	2.3	-8	Classical
6	5.0	-10	Classical

where the Classical Doppler spectrum is defined as:

$$K(f;f_D)=\frac{1}{\sqrt{1-(f/f_D)^2}}$$

The Doppler width parameter should be assigned values corresponding to 60km/h and 350km/h at 600MHz; i.e. **33.3Hz** and **194.8Hz**.

2.3.3 Mobile TU6-based SFN

This profile reproduces the terrestrial propagation in an urban area in a Single Frequency Network (SFN). Each transmitter in the SFN is modelled as one independent TU6 profile and the total Mobile SFN channel is therefore the sum of all individual and independent TU6 channel models, each having a unique level and delay. A frequency shift shall also be introduced in each test path as detailed below.

One particular TU6 profile, i.e. the received paths originating from one particular transmitter, is denoted $\alpha_i TU6(\tau_i)$, where α_i and τ_i are the amplification and delay constants to be applied to all individual paths of that particular TU6 profile. In the special case with only one transmitter the values of α_i and τ_i are set to unity and zero respectively.

The general mobile SFN channel profile, SFN-TU6, with N transmitters can be described in the following way:

$$\text{SFN-TU6} = \sum_{i=1}^{N} \alpha_i TU6(\tau_i)$$

In a real SFN almost any values of α_i and τ_i may appear, τ_i values however being limited by the size of the SFN. Also the value of N may vary a lot depending on SFN, although the actual number of transmitters to be considered in the channel profile modelling may depend on the particular network design and receiver performance.

Important special cases of this general model are the cases with two or three transmitters, i.e. the cases N=2 and N=3 with wide variations of α_i and τ_i values. In case of "classical OFDM" the parameter Δ denotes the guard interval length; in a non-OFDM system it would correspond to the specified maximum delay tolerance of the system.

Two transmitter test profile (N=2)

$\tau_1 = 0$ µs, $\tau_2 = \{0.05\Delta\ 0.9\Delta\}$ $\Delta f_1=0$ $\Delta f_2=+2$Hz

$\alpha_1 = 0$ dB, $\alpha_2 = \{0, -3, -6, -9\}$ dB ("post echo" case)

$\alpha_2 = 0$ dB, $\alpha_1 = \{0, -3, -6, -9\}$ dB ("pre echo" case)

Three transmitter test profile (N=3)

$\Delta f_1=0$ $\Delta f_2=+2$Hz $\Delta f_3=-2$Hz

1st TU6 ("Pre echo")

α_1 = {0, -3, -6, -9} dB

τ_1 = -0.45Δ

2nd TU6 ("Main signal")

α_2 = 0 dB

τ_2 = 0 μs

3rd TU6 ("Post echo")

τ_3 = 0.45Δ

α_3 = {0, -3, -6, -9} dB

Note: α_1 and α_3 values to be varied independently.

3 Multiple-Input-Multiple-Output (MIMO) Channel models

3.1 General approach

The aim is to provide a time-domain model of paths shown as $h_{11}, h_{12}, h_{21}, h_{22}$ in the figure below, where Tx1 and Tx2 represent a cross-polar pair of antennas at a terrestrial transmitter site and Rx1 and Rx2 the two elements of a MIMO receive antenna whether fixed or mobile.

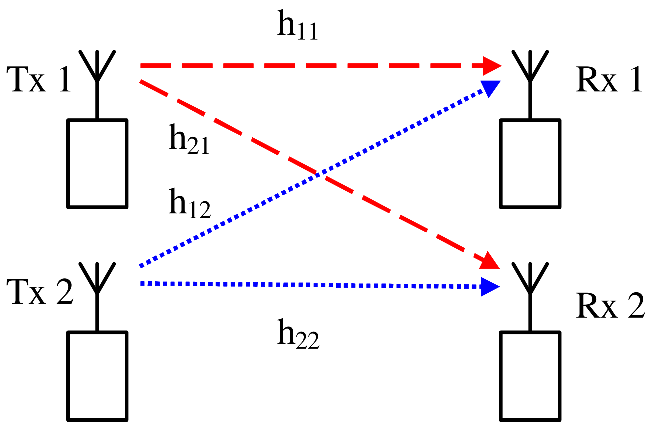

Figure 1 - 2-by-2 MIMO system

The two proposed models, outdoor portable and indoor portable, will now be described.

