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Abstract

This document identifies a set of channel models that are suitable for DVB-T/H/RCT, WIMAX and IEEE 802.11g wireless air interface.

Keyword list: Channel modelling, link budget, fading, multipath, DVB-T/H/RCT, WiMAX, IEEE 802.11g

Fixed and Mobile Channel Models Identifications

SUIT_64

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1 Introduction

The aim of this report is to identify widely known (and standardized) channel models for the evaluation of video transmission over the following wireless air interface: DVB-T/H/RCT, WIMAX and Wireless LAN. This report acts as an input to Activities 2.2, 2.3, 2.4 and 2.5. These activities involve the development of baseband simulation models, which will then be used to generate hard and soft error pattern files. The error pattern files will be used in WP3 to study, develop and improve techniques for video codec error resilience. The simulation results will be considered when setting up the trials in WP6. As the simulation results depend strongly on the radio channel, it is crucial that accurate and realistic channel models are used in the video codec tests. In general, the wireless channel can be characterized by:

- Path loss (including shadowing)
- Multipath delay spread (e.g. RMS delay spread)
- Fading characteristics (e.g. Rayleigh or Rician)
- Doppler spread (e.g. Jake's spectrum)

Typically, multipath delay spread, fading characteristics and doppler spread are jointly considered as the multipath fading model, which can be implemented using the Tapped Delay Line (TDL) filter [1]. The TDL Filter will be discussed in Appendix 1. Multipath fading model will assume a greater importance in this report since they are needed to generate error trace for WP3. Nevertheless, the path loss models are also considered to allow the simulation of capacity and coverage in Activity 2.5.

The report is organized into four sections. Section 1 introduces this deliverable. Section 2 review the concepts of radio propagation engineering which serve as basics to the idea of communication system modelling and channel modelling. Section 3 contains a discussion of the appropriate channel model for the wireless systems being considered within SUIT, which are DVB-T, DVB-RCT, WIMAX and IEEE 802.11g. Note that the discussions of fixed and mobile DVB-T and DVB-RCT have been grouped together because of similarities in their system and the target frequency band. Finally, Section 4 summarizes the channel models selected for each wireless system.

The scenarios considered in the deliverable are summarized in Table 1. The target test environment for each wireless system will be described in the individual sections of the report.

Table 1 Targeted scenarios for each wireless system

WP	Air Interface	Frequency	Scenario
2.2	DVB-T/H/RCT	• UHF • VHF	• Fixed wireless: hilly terrain, flat terrain, rural • Mobile wireless: urban, suburban, rural
2.3	WIMAX	• 2-2.7 GHz • 3.5 GHz	• Indoor office • Outdoor to indoor and pedestrian • Vehicular
2.4	IEEE 802.11g	• 2.4 GHz	• Indoor • Limited outdoor

Note that it is not the scope of this deliverable to devise new channel models, but to identify and utilize well established or standard recommended scenarios and channel models whenever possible. This allows easier simulator validation and also comparison to results in the existing literature.

2 Basics of Radio Propagation Engineering

This section reviews the basics of communication system modelling. Section 2.1 outlines a typical model of a communication system. Section 2.2 describes how to convert bit energy to noise spectral density, E_b/N_0, to the average carrier to noise power ratio C/N. Section 2.3 illustrates the typical link budget which also reflects how channel models in Section 3 (i.e. path loss, shadowing loss, multipath loss) affect the overall link budget. Finally, Section 2.4 discusses the conversion of electrical field to received signal power.

2.1 Introduction

A typical passband communication system is shown in Figure 1. It is expected that the source symbols recovered at the receiver side are replicas of the source symbols generated and encoded at the transmitter.
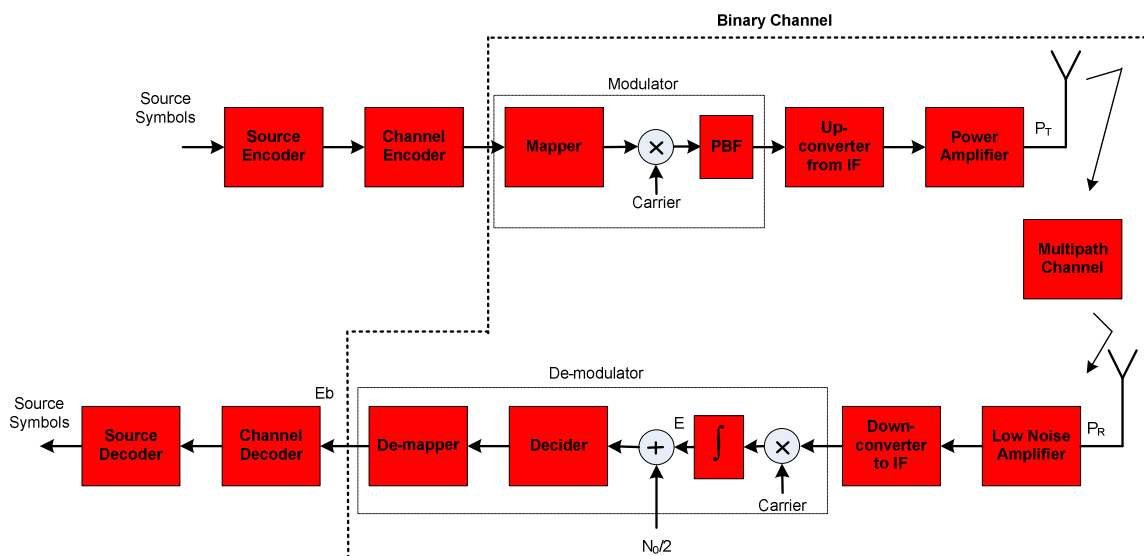

Figure 1 Typical Communications System

The communications system can be composed simply of a few blocks such as a source encoder/decoder, a channel encoder/decoder and a memory/memoryless binary channel. Usually, the transmission bandwidth, B_w, and the transmission power, P_T, are fixed and when the noise (Noise power spectral density-N_0) increases and in order to reduce it, we may use one or a combination of the following solutions with direct consequence on the source bit rate reduction:
- A stronger channel encoder;
- A modulator with less number of levels.

