**IEEE P802.15**

**Wireless Personal Area Networks**

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| --- | --- |
| Project | IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs) |
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| Re: | Task Group 15.4m Technical Guidance for Proposals |
| Abstract | [TG4m - technical guidance for PHY proposals.] |
| Purpose | [Working document for the PAR to the P802.15 Working Group.] |
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1. **Introduction**

**Purpose**

This document provides technical guidance by summarizing parametrically the key PHY characteristics and any necessary MAC changes identified in consideration of WPAN-WS (WPAN white space) application and regulatory requirements. PHY parameters and criteria to guide the preparation and selection of proposals for Task Group 802.15.4m are presented. This document defines the PHY characteristics and MAC amendment requirements with guidance on how proposals might address them, and provides a framework for evaluating proposals.

The intent of the task group is to use a flexible and efficient process that provides sufficient descriptions of the technical requirements to enable relevant responses, with efficiency of effort while meeting the critical need for a timely standard. The TG4m task group will use this document to help qualify MAC and PHY protocol proposals.

## Methodology

The methodology provides a consensus approach to defining a minimal set of features, characteristics, performance and constraints to be considered. This document provides:

* A functional view of the PHY characteristics, in the form of specific parameters which define externally verifiable performance and interoperability characteristics; and
* Application/performance description~~s~~ that characterizes the types of WPAN-WS applications and the derived performance characteristics.

The PHY parameters table provides guidance on developing complete technical proposals. This represents a subset of parameters, and the absence of a parameter should not be seen as a constraint. The PHY parameter column consists of two sub-columns. The first identifies the parameters based on the application mentioned in the application requirements matrix and; the second provides some examples of how this might be addressed in a proposal; there will be alternatives appropriate to specifying the characteristic depending on the specifics of the proposal. The performance criteria column includes potential requirements, constraints, and/or explanations that may help in consideration during the proposal preparation. The “regulatory” column is intended to identify where regional differences in regulations (present and anticipated) may affect the PHY characteristics.

In preparing proposals, this can be used as a framework to produce a concise summary of the characteristics of each given proposal, and will allow the group to see the similarities and differences in submitted proposals.

# Requirements Discussion

## Summary of PAR

**2.1 Title:**

IEEE Standard for Local and Metropolitan Area Networks Part 15.4: Low Rate Wireless Personal Area Networks (LR-WPANs) Amendment: TV White Space between 54 MHz and 862 MHz Physical Layer

**5.2 Scope:**

This amendment specifies a physical layer for 802.15.4 meeting TV white space regulatory requirements in as many regulatory domains as practical and also any necessary Media Access Control (MAC) changes needed to support this physical layer. The amendment enables operation in the VHF/UHF TV broadcast bands between 54 MHz and 862 MHz, supporting typical data rates in the 40 kbits per second to 2000 kbits per second range, to realize optimal and power efficientdevice command and control applications.

**5.5 Need for the Project:**

There are many instances in large area device command and control applications where infrastructure requirements need to be minimized for effective deployment. These needs are effectively served by the ability to operate 802.15.4 class networks in the TV white space spectrum.

The PAR can be found on the IEEE802 web site: (https://mentor.ieee.org/802.15/dcn/11/15-11-0643-00-004m-tg4m-par.pdf).

## High Level Requirements Overview

From the PAR and general procedural rules, key overall goals and requirements of this project can be summaried as follows:

* The amendment shall specify operations meeting at least one, and as many as practical, TV White Space regulatory requirements.
* The amendment shall specify operations in TV white space frequency bands under regulatory constraints that can be identified.
* The amendment shall provide operation modes that support PHY data rate of typically 40kbps to 2000kbps. Proposers are encouraged to provide optional operation modes that support PHY data rates of ~10Mbps.
* The amendment shall achieve operating range of at least 1km.
* The amendment shall provide at least one operation mode that supports up to at least 1000 direct neighboring devices.
* The amendment should provide a means for frequency band and channel switching for radios with multi-band capability.
* The amendment shall provide mechanism to enable coexistence with users (*e.g.* TV broadcasting) protected by regulations.
* The amendment should support coexistence with other 802 systems operating in the TV white space fulfilling the requirements of providing the Coexistence Assurance Document.
* The amendment complies with the P802.15.4m PAR and 5 Criteria.
* The amendment will include a PICS proforma.