3.2 Outdoor portable model

An 8-tap model of the propagation paths is proposed. The delays and relative power gains of the direct paths h_{11}, h_{22} are tabulated below in Table 1. Taken together with the cross-polar terms h_{12}, h_{21} the sum of the tap powers is unity (0dB).

Table 2: Power delay profile of the 8-tap outdoor model.

Tap number, *p*	**Excess delay, τ_p (µs)**	**Co-polar power gain $\sigma_{11}(\tau_p)^2 = \sigma_{22}(\tau_p)^2$ (dB)**
1	0	-4.0
2	0.1094	-7.5
3	0.2188	-9.5
4	0.6094	-11
5	1.109	-15
6	2.109	-26
7	4.109	-30
8	8.109	-30

When used in a discrete baseband model, the excess delays will be rounded to integer sample periods. For instance, in the case of an 8 MHz bandwidth the sample period T is 7/64 us and the resulting discrete excess delays are 0, 1, 2, 6, 10, 19, 38, and 74 samples.

The cross-polar discrimination (XPD) is defined as the ratio of the co-polarized average received power to the cross-polarized average received power. XPD quantifies the separation between the two cross-polarized channels. The larger the XPD, the less energy is coupled between the cross-polarized channels.

The XPD for outdoor and indoor reception takes the following values:

Table 3: Cross-polar discrimination for outdoor reception.

Environment	***XPD* (linear scale)**	***XPD* (log scale)**
Outdoor	4	6 dB

The reciprocal XPD factor w^2 for tap p is defined as $w^2 = \sigma_{12}^2(\tau_p)/\sigma_{11}^2(\tau_p) = \sigma_{21}^2(\tau_p)/\sigma_{22}^2(\tau_p)$.

The time-variant channel model for the link between TX antenna n and RX antenna m can be written as:

$$h_{mn}(t,\tau) = \sum_{p=1}^{N_p} g_{mn}(t,\tau_p)\delta(\tau - \tau_p) \qquad (2)$$

Where t is time index, τ the delay index, N_p (= 8) the number of paths, τ_p the p-th excess delay (τ_1 = 0), and $g_{mn}(\tau_p, t)$ the p-th time-variant complex-valued gain.

A 2x2 time-variant matrix **H** is then defined as:

$$\mathbf{H}(t,\tau) = \begin{bmatrix} h_{11}(t,\tau) & h_{12}(t,\tau) \\ h_{21}(t,\tau) & h_{22}(t,\tau) \end{bmatrix} \qquad (3)$$

3.2.1 Outdoor portable parameters

In the outdoor portable environment, the XPD is 4, as tabulated in **Error! Reference source not found.**.

For the **first tap** τ_1, the complex-valued gain is purely LOS:

$$g_{mn}(t,\boldsymbol{\tau}_1) = [\boldsymbol{\sigma}_{mn}(\boldsymbol{\tau}_1)\exp(j\boldsymbol{\theta}_{mn})]\ldots(m=n) \qquad (4A)$$

$$g_{12}(t,\boldsymbol{\tau}_1) = [\boldsymbol{\sigma}_{12}(\boldsymbol{\tau}_1)\exp(j(\boldsymbol{\theta}_{12} + 4\boldsymbol{\pi}t))] \qquad (4B)$$

$$g_{21}(t,\boldsymbol{\tau}_1) = [\boldsymbol{\sigma}_{21}(\boldsymbol{\tau}_1)\exp(j(\boldsymbol{\theta}_{21} - 4\boldsymbol{\pi}t))] \qquad (4C)$$