Figure 2 shows a typical communication performance in uncoded and coded with a code rate R_c. The bit energy obtained at the binary channel output is E_b (see Figure 1).

The uncoded curve shape depends on the multipath channel, on the modulation scheme and on the equalizer (not shown in Figure 1). The equalizer is used to combat frequency selective fading caused by multiple paths. This deliverable will discuss several multipath models. Several factors do not allow us to obtain an exact closed expression for the error probability namely because the equalizer is normally not standardized, there may not be a performance closed expression for some channel codecs and even for some modulators. Therefore, the curves like those shown in Figure 2 are obtained experimentally or by simulations.
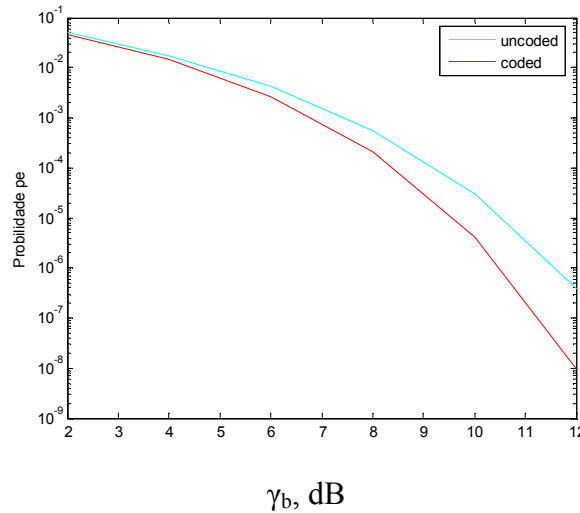
γ_b, dB
Figure 2 The Error Probability, Pe=f(γ_b), with $\gamma_b=E_b/N_0$

In the case where there is only one transmitter, the receiver performance is only limited by noise N_0. The total noise power is given by:

$$N = N_0 B_w = kTFB_w \tag{1}$$

where k, T, B_w and F are the Boltzman constant, the absolute temperature in degrees Kelvin, the double-sideband noise bandwidth of the receiver and the noise figure of the receiver, respectively. The receiver noise figure, F, is calculated from the noise figures of all receiver blocks. The LNA noise figure is the greatest contributor to the overall receiver noise figure F. At a room temperature of 17ºC, the product kT is given by -174 dBm/Hz and kTB_w is the noise floor.

The bit energy, E_b, is related to the receiving power P_r, and P_r is related to the transmitted power P_T. Since it is more convenient to measure the average carrier-to-average noise, C/N, the ratio E_b/N_0 can be rewritten in function of the power ratio C/N. These relationships are discussed in the following sections.

2.2 Relationship between C/N and E_b/N_0

The following relations convert from C/N into E_b/N_0:

$$E_b = CT_b = \frac{C}{R_b} \tag{2}$$

$$N_0 = \frac{N}{B_w} \tag{3}$$

$$\frac{E_b}{N_0} = \frac{C}{N}\frac{B_w}{R_b} \tag{4}$$

In decibels:

$$\frac{C}{N} = \frac{E_b}{N_0} + 10\log\frac{R_b}{B_w} \tag{5}$$

For example, let us assume that we would like to achieve an error probability, Pe of 10^{-4}. From Figure 2 (uncoded curve), E_b/N_0=9 dB. Therefore, assuming QPSK where the bandwidth is half the bit rate, we achieve:

$$\frac{C}{N} = 9 + 10\log\frac{R_b}{R_b/2} = 12dB \tag{6}$$

If we assume that the receiver noise figure is F=5 dB and for 8MHz channels, B_w=7.61 MHz, we have, from (1):

$$N=-174dBm/Hz+10\log(7.61 \times 10^6)+5dB=-100.2dBm \qquad (7)$$

and the average power required is given by:

$$C=N[dBm]+C/N[dB]=-100.2+12=-88.2dBm \qquad (8)$$

In DVB-T/H, the minimum required C/N to achieve an error probability of 10^{-4} after the internal decoder (Viterbi decoder) and quasi-error free after the external decoder (Reed-Solomon decoder) is tabled in the standard [2]. In DVB-H, C/N for some modulations, code rates and mobile speeds as well as the noise floor, KTB_w, are tabled [3]. The receiver noise figure should be better than 5 dB and therefore N=-100.2 dBm for 8MHz channels.

2.3 Relationship between C and P_T

The link budget is:

$$C=G_{LNA}+P_R \qquad (9)$$

where G_{LNA} includes all block gains from the antenna until the Decider input (see Figure 1). The minimum P_R is usually called the receiver sensitivity. C can now be expressed in function of the transmitting power P_T:

$$C=G_{LNA}+P_T+G_T+G_R-L_{Loss}-L_{LV}-L_{Bld}-L_H \qquad (10)$$

The antenna gain [4] is given by

$$G_{T,R}=\frac{4\pi A}{\lambda^2} \qquad (11)$$

where A is the antenna effective aperture,

$$\lambda=\frac{c}{f} \qquad (12)$$

and c is the light velocity (3×10^8 m/s) and f is the frequency of the transmitted carrier. An omnidirectional antenna has gain $G_{T,R}$=1. In this case,

$$A=\frac{\lambda^2}{4\pi} \qquad (13)$$

An integrated antenna in a small hand-held device G_R varies from -5 dBi (858 MHz) to -10 dBi (474 MHz) [5]. The path loss, L_{Loss}, is a function of the distance between the transmitter and the receiver d, and is obtained either from a closed expression like Friis formula (free space loss) [6],

$$L_{Loss}=\left(\frac{4\pi d}{\lambda}\right)^2 \qquad (14)$$

or from an empirical model which gives more precise values. Empirical models are discussed in Section 3.