**Application Requirements Matrix**

|  |  |  |  |
| --- | --- | --- | --- |
| **Application** | **Description**  | **Key Parameters** | **Reference** |
| Smart utility networks (SUN) | TV White space application is a good candidate for SUN* + There is no special interference source except TV signal.
	+ Use the similar TV Channel frequencies all over the world
 | - Environment: Indoor/outdoor, Urban/suburban/rural-  Operating range: up to several km-  Up to several thousands of nodes in the network-  Mobility (Device type): fixed-  Security features: required-  Reliability: high-  Device category: as regulations applied to all applications | 15-09-0275-0215-11-0171-00 |
| Intelligent Transportation System | TV bands make signal travel longer distance and less vulnerable in rural areas, which can enable multiple applications between car and fixed node.* Information delivery
* Traffic management
* Logistics tracking/Vehicle location
 | * Environment: Outdoor
* Data rate: Generally <1Mbps, Up to 10Mbps
* PER: < 10%
* Operating range: One controller covers up to 1 square km
* Data flow: two-way, 100 end devices (mobile) to 1 controller (fixed)
* Transmission power: Obey regulations all over the world
* Power type: Mains powered or powered by car engine
 | 15-11-0194-0015-11-0279-01 |
| Surveillance, control and monitoring network | Larger coverage areas due to excellent propagation characteristics, which make it attractive for surveillance, control and monitoring networks | - Environment: Indoor/outdoor- Data rate: up to 2Mbps- PER <1%- Operating range: up to 1 Km- Mobility: support (e.g., up to 10Km/h) | 15-11-0215-02 |
| Infrastructure moditoring network | Larger coverage areas due to excellent propagation characteristics, which make it attractive for infrastructure monitoring | - Environment: outdoor- Data rate: less than 100Kbps- PER < 1%- Operating range: up to several Km- Reliability: high- Mobility: fixed- Energy efficiency: high | 15-11-0215-02 |
| Local network in machine-to-machine (M2M) | Larger coverage areas due to excellent propagation characteristics, which make it attractive for local networks in M2M | - Environment: Indoor/outdoor- Data rate: depends on M2M applications (40Kbps~2Mbps)- PER <1%- Operating range: depends on M2M applications (up to several Km)- Mobility: depends on M2M applications (up to 20~30Km/h) | 15-11-0215-02 |

## White Space Related Regulations

## Summary of Regulations

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Region****/Country** | **TVWS Channel Band** | **Device Type** | **Transmitted Power Requirements** | **GDB \* Requirements** | **Sensing Requirement** |
| **US (FCC)**Related document: FCC 10-174Final order: almost finalized | 6MHz channel allocationFD only: TV channel 2 (54-60MHz); TV channel 5 to 20 (76-512MHz)FD and PPD: TV channel 21 to 35 (512 to 602MHz) and TV channel 39 to 52(620-704MHz) | Fixed Device (FD): capable of geolocation and TV bands database accessPersonal/Portable Device (PPD): Mode I: list of available channels through fixed or Mode II devices; Mode II: capable of geolocation and TV bands database access;Sensing-only PPD: with no geolocation and TV bands database access. | FD: 30dBm (1W) delivered to antenna, 4W EIRP; Mode I and II PPD: 20dBm (100mW) EIRP if the adjacent channel separation requirement is met; 16dBm (40mW) EIRP if the adjacent channel separation requirement is not met; Sensing-only PPD:17dBm (50mW) EIRP Transmit power control required | Must be supported in both Fixed and PPD Mode II devices. | Optional for Fixed and PPD Mode I and II devices,Mandatory for sensing-only PPDs |
| **UK (OFCOM)**Related document: 9 Nov 2010 ConsultationFinal rules pending | 8MHz channel allocationPossibly 470-550 and 614-790MHz and FM radio bands and other bands to be identified | Master device: direct connect to database;Slave device: no need to contacct database, managed by master device | Determined by the database;Transmit power control required | Must be supported in Master devices. | Not to be used in the UK but included to aidinternational harmonisation |
| **Europe (CEPT (ECC))**Related document: ECC Report 159Still in progress | 8MHz channel allocation470-790 MHz | Not defined as devices with specific roles/features.  | Determined by the database;Transmit power control required | Must be supported. | Optional  |
| **Canada (Industry Canada(CRTC))**Related document: SMSE-012-11Still in progress | 6MHz channel allocation54-72, 76-88, 174-216, 470-608, 614-698MHz, | Fixed;Mobile:Mode I: slave device- no direct access to database); Mode II: master device- direct access to database | Fixed: Max EIRP 6dBW;Mobile: Mode I: Max 16dBm EIRP; 20dBm;Mode II: Max 16dBm EIRP; | Must be supported in both Fixed and Mode II devices. | To be considered in the future when technology is mature. |
| **Singapore (IDA)**Related document: IDA White Space Technology Information Package, 7 April 2010Still in progress | VHF 7MHz and UHF 8MHz channel allocationVHF: between 174 to 230 MHz and UHF: between 494 to 790 MHz | Will be developed in future | Sensing only devices: 100mW per channel; 4dBm with adjacent channeloperated by incumbent; 17dBm with N+2 channel operated by incumbent; Device with only geolocation: 100mW per channel | Required | Mandatory for both analogue and digital broadcast services;optional for both analogue and digital wireless microphones  |

