**IEEE P802.15**

**Wireless Personal Area Networks**

|  |  |  |
| --- | --- | --- |
| Project | IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs) | |
| Title |  | |
| Date Submitted | November 6, 2011 | |
| Source | Soo-Young Chang [CSUS], Mi-Kyung Oh, Cheolho Shin, Sangsung Choi [ETRI], Alina Lu, SUM Chin Sean, Hiroshi Harada, F. Kojima [NICT], Kunal Shah, Jay Ramasastry, Cristina Seibert, George Flammer, Steve Shearer [Silver Spring Networks] | E-Mail: [sychang@ecs.csus.edu] |
| 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.] | |
| Notice | This document has been prepared to assist the IEEE P802.15. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein. | |
| Release | The contributor acknowledges and accepts that this contribution becomes the property of IEEE and may be made publicly available by P802.15. | |

Table of Contents

1.Introduction

Purpose

Methodology

# 2.Requirements Discussion

Summary of PAR

## High Level Requirements Overview

Application Requirements Matrix

## Regulations

## Summary of Regulations

Regulatory Requirements

Coexistence

Interoperability

PHY parameters

# Background and Supporting Discussion

Channel characteristics

## Complexity and Cost considerations

Definitions

References

TG4m Technical Guidance Document

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 parameter, which should be addressed in some way in the proposal; 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 between 54 MHz and 862 MHz under regulatory constraints that can be identified.
* The amendment shall provide operation modes that support PHY data rate of typically 40kbps to 2000kbps. The amendment shall provide at least one optional operation mode that supports PHY data rate up to at least 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 seamless 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 ~~SG4TV~~ P802.15.4m PAR and 5 Criteria.
* The amendment will include a PICS proforma.

**Application Requirements Matrix**

|  |  |  |  |
| --- | --- | --- | --- |
| **Application** | **Description** | **Key Parameters** | **Reference** |
| super Wi-Fi hot spots | Access to this spectrum could enable more powerful public Internet connections with extended range, fewer dead spots, and improved individual speeds as a result of reduced congestion on existing networks |  | 15-11-0039-00 |
| campus networks | better able to keep pace with user’s increasing demands for bandwidth |  | 15-11-0039-00 |
| home networks | better able to support real time streaming video applications |  | 15-11-0039-00 |
| remote sensing | water supplies by municipalities and support for the smart grid |  | 15-11-0039-00 |
| 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 * Data rate: up to 1 Mbps * PER<1% * Operating range: up to several km * User capacity: up to several thousands * Mobility: fixed * Security features: required * Reliability: high * Device category (WPAN): FFD (network controller, device), RFD (device) * Device category (regulations): high power device, low power device and very low power device | 15-09-0275-02  15-11-0171-00 |
| Intelligent Transportation System | TV bands make signal travel long distance and less vulnerable in rural areas, which can enable multiple applications between cars in the highways.   * Inter-car video call * Inter-car gaming * Inter-car social networking | * two-way, 100 end devices (mobile) to 1 controller (fixed) * PER: < 10% * One controller covers up to 1 square km | 15-11-0194-00  15-11-0279-01 |
| Surveillance, control and monitoring network |  |  | 15-11-0215-02 |
| Infrastructure moditoring network |  |  | 15-11-0215-02 |
| Local network in machine-to-machine (M2M) |  |  | 15-11-0215-02 |

## Regulations

## Summary of Regulations

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Region**  **/Country** | **TVWS Channel Band** | **Device Type** | **Transmitted Power Requirements** | **GDB \* Requirements** | **Sensing Requirement** |
| **US (FCC)**  Related document: FCC 10-174  Final order: almost finalized | 6MHz channel allocation  FD 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 access  Personal/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 Consultation  Final rules pending | 8MHz channel allocation  Possibly 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 aid  international harmonisation |
| **Europe (CEPT (ECC))**  Related document: ECC Report 159  Still in progress | 8MHz channel allocation  470-790 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-012-11  Still in progress | 6MHz channel allocation  54-72, 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 2010  Still in progress | VHF 7MHz and UHF 8MHz channel allocation  VHF: 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.