In (10), the term L_{LV} is included to introduce the shadowing (long-term fading) effect, mainly caused by terrain features of the land-mobile radio propagation environment. The power varies with the distance. Never confuse shadowing with slow-fading! The mathematical model for shadowing is a lognormal distribution, i.e. a Gaussian distribution in the decibel domain. A typical value for the outdoor standard deviation is 5.5 dB and for indoor 6 dB [3]. Therefore, the total standard deviation is $(5.5^2+6^2)^{1/2}$=8.1dB. As shadowing is modeled as a Gaussian distribution, we conclude that the path loss at the cell edge will be less than the calculated value in (14) for 50% of the edge locations. To achieve higher percentage, we use the Gaussian cumulative function (at 0dB means 50%). For instance, to achieve 90% at the edge, it means 97% location coverage over the whole cell [7], we have to add L_{LV}=10.3 dB.

The building penetration loss L_{Bdl} is 11dB [3]. The propagation prediction methods use reference antennas at a certain height. For instance, ITU-R P.1546-2 [8] uses a receiving height of 10m. Therefore, we have to introduce a correction factor for other antenna heights. For instance, L_H=24dB for Urban areas, at 800 MHz and receiving antenna height of 1.5 m above ground level. The following table summarizes the link budget and determinates the minimum P_T for d=5 km radius cell.

Table 2 Link Budget

Parameter	Value	Unit
Noise Floor, KTB_W	-105.2	dBm
Rx Noise Figure	5	dB
Noise Figure	-100.2	dBm
C/N (QPSK)	12	dB
C	-88.2	dBm
G_{LNA}(AGC Maximum Gain)	10	dB
$P_{R\,min}$ (Rx Sensitivity)	-98.2	dBm
G_T	0	dBi
G_R	-5.5	dBi
L_{Loss}	104	dB
L_{LV}	10.3	dB
L_{Bld}	11	dB
L_H	24	dB
P_T	57.1	dBm
P_T	510	W

We should note that in the link budget in Table 2, the receiver does not include any channel coding. It is expected that the C/N is around 6dB for QPSK. In this case, a 50W power amplifier will allow reception inside a building at a distance of 10km.

2.4 *Electrical Field and Power Relation*

Sometimes, we just know the magnitude of electrical field and we need to convert it to the receiver power. For instance, ITU-R P1546-2 [8] provides field strength curves in function of the distance between the transmitter (1KW EIRP) and the receiver. The following expression [4] gives this relationship:

$$|E| = \sqrt{4\pi\eta \frac{P_R}{G_R} \frac{f}{c}} \tag{15}$$

where η=120π Ω (377 Ω)and represents the intrinsic impedance of free space.

3 Fixed and Mobile Channels

Section 3 describes the channel model for DVB-T/H/RCT, WIMAX and WLAN. Particular attention is paid to the path loss models and the multipath loss models. Note that DVB-T, DVB-H and DVB-RCT channels are discussed in the same section, due to the fact that these systems work at similar frequency band, i.e. UHF and VHF.

3.1 DVB-T, DVB-H, and DVB-RCT Channel Model

This section is divided into two parts. The first part examines the path loss and multipath loss model for fixed DVB-T and DVB-RCT systems, while the second part discusses the path loss and multipath loss model for mobile DVB-T (also known as DVB-H) and DVB-RCT systems. The selection of model leverages the experiences of consortium partner, Runcom, in the area of DVB-T and DVB-RCT systems.

3.1.1 DVB-T and DVB-RCT Fixed Channel Model

Path Loss Model

The Stanford University Interim (SUI) channel models [9] (which is based on the Hata-Okumura model) has been adopted for fixed DVB-T and DVB-RCT wireless systems in this project. SUI has been recommended by consortium partner, Runcom, who will supply the DVB-T and DVB-RCT equipments for the SUIT field trials in WP6. Although SUI was defined for frequencies higher than 2GHz, it can be also used for lower frequencies with the proper corrections, as will be described in the following paragraphs.

The SUI models are divided into three types of terrain, namely A, B, and C. Type A features the greatest path loss, and is intended to represent a hilly terrain with moderate to heavy foliage densities. Type C has the minimum path loss, and represents a rural environment with light tree densities. Type B is intended for simulations involving flat terrains with heavy tree densities, or hilly terrains with light tree densities. The equation for the modified SUI path loss model with correction factors is presented below [10]:

$$PL[dB] = A + 10\,\gamma\,\log(\frac{d}{d_0}) + X_f + X_k + X_\sigma \quad \text{for } d > d_0 \tag{16}$$

where d is the distance between the base station and the receiver antennas in metres, d_0 is the reference distance with value of 100m, and X_σ is a normally distributed factor that is used to account for shadow fading due to trees and other clutter. X_σ has a value between 8.2dB and 10.6dB (see Section 2.3). The parameter γ is defined as the path loss exponent. X_f is a frequency correction factor. The rest of the parameters are:

$$A = 20\log_{10}(\frac{4\pi d_0}{\lambda})$$
$$\gamma = a - bh_b + \frac{c}{h_b} \tag{17}$$

where A is the Friis' formula (14), λ being the wavelength in metres, while the parameter h_b is the base station height above ground in meters (should be between 10m and 80m). The constants used for a, b and c are given in Table 3.