 GDB - Geolocation Database

## Regulatory Requirements

Based on the rules from several regulatory bodies including the Federal Communications Commission (FCC) in the U. S., we can identify a set of common regulatory requirements for white space communications:

Frequency bands:

* Devices shall be operatied in any of the regionally available TV white space frequency bands between 54 MHz and 862 MHz on a license-exempt basis.

Types of white space devices:

* Fixed device
	+ This type of device is operated at a fixed location and is capable of geolocation and TV bands database access.
* Mode II Personal/portable device
	+ This type of deive does not have a fixed location while operating and is a device which has geolocation and database access features.
* Mode I Personal/portable device
	+ This type of device is a device which does not have geolocation and database access features.
* Sensing-only Personal/portable device
	+ This type of device is a device which relys only on sensing to protect incumbent users.

Transmit power:

* Fixed devices:
	+ Maximum 4W EIRP while the maximum power delivered to transmit antenna is 1W regardless of the number of TV channels on which the device operates and the maximum height of their directional antennas is 30 m above ground.
* Mode I and Mode II Personal/portable devices
	+ Maximum 100mW EIRP with permanently attached transmit and receive antennas.
* Sensing-only Personal/portable devices
	+ Maximum 50mW EIRP

Transmit power related requirements:

* All devices shall incoporate transmit power control to limit their operating power to the minimum necessary for successful communication.
* In the TV channels immediately adjacent to the channel in which a device is operating, emissions from the device shall be at least 72.8 dB below the highest average power in the TV channel in which the device is operating.
* At frequencies beyond the television channels immediately adjacent to the channel in which the device is operating, the radiated emissions from devices shall meet the following limit requirements:
	+ 54-88MHz: 100 μV/m @ 3 m;
	+ 88-174MHz: 150 μV/m @ 3 m;
	+ 174-216MHz: 1500 μV/m @ 3 m;
	+ 216-470MHz, 512-566 MHz, 608-614 MHz, 806-862 MHz : 200 μV/m @ 3 m;
	+ 470-512MHz, 566-608 MHz, 614-806 MHz: 5000 μV/m @ 3 m.

Geolocation requirements:

* Fixed devices
	+ The geographic coordinates shall be generated with an accuracy of +/- 50 meters by either an incorporated geo-location capability or a professional installer.
	+ If the fixed device is moved to another location or if its stored coordinates become altered, the operator shall re-establish the device’s geographic location either
		- by means of the device’s incorporated geo-location capability or
		- through the services of a professional installer;

and store this information in the device and re-register with the database based on the device’s new coordinates.

* Mode II personal/portable devices
	+ Accuracy of a geo-location capability to determine its geographic coordinates is +/- 50 meters.
	+ Re-establishment of its position by using its geo-location capability shall be performed:
		- each time it is activated from a power-off condition, and
		- at least once every 60 seconds while in operation, except while in sleep mode, i.e., in a modein which the device is inactive but is not powered-down.

TV bands database access and frequency bands operated:

* Fixed devices only
	+ Prior to their initial service transmission at a given location, a Fixed device shall access a TV bands database over the Internet to determine the TV channels that are available at its geographic coordinates, taking into consideration its antenna height.
* Mode II devices only
	+ Mode II personal/portable devices must access a TV bands database over the Internet to determine the TV channels that are available at their geographic coordinates prior to their initial service transmission at a given location.
	+ A Mode II device shall access the database:
		- each time it is activated from a power-off condition and re-check its location, and
		- if it changes location during operation by more than 100 meters from the location at which it last accessed the database.
	+ A Mode II device that has been in a powered state shall re-check its location and access the database daily to verify that the operating channel(s) continue to be available.
	+ Mode II devices must adjust their use of channels in accordance with channel availability schedule information provided by their database for the 48 hour period beginning at the time of the device last accessed the database for a list of available channels.
	+ A Mode II device may load channel availability information for multiple locations around, *i.e.*, in the vicinity of, its current location and use that information in its operation. A Mode II TVBD may use such available channel information to define a geographic area within which it can operate on the same available channels at all locations, for example a Mode II TVBD could calculate a bounded area in which a channel or channels are available at all locations within the area and operate on a mobile basis within that area. A Mode II TVBD using such channel availability information for multiple locations must contact the database again if/when it moves beyond the boundary of the area where the channel availability data is valid, and must access the database daily even if it has not moved beyond that range to verify that the operating channel(s) continue to be available.
* Common to Fixed and Mode II devices
	+ Fixed and Mode II devices shall access the database at least once a day to verify that the operating channels continue to remain available.
	+ Operation is permitted only on channels that are indicated in the database as being available for the device.
	+ Fixed and Mode II devices must adjust their use of channels in accordance with channel availability schedule information provided by their database for the 48 hour period beginning at the time of the device last accessed the database for a list of available channels.
	+ If a fixed or Mode II personal/portable TVBD fails to successfully contact the TV bands database during any given day, it may continue to operate until 11:59 PM of the following day at which time it must cease operations until it re-establishes contact with the TV bands database and re-verifies its list of available channels.
* Mode I devices
	+ A Mode I device may only transmit upon receiving a list of available channels from a fixed or Mode II device that has contacted a database and verified that the Device Identifier (ID) of the Mode I device is valid. The list of channels provided to the Mode I device must be the same as the list of channels that are available to the fixed or Mode II device, except that a Mode I device may operate only on channels that are permissible for its use.
	+ A fixed device may also obtain from a database a separate list of available channels that includes adjacent channels that would be available to a Mode I personal/portable device and provide that list to the Mode I device. A fixed or Mode II device may provide a Mode I device with a list of available channels only after it contacts its database, provides the database the Device Identifier (ID) of the Mode I device requesting available channels, and receives verification that the Device Identifier (ID) is valid for operation.
	+ To initiate contact with a fixed or Mode II device, a Mode I device may transmit on an available channel used by the fixed or Mode II device or on a channel the fixed or Mode II device indicates is available for use by a Mode I device on a signal seeking such contacts.
	+ At least once every 60 seconds, except when in sleep mode, a Mode I device must either receive a contact verification signalfrom the Mode II or fixed device that provided its current list of available channels or contact a Mode II or fixed device to re-verify/re-establish channel availability.
	+ A fixed or Mode II device shall provide the information needed by a Mode I device to decode the contact verification signal. At the same time it provides the list of available channels.
	+ A Mode I device may respond only to a contact verification signal from the fixed or Mode II device that provided the list of available channels on which it operates.
	+ A Mode I device must cease operation immediately if it does not receive a contact verification signal or is not able to re-establish a list of available channels through contact with a fixed or Mode II device on this schedule. In addition, a Mode II device must re-check/reestablish contact with a fixed or Mode II device to obtain a list of available channels if they lose power. Collaterally, if a Mode II device loses power and obtains a new channel list, it must signal all Mode I devices it is serving to acquire new channel list.
* Fixed devices without a direct connection to the internet.
	+ If a fixed device does not have a direct connection to the Internet and has not yet been initialized and registered with the TV bands database, but can receive the transmissions of another fixed device, the fixed device needing initialization and registration without a direct connection to the internet may transmit to another fixed device on either a channel that that other device has transmitted on or on a channel which that other device indicates is available for use to access the database to register its location and receive a list of channels that are available for its own use. Subsequently, the newly registered device must only use the television channels that the database indicates are available for it to use. A fixed device may not obtain lists of available channels from another fixed device as provided by a TV bands database for such other device, *i.e.*, a fixed device may not simply operate on the list of available channels provided by a TV bands database for another fixed device with which it communicates but must contact a database to obtain a list of available channels on which it may operate.

Security:

* TV band devices shall incorporate adequate security measures
	+ to ensure that they are capable of communicating for purposes of obtaining lists of available channels only with databases operated by administrators, and
	+ to ensure that communications between TV band devices and databases and between TV band devices are secure to prevent corruption or unauthorized interception of data.
* This requirement includes implementing security for communications between Mode I devices and fixed or Mode II devices for purposes of providing lists of available channels. However, it is not necessary for devices to apply security coding to channel availability anchannel access information where they are not the originating or terminating device and that they simply pass through.When a Mode I device makes a request to a fixed or Mode II device for a list of available channels the receiving device shall check with TV bands database that the Mode I device has a valid Device Identifier (ID) before providing a list of available channels. Contact verification signals transmitted for Mode I devices are to be encoded with encryption to secure the identity of the transmitting device. Mode I devices using contact verification signals shall accept as valid for authorization only the signals of the device from which they obtained their list of available channels.