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.

# PHY Parameters:

# To be filled: this section will be filled up after each contributor of applications suggests key parameters for Application Requirements Matrix in the above. Each contribultor will be asked to list some key parameters shortly.

|  |  |  |  |
| --- | --- | --- | --- |
| PHY Parameter | | Performance Criteria, Constraints, Comments | Regional Regulatory |
| Parameter: | Example: |
| Operating band  (band/channel plan) | * Target band(s) * Channel bandwidth used * Channelization methods |  |  |
| Environmental Considerations | * Assumed channel conditions and dynamics of channel conditions |  |  |
| Modulation and Coding Scheme(s) | * Modulation method * Methods for adaptability (knobs) |  |  |
| Data rate(s) | * Range of rates * How achieved * Dynamic vs. Static |  |  |
| Symbol / chip rate(s) | * As appropriate to the proposed technique |  |  |
| Synchronization and Timing | * might come from specific sync mechanisms or may be dependent on other PHY features * clock accuracy / stability required |  |  |
| PHY frame structure | * Pre-amble * Sync Header, SFD * codes and/or patterns * (as appropriate to proposal) |  |  |
| Transmit Power | * MAX * MIN * Peak to Average * Management, control |  |  |
| PSD | * In band * Out of band |  |  |
| Channel availability (interference detection) | * Spectrum scanning * CCA |  |  |
| Link Quality Indication | * Technique used * Frequency of assessment * Accuracy and resolution * Bi-directional (cooperative)? |  |  |
| Reliability enhancing features/  methods | * Error Detection * Error Correction and recovery * Interference mitigation/avoidance * Collision avoidance |  |  |
| Interoperability |  |  |  |
| Co-existence features |  |  |  |
| MAC dependencies / support required |  |  |  |
| Energy consumption |  |  |  |

# Background and Supporting Discussion

This section identifies performance considerations, constraints and requirements. This section provides background for the requirements captured in the prior section.

To be filled.

Need to explain more in detail the following requirement from the above High Level Requirements Overview in this section for clarification.

* The amendment should provide a means for seamless frequency band and channel switching for radios with multi-band capability.

## Channel Characteristics

*Channel Model*

1). Path loss model (for link budget calculation)

**a. LOS (**The Friis free space equation)



Where , *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. NLOS (**Hata model)

Indoor propagation model: 

Where *R*: transmitter-receiver separation (m)

*n*: number of floors in the path



Where f=carrier frequency (MHz)

d=separation between base station and mobile unit (km)

hb=height of the base station antenna (m)

hmu=height of the mobile unit antenna (m)

a(hmu)=correction factor for mobile unit antenna height

For Large cities,



For small and medium cities,



2). Channel Impulse Response model (for PHY simulations)

a). For indoor scenario (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 |

b). For Outdoor scenario

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | 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 |

## Complexity and Cost considerations

**TBD (To be filled)**

# Definitions

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

**To be filled later at the time when the above items are almost done.**

|  |  |
| --- | --- |
| Term: | Definition |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |

# References

1. 15-11-0039-00-04tv-introduction-of-tv-white-space
2. 15-09-0275-02-004g-phy-proposal-for-802-15-4g-based-on-ofdm-technology-using-tv-white-space
3. 15-11-0000-00-04tv-possible-PHYs-for-upcoming-TG4m
4. 15-11-0394-00-04tv-tv-white-space-operation-for-wpan
5. 15-11-0171-00-04tv-usage-model-and-system-design-considerations-for-low-rate-wpan-operating-in-tv-white-space
6. 15-11-0194-00-04tv-tv-white-space-used-for-intelligent-transportation-system
7. 15-11-0215-02-04tv-wpan-applications-operating-in-tv-white-space
8. 15-11-0279-01-04tv-tv-white-space-for-vehicle-application
9. 15-11-0543-00-04tv-possible-phys-for-upcoming-tg4m
10. 15-11-0546-00-04tv-TV-white-space-issues-for-15.4