For a given terrain type the path loss exponent, γ, is determined by h_b. The correction factors, X_f, for the operating frequency and for the receiver antenna height for the model are:

Table 3 Numerical values for the SUI model parameters

Model Parameter	Terrain A	Terrain B	Terrain C
a	4.6	4.0	3.6
b (m^{-1})	0.0075	0.0065	0.005
c (m)	12.6	17.1	20

$$X_f = 6\log_{10}(f/2000) \tag{18}$$

and

$$X_k = \begin{cases} -10.8\log_{10}(hr/2000) & \text{for Terrain A and B} \\ -20.0\log_{10}(hr/2000) & \text{for Terrain C} \end{cases} \tag{19}$$

where f is the operating frequency in MHz and hr is the receiver antenna height above the ground in metres.

Multipath Loss Model

Due to the scattering environment, the signal power that arrives at the receiver contains the echoes of the transmitted power, bounced off objects in different locations at different distances from the receiver. The channel can then be characterized by the power components received, each associated to a particular propagation delay. The profile of the power component and the associated delay is called the multipath delay profile. The adopted for the system is the multipath delay model defined for IEEE 802.16d system [9]. The IEEE 802.16d's multipath models can be used here since they are defined for fixed wireless system.

For IEEE 802.16d multipath model, the power delay profile of system with directive antennas can be represented by spike-plus-exponential shape [11]:

$$P(\tau) = A\delta(\tau) + B\sum_{i=0}^{\infty}\exp(-i\Delta\tau/\tau_0)\delta(\tau - i\Delta\tau) \tag{20}$$

where $P(\tau)$ is the power received at delay τ. A, B and τ_0 are constants that are determined empirically. Furthermore, the paper [11] has discussed a method to calculate τ_0 by using the RMS delay spread τ_{rms} estimated from the target environment. Mathematically, the RMS delay spread, τ_{rms}, of the propagation environment can be defined as:

$$\tau_{rms} = \sum_j P_j \tau_j^2 - (\tau_{avg})^2 \tag{21}$$

where

$$\tau_{avg} = \sum_j P_j \tau_j \tag{22}$$

while τ_j and P_j are respectively the delay of jth delay component of the profile and power in jth delay component divided by the total power in all components. The paper [12] have studied the empirical behaviour of τ_{rms} for various propagation environments and proposed a statistical model based on the analysis. It has been found that the RMS delay spread follows the lognormal distribution, and that the main median of this distribution grows as power of distance. Based on the observation, the RMS delay spread model was proposed:

$$\tau_{rms} = T_1 d^\varepsilon y \tag{23}$$

where τ_{rms} is the RMS delay spread, d is the distance in km, T_1 is the median value of τ_{rms} at d=1km, ε is an exponent that lies between 0.5 and 1.0, and y is a lognormal variable with standard

deviation σ_y. The model was developed for rural, suburban, urban, and mountainous environments. The parameter values for each environment can be obtained from Table-III in [12]. The parameter values are also portrayed in Table 4. It should be noted that the results are valid only for omni directional antennas. To consider the directive antennas, τ_{rms} should be reduced by a factor of 2.3 for a 32º directional antenna and by 2.6 for a 10º directional antenna. Depending on the terrain, distances, antenna directivity and other factors, the RMS delay spread values can span from very small values (tens of nanoseconds) to large values (microseconds).

Table 4 Numerical values for multipath delay model

Model Parameter	Value
T_1	0.4 µs (urban microcell)
	0.4 - 1.0 µs (urban macrocell)
	0.3 µs (suburban areas)
	0.1 µs (rural areas)
	$\geq$ 0.5 µs (mountainous areas)
ε	0.5 (urban, suburban, rural)
	1.0 (mountainous areas)
σ_y	2 - 6 dB

Another model for fixed and portable terminals is defined in the DVB-T/H standard [2]. It actually defines a fixed channel, F1, and a portable channel P1. The latter has 20 paths, whereas the former has 21 paths, where the extra path is the LOS path.

3.1.2 DVB-T and DVB-RCT Mobile Channel Model

Path Loss Model

For mobile DVB-T (also known as DVB-H) and DVB-RCT, the COST231 Hata model [10;13] (an extension of the Hata-Okumura model) has been chosen as the path loss model. The COST231 Hata model is designed to be used in the frequency band from 500MHz to 2000MHz. It also contains corrections for urban, suburban and rural (flat) environments, which will be described in this section. For small cell sizes, COST231 Walfish-Ikegami can be used.

COST231-Hata Model For Macrocells

The COST231 Hata path loss equation is presented below [10]:

$$PL[dB] = 46.3 + 33.9\log_{10}(f) - 13.82\log_{10}(h_b) - ah_m + (44.9 - 6.55\log_{10}(h_b))\log d + C_m + X_\sigma \quad (24)$$

where f is the frequency in MHz, d is the distance between base station and the receiver antenna in km, and h_b is the base station antenna height above ground in metres. The parameter C_m is defined as 0dB for suburban or open environments, and 3dB for urban environments. X_σ is a normally distributed variable that captures the shadowing loss component, with its standard deviation being 8dB for both urban and suburban environments. ah_m can be defined for urban areas as follows:

$$ah_m = 3.20(\log_{10}(11.75h_r))^2 - 4.97, \text{ for } f > 400 \text{ MHz} \quad (25)$$

and for suburban or rural areas (flat) as follows:

$$ah_m = (1.1 \times \log_{10} f - 0.7)h_r - (1.56\log_{10} f - 0.8) \tag{26}$$

where h_r is the receiver antenna height. By observing PL, it can be seen that the COST 231 Hata model predicts the path loss exponent to be:

$$n = (44.9 - 6.55\log10(h_b))/10. \tag{27}$$

where n is the parameter of simpler path loss equation obtained using Least Square regression analysis [10]:

$$L_p[dB] = L(d_0) + 10n\log_{10}(\frac{d}{d_0}) \tag{28}$$

where n is also called the path loss exponent, d_0 is the reference distance, while $L(d_0)$ is the path loss at the reference distance. The path loss exponent is a valuable parameter as it shows the rate of increase of path loss with respect to distance.