Sensing requirements for sensing only devices:

* Detection threshold: referenced to an omnidirectional receive antenna with a gain of 0 dBi
	+ ATSC digital TV signals: -114 dBm, averaged over a 6 MHz bandwidth;
	+ NTSC analog TV signals: -114 dBm, averaged over a 100 kHz bandwidth;
	+ Low power auxiliary, including wireless microphone, signals: -107 dBm, averaged over a 200 kHz bandwidth.
* Channel availability check time
	+ A TVBD may start operating on a TV channel if no TV, wireless microphone or other low power auxiliary device signals above the detection threshold are detected within a minimum time interval of 30 seconds.
* In-service monitoring
	+ In-service monitoring of an operating channel shall be performed at least once every 60 seconds.
* Channel move time
	+ After a TV, wireless microphone or other low power auxiliary device signal is detected on a channel that a device is operating, all transmissions by the device must cease within 2 seconds.

**Coexistence**

The amendment should provide mechanism to fulfil the requirements outlined in different regulatory domain, particularly in addressing the coexistence with users protected by the regulations.

The importance of successful coexistence between 802 wireless systems has been an increasingly important concern within (and between) 802 wireless working groups. 15.4m devices must successfully operate in proximity to other wireless devices. There is established methodology in 802.15.4 (Annex E) for evaluating the coexistence implications of each PHY. As part of the project scope, TG4m must assure acceptable coexistence properties. Two views of coexistence - tolerance to other systems in the same space and impact on other systems in the same space - must be considered, including transmitters which might intentionally share the band and unintentionally impact the band. Coexistence mechanisms span both MAC and PHY layers.

Coexistence among systems within the same band should be addressed fulfilling the requirements of the coexistence assurance document.

**Interoperability**

Proposals should discuss levels of interoperability. Support for previously deployed systems is not a consideration.

As guidance to the drafters of the standard, the standard should be written such that there may be behavior that will facilitate interoperability and coexistence with existing devices in the field. The drafters should make a reasonable attempt to include the majority of currently deployed systems.

## Complexity and Cost considerations

The PHY(s) defined by TG4m should be realizable by low complexity implementations to minimize cost and to enable mass adoption of the standard. The cost considerations are not only for low capital expenditure, but also low operational expenditure. One of this proposed amendment’s objectives includes low cost installation with minimal to no operator intervention.

Cost effective communication and simple modulation techniques are potential mechanisms that help meet the low complexity, low cost requirements.

## Channel Characteristics

To evaluate the proposed systems, channel models are needed which represent target environments given for applications considered for TG4m. Two types of models are considered – channel models for calculation of path losses and ones for multipath delay profiles which consist of delayed taps.

**Path Los Channel Models** (for link budget calculation)

1. *Line-of-Sight (LOS) Propagation Model*

Friis free space equation is applied for the line-of-sight propagation model for path loss calculations:



where , and *c* is the speed of light. Additionally, *d*, *f*, *G*B and *G*T specify the transmitter-receiver-distance in meters, the frequency in Hertz and the base and terminal station antenna gain values in dBi, respectively. This model does not take the contributions from additional reflected and scattered signal paths into account.

***b.*** *Non-Line-of-Sight (NLOS) Propagation Model*

For the NLOS models for this project, two models were considered – Okumura-Hata model and a model from ITU-R P.1546-1. These two models are explained and compared in detail in Annex.

Through technical examination and consideration of the TG4m applications, it is found that ITU-R P.1546-1 model is more appropriate for TG4m situations. Thus this model is adopted for the NLOS model for this project.

ITU-R P.1546-1 has annexes which can be used for calculation of path losses for various environments for this project as follows:

* + Annex 1: Introduction
	+ Annex 2: Frequency range 30 MHz to 300 MHz
	+ Annex 3: Frequency range 300 MHz to 1000 MHz
	+ Annex 5: Additional information and methods for implementing the prediction method
	+ Annex 6: Procedure for the application of this Recommendation
	+ Annex 7: Comparison with the Okumura-Hata method
	+ Annex 8: Additional information and methods to calculate the field strength of any point contained within the envelope of the land family of curves
	+ Annex 9: Adjustment for different climatic regions

The model consists in a set of propagation curves that represent field-strength values for 1 kW effective radiated power (e.r.p.) at nominal frequencies of 100, 600 and 2 000 MHz, respectively, as a function of various parameters. The model includes the methods to interpolate and extrapolate field-strength values from these three nominal frequencies. These propagation curves were derived from the original “F-curves” still in use by the FCC in the USA for prediction broadcasting coverage.

This ITU-R P.1546-1 provides the procedure to calculate path losses applying this Recommendation step by step.