- The overall K-factor of the outdoor model (K_0) is 1.0
- θ_{mn} are the initial phases of the LOS component. They are real-valued i.i.d. random variables uniformly distributed in the interval [0, 2π). The LOS components of the direct terms (n=m) have no Doppler shift, whereas for cross-terms a shift of ±2Hz is specified.
- $w^2 = 0.25$

For the **remaining taps** (p = 2…8), only NLOS component is assumed, as expressed below:

$$g_{mn}(t, \tau_p) = \varphi_{pmn}(t) \tag{5}$$

- $w^2 = 0.25$
- $\varphi_{pmn}(t)$ are the time-variant random components of the tap, which model the Doppler spread. They are complex-valued zero-mean Gaussian processes having a combination of a Jakes spectrum and a fixed frequency offset and exhibiting intra-tap correlation. The vector $\varphi_p(t) = [\varphi_{p11}(t) \quad \varphi_{p12}(t) \quad \varphi_{p21}(t) \quad \varphi_{p22}(t)]^T$ is specified to have the following covariance matrix at the p^{th} tap:

$$\mathbf{R}_p = \sigma_{11}^2(\tau_p)\begin{pmatrix} 1.00 & 0.06 & 0.06 & 0.05 \\ 0.06 & 0.25 & 0.03 & 0.05 \\ 0.06 & 0.03 & 0.25 & 0.06 \\ 0.05 & 0.05 & 0.06 & 1.00 \end{pmatrix} \tag{6}$$

The Cholesky decomposition can be used to provide a transition matrix to pre-multiply a 4-element i.i.d. vector at each tap to create the above autocorrelation properties. A suitable matrix is

$$\mathbf{V} = \begin{pmatrix} 1.00 & 0 & 0 & 0 \\ 0.06 & 0.4964 & 0 & 0 \\ 0.06 & 0.0532 & 0.4935 & 0 \\ 0.05 & 0.0947 & 0.1053 & 0.9887 \end{pmatrix} \tag{7}$$

N.B. Using the matrix **V** does not remove the need for the term $\sigma_{11}^2(\tau_p)$

The Jakes spectrum $S(f, f_d)$ is characterized by the following equation:

$$S(f, f_d) = \frac{1}{\pi f_d \sqrt{1 - \left(\frac{f}{f_d}\right)^2}} \quad \forall f \in \left]-f_d, f_d\right[; \quad = 0 \quad \text{elsewhere} \tag{8}$$

Where f_d is the maximum Doppler frequency, which is chosen to be proportional to an assumed vehicle speed v. In (8), f_d is strictly greater than 0.

The typical receiver velocities we consider for outdoor portable reception are **0km/h** and **3 km/h**. At a carrier frequency of 600 MHz the resulting Doppler frequency f_d is **1.67 Hz**.

The spectrum of the p^{th} tap is shown in the table below:

Table 3: Tap spectral characteristics of the 8-tap outdoor model.

Tap number, *p*	
1	LOS only, no additional Doppler shift
2	$S\left(f-\frac{3f_d}{4},\frac{f_d}{4}\right)$
3	$S\left(f-\frac{3f_d}{4},\frac{f_d}{4}\right)$
4	$S\left(f+\frac{3f_d}{4},\frac{f_d}{4}\right)$
5	$S\left(f+\frac{3f_d}{4},\frac{f_d}{4}\right)$
6	$S\left(f+\frac{3f_d}{4},\frac{f_d}{4}\right)$
7	$S\left(f+\frac{3f_d}{4},\frac{f_d}{4}\right)$
8	$S\left(f+\frac{3f_d}{4},\frac{f_d}{4}\right)$

3.3 Indoor portable model

An 8-tap model of the propagation paths is again proposed. The delays and relative power gains of direct paths h_{11}, h_{22} are tabulated below in Table 4. Taken together with the cross-polar terms h_{12}, h_{21} the sum of the powers is unity (0dB).

Table 4: Power delay profile of the 8-tap indoor model.