COST231 Walfish–Ikegami for Microcell

In a small cell with a 500 metre radius, the COST231 Walfish–Ikegami (W-I) model can be adopted [14]. The model can be divided in NLOS and LOS cases. In NLOS environment, the path loss model is:

$$PL[dB] = -55.9 + 38\log_{10}(d) + (24.5 + 1.5f_c/925)\log_{10}(f_c) + X_\sigma \tag{29}$$

where d is the distance between transmitter and receiver in meters while f_c is the carrier frequency. X_σ is a normal variate that captures the shadowing component, with its standard deviation of 10dB. As for the LOS environment, the path loss model is:

$$PL[dB] = -35.4 + 26\log_{10}(d) + 20\log_{10}(f_c) + X_\sigma \tag{30}$$

where the symbols in the above equation have the same meaning to the NLOS case. The standard deviation for normal distributed variate, X_σ, is 4dB.

Multipath Loss Model

The following six tap multipath profiles, defined in Table 5 below, are provided for the DVB-H/RCT systems. These profiles are provided by Runcom, extended from the COST231 multipath delay profile using a channel fading simulator and a channel sounder. The amplitude is shown in dB, relative to the strongest signal path, i.e. the reference signal path.

Table 5 Vehicular TDL parameters - high antenna

Tap	Profile A Relative delay (μs)	Profile A Average power (dB)	Profile B Relative delay (μs)	Profile B Average power (dB)	Profile C Relative delay (μs)	Profile C Average power (dB)	Profile D Relative delay (μs)	Profile D Average power (dB)	Doppler spectrum
1	0	0	0	-6	0	-9	0	-10	classic
2	3	-7	3	0	2	0	2	0	classic
3	8	-15	5	-7	5	-19	5	-22	classic
4	11	-22	7	-22	16	-14	16	-18	Classic
5	13	-24	10	-16	24	-24	22	-21	Classic
6	21	-19	14	-20	33	-16	30	-7	Classic

The term "Classic" in the table refers to the classical (Jake's) Doppler spectrum. For a multipath delay profile, another important parameter is the Rician K-factor. The K-factor, only used in LOS modelling, is defined as the ratio of signal power in the dominant component over the (local-mean) scattered power. The K-factor is set by the equation [14]:

$$K[dB] = 13 - 0.03d, \quad d < 300 \text{ meter} \tag{31}$$

where d is the distance between transmitter and receiver in meters. The K-factor is defined only for microcell LOS case. LOS modelling will not be defined for the suburban or urban macro cases due to the low probability of occurrence [14].

Other models for mobile terminals are defined in COST 207 [15]. Two specific channels may be used in SUIT, the *Typical Urban* (TU-6) and the *Hilly Terrain* (HT-6), both with 6 paths. The power profiles are given by $P_m = \{-3, 0, -2, -6, -8, -10\}$ and $P_m = \{0, -2, -4, -7, -6, -12\}$ (dB) and delays $\{0, 0.2, 0.5, 1.6, 2.3, 5.0\}$ and $\{0, 0.2, 0.4, 0.6, 15.0, 17.2\}$ (μs), respectively.

3.2 WIMAX Channel Model

The channel model for the mobile WIMAX system (based on IEEE802.16e) will be adopted from ITU-R Recommendation M.1225 [16]. This following section describes the channel model in ITU-R Recommendation M.1225, i.e. the path loss and multipath fading channel model, for selected target environments including indoor office, outdoor to indoor and pedestrian, and vehicular test environments. The attributes associated with each test environment are illustrated in Table 6.

Table 6 Attributes of test environment

Test Environment	Attributes
Indoor office	• Small cell, low transmit power • Indoor base stations • Indoor users
Outdoor to indoor and pedestrian	• Small cell, low transmit power • Outdoor base stations with low antenna height • Outdoor users on street and indoor users inside building or residences.
Vehicular	• Large cell, high transmit power • Outdoor base stations • Outdoor users in urban or suburban area.

3.2.1 Path Loss Model
The path loss models for the targeted environment outlined in Table 6 are described below. The described path loss models are for frequencies around 2GHz. The path loss model for 3.5GHz is not included at the time of writing as it is not widely available, but the consortium partner, Runcom, will provide input in this respect in the near future. These details will be included in the deliverable associated with Activity 2.3.

Path loss model for an indoor office test environment
The indoor path loss model, derived from the COST 231 indoor model, is presented below:

$$L[dB]=37+30\log_{10}(R)+18.3n^{\left(\frac{n+2}{n+1}-0.46\right)}+X_{\sigma} \tag{32}$$

where R is the transmitter-receiver separation (in metres), and n is the number of floors in the path. X_{σ} is a normal distributed variate that models the shadow fading component with a standard deviation of 12dB. Note that L should not be less than the free space loss.