**Channel Impulse Response model** (for PHY simulations)

1. For indoor scenarios (to be included)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Path 1  | Path 2  | Path 3  | Path 4  | Path 5  | Path 6  |
| Indoor-B as defined in ITU-R M.1225  |
| Path Delay (us)  | 0  | 0.1  | 0.2  | 0.3  | 0.5 | 0.7 |
| Avg PathGain  | 0  | -3.6 | -7.2 | -10.8 | -18.0 | -25.2 |

1. For Outdoor scenarios

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Path 1  | Path 2  | Path 3  | Path 4  | Path 5  | Path 6  |
| d=1.5 km Profile A  |
| Path Delay (us)  | 0  | 0.7  | 1.2  | 3.2  | 5.5  | 6.8  |
| Avg PathGain  | 0  | -34.9  | -25.9  | -22.7  | -24.8  | -34.6  |
| d=2.7 km Profile B  |
| Path Delay  | 0  | 0.9  | 1.7  | 3.1  | 3.8  | 7.5  |
| Avg PathGain  | 0  | -18.2  | -20.6  | -25  | -26.5  | -19.6  |
| d=6.1 km Profile C  |
| Path Delay  | 0  | 0.6  | 5.3  | 6.2  | 7.5  | 19.5  |
| Avg PathGain  | 0  | -12.1  | -25.2  | -22.2  | -18.5  | -21.8  |
| COST 207 Profile D  |
| Path Delay  | 0  | 0.2 | 0.5 | 1.6 | 2.3 | 5 |
| Avg PathGain  | -3 | 0 | -2 | -6 | -8 | -10 |

# Definitions

The following provides definition of specific terms in the context of discussion with respect to TG4m applications and PHY proposals**.**

Available Channel:

A TV channel, which is not being used by an authorized service at or near the same geographic location as the TVBD and is acceptable for use by an unlicensed device, for example 6 MHz in U.S.

Fixed device:

A TVBD that transmits and/or receives radio-communication signals at a specified fixed location. A fixed TVBD may select channels for operation itself from a list of available channels provided by a TV bands database, initiate and operate a network by sending enabling signals to one or more fixed TVBDs and/or personal/portable TVBDs.

Geo-location capability:

The capability of a TVBD to determine its geographic coordinates within the level of accuracy. This capability is used with a TV bands database approved by the regulation (e.g. FCC) to determine the availability of TV channels at a TVBD’s location.

Mode I personal/portable device:

A personal/portable TVBD that does not use an internal geo-location capability and access to a TV bands database to obtain a list of available channels. A Mode I device must obtain a list of available channels on which it may operate from either a fixed TVBD or Mode II personal/portable TVBD.

Mode II personal/portable device:

A personal/portable TVBD that uses an internal geo-location capability and access to a TV bands database, either through a direct connection to the Internet or through an indirect connection to the Internet by way of fixed TVBD or another Mode II TVBD, to obtain a list of available channels.

Personal/portable device:

A TVBD that transmits and/or receives radio-communication signals at unspecified locations that may change. In U.S. personal/portable devices may only transmit on available channels in the frequency bands 512-608 MHz (TV channels 21-36) and 614-698 MHz (TV channels 38- 51).

Sensing (also known as detection):

Devices that monitor frequencies for any radio transmissions. If the devices do not detect any radio transmission, assume that the channel is free and can be used.

Television band device (TVBD) :

Intentional radiators that operate on an unlicensed basis on available channels in the broadcast television frequency bands. For example in U.S. at 54-60 MHz (TV channel 2), 76-88 MHz (TV channels 5 and 6), 174-216 MHz (TV channels 7-13), 470-608 MHz (TV channels 14-36) and 614-698 MHz (TV channels 38-51).

TV bands database:

A database system that maintains records of all authorized services in the TV frequency bands, is capable of determining the available channels as a specific geographic location and provides lists of available channels to TVBDs.

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11. ITU Recommendation, ITU-R P.1546-1

**Annex**

**Non-Line-of-Sight (NLOS) Propagation Models**

In this annex, two non-line-of-sight (NLOS) propagation models are introduced – Okumura-Hata model and ITU-R P.1546-1 model - to explain how path losses can be calculated through these models. These two models are compared in detail and some calculation results are suggested for a specific scenario for comparison.

**NLOS Okumura-Hata Model**

In NLOS scenarios an additional path loss results from scattering, diffraction and reflection effects. This is modelled by the term *L*excess, i.e.,

 [dB]

Besides of the frequency and the transmitter-receiver separation the excess path loss depends on the base and terminal station antenna heights denoted by *h*B and *h*T, respectively, in meters. For frequencies within 150-1500 MHz and distances from one up to 20 kilometres, Hata’s model may be employed for the excess path loss prediction. The model is based on extensive measurements in Tokyo and makes a distinction between small/medium and large cities as well as between urban, suburban and open rural areas. For *f*0 = 1 GHz, the excess path loss according to Hata’s model can be expressed by

 .