Tap number, *p*	**Excess delay, τ_p (µs)**	**Co-polar power gain $\sigma_{11}^2 = \sigma_{22}^2$ (dB)**
1	0	-6.0
2	0.1094	-8.0
3	0.2188	-10
4	0.6094	-11
5	1.109	-16
6	2.109	-20
7	4.109	-20
8	8.109	-26

The XPD for outdoor and indoor reception takes the following values:

Table 5: Cross-polar discrimination for outdoor reception.

Environment	***XPD* (linear scale)**	***XPD* (log scale)**
Indoor	1.78	2.5 dB

3.3.1 Indoor portable parameters

For the **first tap** τ_1, the complex-valued gain is split into two components, LOS and NLOS. This writes as:

$$g_{mn}(t,\tau_1) = \left[\underbrace{\sigma_{mn}(\tau_1)\sqrt{\frac{K}{1+K}}\exp(j\theta_{mn})}_{LOS} + \underbrace{\sqrt{\frac{1}{1+K}}\varphi_{1mn}(t)}_{NLOS} \right] \ldots (m=n) \tag{4A}$$

- $$g_{12}(t,\tau_1) = \left[\underbrace{\sigma_{12}(\tau_1)\sqrt{\frac{K}{1+K}}\exp(j\theta_{12})}_{LOS}\exp(j4\pi t) + \underbrace{\sqrt{\frac{1}{1+K}}\varphi_{112}(t)}_{NLOS} \right] \tag{4B}$$

- $$g_{21}(t,\tau_1) = \left[\underbrace{\sigma_{21}(\tau_1)\sqrt{\frac{K}{1+K}}\exp(j\theta_{21})}_{LOS}\exp(-j4\pi t) + \underbrace{\sqrt{\frac{1}{1+K}}\varphi_{121}(t)}_{NLOS} \right] \tag{4C}$$

- The overall K-factor of the indoor model (K_0) is approximately 0.2
- K, the Ricean-K factor for the first tap is 1
- $w^2 = 0.56$
- Note that $\varphi_{pmn}(t)$ exists in the indoor model for p=1 as well as p=2-8.

The indoor covariance matrices (for taps 2-8 and the NLOS part of tap 1) are defined as

$$\mathbf{R}_p = \sigma_{11}^2(\tau_p)\begin{pmatrix} 1.00 & 0.15 & 0.10 & 0.15 \\ 0.15 & 0.56 & 0.06 & 0.04 \\ 0.10 & 0.06 & 0.56 & 0.15 \\ 0.15 & 0.04 & 0.15 & 1.00 \end{pmatrix} \tag{9}$$

A suitable transition matrix for the indoor case is

$$\mathbf{V} = \begin{pmatrix} 1.00 & 0 & 0 & 0 \\ 0.15 & 0.7331 & 0 & 0 \\ 0.10 & 0.0614 & 0.7391 & 0 \\ 0.15 & 0.0239 & 0.1807 & 0.9717 \end{pmatrix} \qquad (10)$$

The typical receiver velocities we consider for indoor portable reception are **0km/h** and **3 km/h**. At a carrier frequency of 600 MHz the resulting Doppler frequency f_d is **1.67 Hz**.

The spectrum of the p^{th} tap is shown in the table below:

Table 6: Tap spectral characteristics of the 8-tap indoor model.

Tap number, *p*	
1 (NLOS component)	$S(f, f_d)$
2	$S\left(f - \frac{3f_d}{4}, \frac{f_d}{4}\right)$
3	$S\left(f - \frac{3f_d}{4}, \frac{f_d}{4}\right)$
4	$S\left(f + \frac{3f_d}{4}, \frac{f_d}{4}\right)$
5	$S\left(f + \frac{3f_d}{4}, \frac{f_d}{4}\right)$
6	$S\left(f + \frac{3f_d}{4}, \frac{f_d}{4}\right)$
7	$S\left(f + \frac{3f_d}{4}, \frac{f_d}{4}\right)$
8	$S\left(f + \frac{3f_d}{4}, \frac{f_d}{4}\right)$

3.4 Additional antenna rotation and asymmetry terms

The following applies to both outdoor and indoor models.