Path loss model for outdoor to indoor and pedestrian test environments
The path loss model for outdoor to indoor and pedestrian test environments has the following form:

$$L[dB]=40\log_{10}(R)+30\log_{10}(f)+49+X_{\sigma} \tag{33}$$

where R is separation between the base station and the mobile station (km), and f is the carrier frequency. X_{σ} is a normal distributed variable that models the shadow fading component. The standard deviation for outdoor users is 10dB while 12dB is assumed for indoor users. The average building penetration loss is 12dB with a standard deviation of 8dB. Note that L should not be less than the free space loss. It is valid for NLOS cases only and considers the worst case propagation.

Path loss model for a vehicular test environment
This model below is applicable for the test scenarios in urban and suburban areas outside the high rise core, where the buildings are nearly uniform height:

$$L[dB]=40(1-4\times10^{-3}\Delta h_{b})\log_{10}(R)-18\log_{10}(\Delta h_{b})+21\log_{10}(f)+80+X_{\sigma} \tag{34}$$

where R is the base station and mobile station separation (km), f is the carrier frequency, Δh_{b} is the base station antenna height (m) measured from the average rooftop level and X_{σ} is a normally distributed variable with 10dB standard deviation for urban and suburban area.

The path loss model is only valid for a range of Δh_{b} from 0 to 50m. Note that L should not be less than the free space loss. This model is valid for the NLOS case only and considers the worst case propagation.

3.2.2 Multipath Loss Model

ITU-R M.1225 recommendation [16] specifies two multipath channels for each test environment in Table 7: channel A and channel B. Two multipath channel models are used for each test environment due to the difficulty in capturing the delay spread variability by using only a single tapped line. Channel A represents the low delay spread case, whereas channel B represents the medium delay spread case. It is expected that these channels will be encountered for certain percentage of time (95%) for a given test environment. Table 7 gives the percentage of time of channel A and channel B that may be encountered, with the associated RMS average delay spread listed next to it.

Table 8 to Table 10 portray the TDL parameters for the discussed test environments. For each tap of the channels, three parameters are given: the time delay relative to the first tap, the average power relative to the strongest tap and the Doppler spectrum of each tap. A small variation, ±3%, in the

relative time delay is permitted so that the channel sampling rate can be matched to the multiples of the link simulation sample rate.

Table 7 Average RMS delay and percentage of channel encountered

Test Environment	Channel A		Channel B	
	RMS (ns)	P (%)	RMS (ns)	P (%)
Indoor office	35	50	100	45
Outdoor to indoor and pedestrian	45	40	750	55
Vehicular – high antenna	370	40	4000	55

Table 8 Indoor office test environment TDL parameters

Tap	Channel A		Channel B		Doppler spectrum
	Relative delay (ns)	Average power (dB)	Relative delay (ns)	Average power (dB)	
1	0	0	0	0	Flat
2	50	-3.0	100	-3.6	Flat
3	110	-10.0	200	-7.2	Flat
4	170	-18.0	300	-10.8	Flat
5	290	-26.0	500	-18.0	Flat
6	310	-32.0	700	-25.2	Flat

Table 9 Outdoor to indoor and pedestrian test environment TDL parameters

Tap	Channel A		Channel B		Doppler spectrum
	Relative delay (ns)	Average power (dB)	Relative delay (ns)	Average power (dB)	
1	0	0	0	0	Classic
2	110	-9.7	200	-0.9	Classic
3	190	-19.2	800	-4.9	Classic
4	410	-22.8	1200	-8.0	Classic
5	-	-	2300	-7.8	Classic
6	-	-	3700	-23.9	Classic

Table 10 Vehicular test environment, high antenna, TDL parameters

Tap	Channel A		Channel B		Doppler spectrum
	Relative delay (ns)	Average power (dB)	Relative delay (ns)	Average power (dB)	
1	0	0	0	-2.5	Classic
2	310	-1.0	300	0	Classic
3	710	-9.0	8900	-12.8	Classic
4	1090	-10.0	12900	-10.0	Classic
5	1730	-15.0	17100	-25.2	Classic
6	2510	-20.0	20000	-16.0	Classic

3.3 IEEE 802.11g Channel Model Descriptions

This section describes the path loss model and multipath loss model for IEEE 802.11g. These models have been designed to consider various target indoor environments and have been used extensively in the standardization process as well as the literature [17-20]. The model will be described in detail in the following sections.

3.3.1 Path Loss Model

In both indoor and outdoor environments, transmitted signal power decays with distance and obstruction before reaching the receiver. The path loss is site-specified due to the differences in building structure, building material and obstructions etc. The overall propagation path loss can be modelled using the Log-Distance model [19;20]:

$$PL_{dB} = PL(d_0) + 10n\log10(\frac{d}{d_0}) + X_\sigma \tag{35}$$

where $PL(d_0)$ is the path loss at reference distance d_0. d in the above equation is the distance between the transmitter and the receiver, while n is the propagation environment specific path loss exponent. X_σ is the normal distributed variable, with standard deviation of σ dB, which contributes to the shadowing loss. Note that the unit of path loss, PL_{dB}, is in dB. Various measurements have been made, and the reference values for $PL(d_0)$ and n for a typical indoor environment can be obtained from [19].

3.3.2 Multipath Loss Model

There are two existing multipath channel models for IEEE 802.11g. The first model is the Exponential Decaying Rayleigh Fading Channel Model [18] chosen by the IEEE 802.11 committee for system evaluation during the standardization process. The second model is the HiperLAN/2 Channel Model A to E [17] chosen by the ETSI BRAN committee for HiperLAN/2 standardization. In both cases, these models target the indoor environment and are suitable for evaluation of IEEE 802.11g. Both models will be described in the following sections.

Exponential Decaying Rayleigh Fading Channel Model

The IEEE 802.11 committee had defined a baseline model, called the Exponential Decaying Rayleigh Fading Channel Model [18], for the evaluation of the physical layer performance. The model is described in the following paragraphs.