The applicable coefficients *L*HATA and *μ*HATA for different *h*B and *h*T are summarised in the following tables for small/medium cities, for large cities and for suburban and open areas. These tables provide the coefficients *L*HATA and *μ*HATA for the excess path loss calculation based on *f*0 = 1 GHz. for different *h*B and *h*T according to Hata’s model.

**Table A1: Hata's model excess path loss coefficients for small/medium cities at *f*0 = 1 GHz.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | *h*T = 1 m  | *h*T = 4 m  | *h*T = 7 m  | *h*T = 10 m  |
| *h*B = 30 m  | *L*HATA = -9.22 *μ*HATA = 15.22  | *L*HATA = -17.02 *μ*HATA = 15.22  | *L*HATA = -24.82 *μ*HATA = 15.22  | *L*HATA = -32.62 *μ*HATA = 15.22  |
| *h*B = 50 m  | *L*HATA = -7.93 *μ*HATA = 13.77  | *L*HATA = -15.73 *μ*HATA = 13.77  | *L*HATA = -23.53 *μ*HATA = 13.77  | *L*HATA = -31.33 *μ*HATA = 13.77  |
| *h*B = 100 m  | *L*HATA = -6.17 *μ*HATA = 11.80  | *L*HATA = -13.97 *μ*HATA = 11.80  | *L*HATA = -21.77 *μ*HATA = 11.80  | *L*HATA = -29.57 *μ*HATA = 11.80  |
| *h*B = 200 m  | *L*HATA = -4.42 *μ*HATA = 9.83  | *L*HATA = -12.22 *μ*HATA = 9.83  | *L*HATA = -20.02 *μ*HATA = 9.83  | *L*HATA = -27.82 *μ*HATA = 9.83  |

**Table A2: Hata's model excess path loss coefficients for large cities at *f*0 = 1 GHz.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | *h*T = 1 m  | *h*T = 4 m  | *h*T = 7 m  | *h*T = 10 m  |
| *h*B = 30 m  | *L*HATA = -9.22 *μ*HATA = 15.22  | *L*HATA = -17.02 *μ*HATA = 15.22  | *L*HATA = -24.82 *μ*HATA = 15.22  | *L*HATA = -32.62 *μ*HATA = 15.22  |
| *h*B = 50 m  | *L*HATA = -7.93 *μ*HATA = 13.77  | *L*HATA = -15.73 *μ*HATA = 13.77  | *L*HATA = -23.53 *μ*HATA = 13.77  | *L*HATA = -31.33 *μ*HATA = 13.77  |
| *h*B = 100 m  | *L*HATA = -6.17 *μ*HATA = 11.80  | *L*HATA = -13.97 *μ*HATA = 11.80  | *L*HATA = -21.77 *μ*HATA = 11.80  | *L*HATA = -29.57 *μ*HATA = 11.80  |
| *h*B = 200 m  | *L*HATA = -4.42 *μ*HATA = 9.83  | *L*HATA = -12.22 *μ*HATA = 9.83  | *L*HATA = -20.02 *μ*HATA = 9.83  | *L*HATA = -27.82 *μ*HATA = 9.83  |

**Table A3: Hata's model excess path loss coefficients for suburban and open areas at *f*0 = 1 GHz.**

|  |  |  |
| --- | --- | --- |
|  | Suburban areas  | Open areas  |
| *h*B = 30 m  | *L*HATA = -20.72 *μ*HATA = 15.22  | *L*HATA = -39.47 *μ*HATA = 15.22  |
| *h*B = 50 m  | *L*HATA = -19.43 *μ*HATA = 13.77  | *L*HATA = -38.18 *μ*HATA = 13.77  |
| *h*B = 100 m  | *L*HATA = -17.67 *μ*HATA = 11.80  | *L*HATA = -36.42 *μ*HATA = 11.80  |
| *h*B = 200 m  | *L*HATA = -15.92 *μ*HATA = 9.83  | *L*HATA = -34.67 *μ*HATA = 9.83  |

* + Frequency Dependency of the Excess Path Loss

As the above calculations are based on a radio frequency of 1 GHz they are not directly applicable to the TG4m system. Clearly, the excess path loss is frequency dependent as at least the diffraction losses increase with *f*. Reliable investigations on the frequency dependency of the path loss based on measurements are rare since most channel sounders operate within a very limited band only. A model was proposed based on experiments at 0.45, 0.9, and 3.7 GHz. An excess path loss exponent of 0.6 was found appropriate for the modelling of the frequency dependency. With this extrapolation, the excess path loss in the above equation can be predicted according to



where *μ*excess = 6.