In deriving the antenna-specific data from which the model parameters were derived, the raw data was rotated by up to ±40° to find the angle which maximised the cross-polar discrimination. This was to correct for both physical mounting differences and antenna axis differences with respect to the casing. It also ensured averaging across antennas retained legitimacy in terms of cross-polar discrimination.

However in practice this 'ideal' alignment may not be representative and so a further rotation matrix **W**, with angle Ω chosen from the set {-45 °, 0 °, +45 °} is recommended with the angle fixed for a particular simulation run.

In addition, an asymmetry matrix **Γ** is included to model observed H/V asymmetries which persist over many contiguous channel realisations (typically over 10m). **Γ** should also be taken as fixed for a particular simulation run. It takes values from the set

$$\left\{ \begin{bmatrix} 1.1074 & 0 \\ 0 & 0.8796 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 0.8796 & 0 \\ 0 & 1.1074 \end{bmatrix} \right\}.$$

The resulting channel matrix $\mathbf{H_c}(t,\tau)$ is hence derived from $\mathbf{H}(t,\tau)$ as follows:

$$\mathbf{H_c}(t,\boldsymbol{\tau}) = \mathbf{WH}(t,\boldsymbol{\tau})\mathbf{\Gamma} = \begin{bmatrix} \cos\Omega & -\sin\Omega \\ \sin\Omega & \cos\Omega \end{bmatrix} \begin{bmatrix} h_{11}(t,\boldsymbol{\tau}) & h_{12}(t,\boldsymbol{\tau}) \\ h_{21}(t,\boldsymbol{\tau}) & h_{22}(t,\boldsymbol{\tau}) \end{bmatrix} \begin{bmatrix} \Gamma_{11} & 0 \\ 0 & \Gamma_{22} \end{bmatrix} \qquad (11)$$

3.5 Simulation practicalities

3.5.1 Updating LOS phases, W and Γ

The LOS phases θ_{mn} and parameters **W** and **Γ** are both intended to be fixed for periods of five seconds before re-initialisation. This can be relaxed if the time-interleaving length of the system is considerably shorter than this such that no material change in the results would be expected. Indeed, re-initialising per TI frame is acceptable if it is clear this is equivalent to the longer runs. Sudden changes of parameters during OFDM blocks should be avoided however.

Furthermore, regarding matrix **W**, if it is clear that the angles +45° and -45 ° give the same result in a particular scheme, the requirement to do both can be dropped.

3.6 Generating fixed channel realizations (0Hz Doppler snapshots)

If we simulate a time-invariant channel, i.e. $f_d = 0$, the Doppler shift for the LOS components and the Doppler spreads for the NLOS components are not modelled. Instead, it suffices to generate a number of independent realizations.

For each LOS component we generate four real-valued i.i.d. phases θ_{mn} with uniform distribution. For the NLOS components we need to generate four complex-valued variables $\boldsymbol{\varphi}_{pmn}$ with the prescribed intra-tap correlation properties.

3.7 Mobile vehicular outdoor model

For the mobile case, we use the outdoor model and consider two receiver velocities: **60 km/h** and **350 km/h**. At a carrier frequency of 600 MHz the resulting Doppler frequencies f_d are **33.3 Hz** and **194.8 Hz** respectively.

3.8 4 x 2 model (& 2-tower SFN)

A pair of uncorrelated 2 x 2 models should be invoked, one of which has a time offset taken from {0.05Δ, 0.9Δ}

where Δ denotes the guard interval length for an OFDM system. In a non-OFDM system it would correspond to the specified maximum delay tolerance of the system.

The time-shifted element should additionally have a fixed frequency offset of +1.0Hz.

A second parameter is the power ratio between the signals received from the two towers, which models the power imbalance. Suggested values are {0, -3, -6, -9} dB.

4 SISO, MISO and SIMO systems

Appropriate transmission paths of the MIMO model may be selected to provide SISO, MISO and SIMO models.