The channel impulse response, h_k, is a complex samples, where the magnitude of the sample be Rayleigh distributed. In the model, the average power of the channel impulse response decays exponentially. h_k is expressed mathematically as:

$$h_k = N(0, \frac{1}{2}\sigma_k^2) + jN(0, \frac{1}{2}\sigma_k^2) \tag{36}$$

where $N(0, \frac{1}{2}\sigma_k^2)$ is a zero mean Gaussian random variable with variance $\frac{1}{2}\sigma_k^2$. σ_k^2 is the power term defined as:

$$\sigma_k^2 = \sigma_0^2 e^{-kT_S/T_{RMS}} \tag{37}$$

where T_S and T_{RMS} are the sampling time and RMS delay spread respectively. In addition, $\sigma_0^2 = 1 - e^{-T_S/T_{RMS}}$ is chosen so that the average power is normalized, i.e. $\sum \sigma_k^2 = 1$. The maximum number of taps, k_{max}, of the channel impulse response should be long enough to allow sufficient decay of the impulse response, e.g. $k_{max} = 10 T_{RMS}/T_S$. The T_{RMS} is an adjustable parameter to take into account different ranges of conditions, from a small office to an outdoor picocell i.e. large T_{RMS} value for large indoor space. The T_{RMS} value in a typical office environment is 50ns. During the simulation, the channel should be held static throughout a packet duration, but can vary from packet to packet [18].

HiperLAN/2 Channel Models

The ETSI BRAN has defined a set of indoor channel models to be used for HIPERLAN/2 simulations [17]. The models are named Channel- A, B, C, D, and E, and represent different indoor and outdoor environments. Channels- A, B, C, and E all feature NLOS conditions, while channel E has a LOS component. Channel A corresponds to a typical office environment. Channel B corresponds to a typical large office environment. Channel C and E correspond to typical large indoor open space or outdoor environments with large delay spread. Model D corresponds to large indoor open space or outdoor environment with LOS component. The channel models in the HIPERLAN/2 standard are specified in the form of TDL filter tap gain portrayed in Table 11 to Table 15. A terminal speed of 3m/s is assumed for all the taps.

Table 11 Model A, corresponding to a typical office environment with 50ns RMS delay spread.

Tap Number	Delay (ns)	Average Power (dB)	Ricean K	Doppler Spectrum
1	0	0.0	0	Classic
2	10	-0.9	0	Classic
3	20	-1.7	0	Classic
4	30	-2.6	0	Classic
5	40	-3.5	0	Classic
6	50	-4.3	0	Classic
7	60	-5.2	0	Classic
8	70	-6.1	0	Classic
9	80	-6.9	0	Classic
10	90	-7.8	0	Classic
11	110	-4.7	0	Classic
12	140	-7.3	0	Classic
13	170	-9.9	0	Classic
14	200	-12.5	0	Classic
15	240	-13.7	0	Classic
16	290	-18.0	0	Classic
17	340	-22.4	0	Classic
18	390	-26.7	0	Classic

Table 12 Model B, corresponding to typical large office environment with 100ns RMS delay spread.

Tap Number	Delay (ns)	Average Power (dB)	Ricean K	Doppler Spectrum
1	0	-2.6	0	Classic
2	10	-3.0	0	Classic
3	20	-3.5	0	Classic
4	30	-3.9	0	Classic
5	50	0.0	0	Classic
6	80	-1.3	0	Classic
7	110	-2.6	0	Classic
8	140	-3.9	0	Classic
9	180	-3.4	0	Classic
10	230	-5.6	0	Classic
11	280	-7.7	0	Classic
12	330	-9.9	0	Classic
13	380	-12.1	0	Classic
14	430	-14.3	0	Classic
15	490	-15.4	0	Classic
16	560	-18.4	0	Classic
17	640	-20.7	0	Classic
18	730	-24.6	0	Classic

Table 13 Model C, corresponding to typical large open space environment with 150ns RMS delay spread.

Tap Number	Delay (ns)	Average Power (dB)	Ricean K	Doppler Spectrum
1	0	-3.3	0	Classic
2	10	-3.6	0	Classic
3	20	-3.9	0	Classic
4	30	-4.2	0	Classic
5	50	0.0	0	Classic
6	80	-0.9	0	Classic
7	110	-1.7	0	Classic
8	140	-2.6	0	Classic
9	180	-1.5	0	Classic
10	230	-3.0	0	Classic
11	280	-4.4	0	Classic
12	330	-5.9	0	Classic
13	400	-5.3	0	Classic
14	490	-7.9	0	Classic
15	600	-9.4	0	Classic
16	730	-13.2	0	Classic
17	880	-16.3	0	Classic
18	1050	-21.2	0	Classic

Table 14 Model D, same as model C but for LOS conditions. A 10 dB spike at zero delay has been added.
The RMS delay spread is 140ns.