* + Location Variability

The large-scale path loss values depend on a great number of environmental factors. When the terminal or base stations move around in space, the received signal strength varies since the situation changes in terms of shadowing, number of reflected paths etc. It has turned out that the signal strength variations are quite well described by a lognormal distribution. Hence, *L*excess provides the mean excess path loss in dB while *σL* is the standard deviation of the normal distributed signal strength in dB, known as the location variability. In fact, *σL* depends on the frequency and the environment. *σL* is modelled according to

with *S*E = 5.2 for urban and *S*E = 6.6 for suburban environments, respectively.

Since the TG4m systems is planned to be fixed located, this equation will in fact not be exercised.

**NLOS ITU-R P.1546-1 Propagation Prediction Model**

The propagation prediction model contained in ITU-R Recommendation P.1546-1 has been developed over the years for the point-to-area prediction of field-strength for the broadcasting, land mobile, maritime mobile and certain fixed services (e.g., those employing point-to-multipoint systems) in the frequency range of 30 MHz to 3 000 MHz and for the distances range 1 km to 1000 km.

This model consists of a set of propagation curves that represent field-strength values for 1 kW effective radiated power (e.r.p.) at nominal frequencies of 100, 600 and 2 000 MHz, respectively, as a function of various parameters. The model includes the methods to interpolate and extrapolate field-strength values from these three nominal frequencies. These propagation curves were derived from the original “F-curves” still in use by the FCC in the USA for prediction broadcasting coverage.

The model also includes the method to obtain the effective height of the transmitting/base antenna above terrain height averaged between distances of 3 to 15 km in the direction of the receiving antenna. For paths shorter than 15 km, the method can take account of the height of the transmitting/base antenna above the height of a representative clutter around its location. The curves are produced for a receive antenna height corresponding to the representative height of the ground cover surrounding the receiving antenna location, i.e., 30m for dense urban area, 20 m for urban area and 10 m for suburban, rural and sea paths. A correction method is provided if receiving antennas at different heights.

The model includes curves for 1%, 10% and 50% time availability and a method is given to interpolate for time availability in the range from 1% to 99%. It also includes prediction over mixed land and sea propagation paths. The propagation curves represent the field strength value exceeded at 50% of locations within any area of typically 200 m by 200 m. A method is given for a correction for different percentages of location based on a standard deviation of 5.5 dB for wideband digital broadcasting.

The following figure shows an example of these curves included in this recommendation for this model.



**Figure A1. An example curve of field strength vs distance**

**for 100 MHz, land path, 50% time**

**NLOS: comparison between Okumura-Hata and ITU-R P.1546-1 models**

In Annex 7 of the ITU-R P.1546-1 Recommendation this ITU model gives results compatible with the Okumura-Hata model in the condition of mobile services in an urban environment for receive antenna height of 1.5 m, clutter height of 15 m and distances up to 10 km. However, a comparison was made with the two models at 600 MHz, 10 m receive antenna height, and for 50% location availability in open rural areas and the results indicate that the Okumura-Hata model predicts higher received field-strengths than the P.1546-1 model. Table A4 gives the results of this comparison.

Here are some further comparative notes on the two models:

* + - The Hata model covers the range of base antenna height of 30 m to 200 m whereas the P.1546-1 covers a range of 10 m to 1200 m;
		- The Hata model covers the range of user terminal antenna heights from 1 m to 10 m whereas the P-1546-1 model assumes that the antenna is at the same height as the local clutter or ground cover (i.e., 30 m in dense urban, 20 m in urban and 10 m elsewhere) with a correction factor depending on the path length for different antenna height;
		- The Hata model predict up to a range of 20 km whereas the P-1546-1 model goes up to 1 000 km;
		- The frequency range of the Hata model is from 150 MHz to 2 000 MHz whereas the P-1546-1 allows interpolation and extrapolation from 30 MHz to 3 000 MHz based on three nominal frequencies (100, 600 and 2 000 MHz);
		- The excess path loss increases by 6 dB per decade in the Hata model whereas it is distance independent in the P-1546-1 model.
		- The standard deviation for the location variability is frequency dependent and found to be 8 dB at 600 MHz whereas it is equal to 5.5 dB for wideband digital broadcast signals and frequency independent in the P.1546-1 model;
		- The Hata model does not allow for a variation of time availability;
		- The Hata model does not include prediction over sea paths.

**Table A4: Field-strength prediction difference between the Okumura-Hata model and ITU-R P.1546-1 model expressed in dB and in % (for 50% and 50%)** (Positive values indicate larger excess path loss predicted by P.1546-1.)



From the result of this comparison, ITU-R P.1546.1 model is adopted for TG4m channel evaluation.