Tap Number	Delay (ns)	Average Power (dB)	Ricean K	Doppler Spectrum
1	0	0.0	10	Classic + Spike
2	10	-10.0	0	Classic
3	20	-10.3	0	Classic
4	30	-10.6	0	Classic
5	50	-6.4	0	Classic
6	80	-7.2	0	Classic
7	110	-8.1	0	Classic
8	140	-9.0	0	Classic
9	180	-7.9	0	Classic
10	230	-9.4	0	Classic
11	280	-10.8	0	Classic
12	330	-12.3	0	Classic
13	400	-11.7	0	Classic
14	490	-14.3	0	Classic
15	600	-15.8	0	Classic
16	730	-19.6	0	Classic
17	880	-22.7	0	Classic
18	1050	-27.6	0	Classic

Table 15 Model E, corresponding to typical large open space environment with 250ns RMS delay spread

Tap Number	Delay (ns)	Average Power (dB)	Ricean K	Doppler Spectrum
1	0	-4.9	0	Classic
2	10	-5.1	0	Classic
3	20	-5.2	0	Classic
4	40	-0.8	0	Classic
5	70	-1.3	0	Classic
6	100	-1.9	0	Classic
7	140	-0.3	0	Classic
8	190	-1.2	0	Classic
9	240	-2.1	0	Classic
10	320	0.0	0	Classic
11	430	-1.9	0	Classic
12	560	-2.8	0	Classic
13	710	-5.4	0	Classic
14	880	-7.3	0	Classic
15	1070	-10.6	0	Classic
16	1280	-13.4	0	Classic
17	1510	-17.4	0	Classic
18	1760	-20.9	0	Classic

4 Summary

In the previous sections, a set of channel models for DVB-T/H, DVB-RCT, WIMAX, and IEEE 802.11g have been selected. The selection was made based on the model applicability, recommendations from standard bodies (e.g. IEEE, ITU and WIMAX forum), and consortium partners' experience in these wireless systems. While this document provides baseline reference scenarios to WP2 Activities 2.2, 2.3, 2.4 and 2.5, future work will not be limited to these models. This will allow other relevant/better model to be added over time should they become available. The selected channel models in this activity are summarized in Table 16 below.

Table 16 Summary of selected channel models

Wireless System	Type of Model	Description
DVB-T/RCT Fixed Environment	Propagation Model	Modified SUI - Terrain A, B, C
	Multipath Model	IEEE 802.16d multipath delay model
DVB-T/RCT Mobile Environment	Propagation Model	COST231 Hata model for macrocell COST231 Walfish-Ikegami for microcell
	Multipath Model	Runcom's multipath delay model, modified from COST231 multipath model, and COST207 TU6
Mobile WIMAX	Propagation Model	ITU-R M.1225 propagation model • Indoor • Outdoor and Pedestrian • Vehicular
	Multipath Model	ITU-R M.1225 multipath model • Indoor • Outdoor and Pedestrian • Vehicular
IEEE 802.11g	Propagation Model	Log distance
	Multipath Model	• IEEE 802.11 Exponential Decaying Rayleigh Fading Model • ETSI BRAN HiperLAN Model A-E

5 Acronyms

BRAN	Broadband Radio Access Networks
COST	European Cooperation in the field of Scientific and Technical Reseach
DVB-H	Digital Video Broadcasting Handheld
DVB-T	Digital Video Broadcasting Terrestrial
DVB-RCT	Digital Video Broadcasting Return Channel Terrestrial
dB	decibels
ETSI	European Telecommunications Standards Institute
HiperLAN	HIgh PErformance Radio LAN
IEEE	Institute of Electrical and Electronics Engineers
IMT-2000	International Mobile Telecommunications-2000
ITU	International Telecommunication Union
LAN	Local Area Network
LOS	Line of Sight
NLOS	None Line of Sight
RMS	Root Mean Square
RTT	Radio Transmission Technologies
SUI	Stanford University Interim
SUIT	Scalable, Ultra-fast and Interoperable Interactive Television
UHF	Ultra High Frequency
VHF	Very High Frequency
WIMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless LAN
WP	Workpackage

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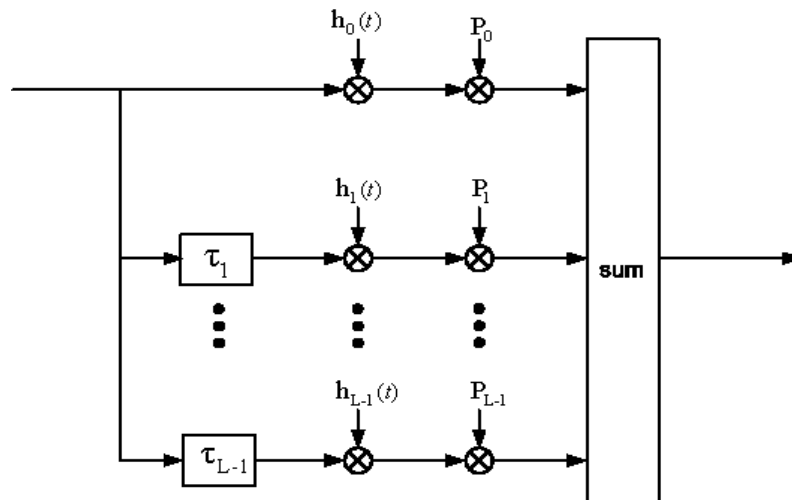## Appendix 1. Tapped Delay Line (TDL)

Figure 3 Tapped Delay Line Filter

The multipath channel model in the literature is commonly specified as parameters of the Tapped Delay Line (TDL) filter [1]. The TDL filters are usually defined by the following parameters:

- The number of taps, L.
- The time delay relative to the first tap, τ_1.
- The average power relative to the strongest tap, P_1.
- The Doppler spectrum of each tap, e.g. Jakes.
- The fading distribution of each tap, e.g. Rayleigh or Rician.

Mathematically, the TDL filter response to an impulse $c(t)$ is represented as:

$$H(t,P,\tau) = \sum_1 P_1 \cdot h_1(t) \cdot c(t-\tau_1)$$

where P_1, and τ_1 are explained above while h_1 is the time-varying complex tap amplitude generated from Doppler spectrum filtered Rayleigh or Rician random variables. The TDL filter is graphically portrayed in Figure 3. L, P_1, τ_1 and h_1 profiles are jointly considered as a channel profile. An example of the channel profile for a given environment is specified in Table 5.