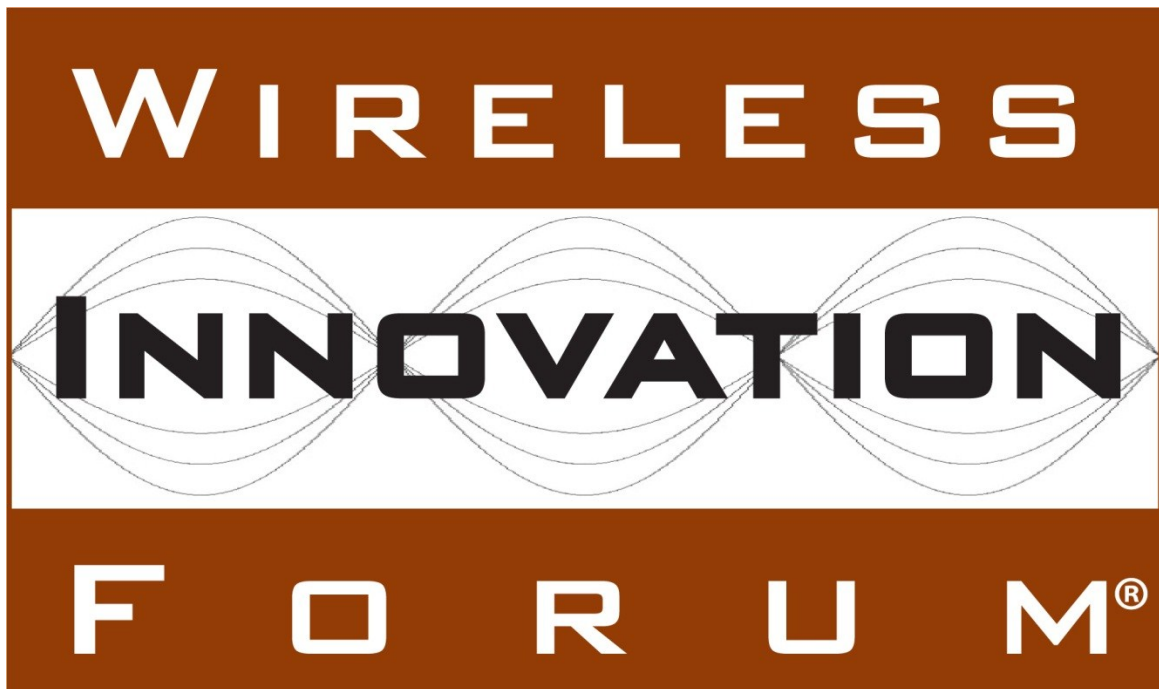




TD-LTE in White Space

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Table of Contents

TERMS, CONDITIONS & NOTICES	i
Executive Summary	vi
1. Introduction	1
1.1 Motivation	1
1.2 Scope of Project	1
1.3 Organization of the Contents	2
1.4 Definition of Terms	2
2. Regulation and Standardization	2
2.1 Regulatory issues	2
2.1.1 Federal Communications Commission (FCC)	2
2.1.2 Canada	5
2.1.3 European Union (EU)	8
2.2 Standardization analysis	10
2.2.1 IEEE 802.11af	10
2.2.2 IEEE 802.19	12
2.2.3 IEEE 802.22 [9]	15
2.2.4 ECMA-392	17
2.2.5 ETSI TC-RRS	18
2.2.6 IETF PAWS	23
2.3 Challenges of deploying TD-LTE in White Space	29
2.3.1 Overview of 3GPP TD-LTE	29
2.3.2 Radio Transmission Characteristics	34
2.3.3 Challenges of deploying TD-LTE in White Space	40
3. Application Scenario	42
3.1 Land Mobile Connectivity	42
3.2 High Speed Broadband Vehicle Access	43
3.3 Transportation and Logistics	44
3.4 Utility Grid Networks	46
3.5 Emergency and Public Safety	47
3.6 Local Broadcasting	48
3.7 Carrier Aggregation in the TD-LTE Band and TV White Space Band	49
3.8 Backhaul link using TVWS frequency band	50
3.9 Asia-Pacific Specific	51
4. Enabling Technologies	52
4.1 Cognitive Information Acquisition	52
4.1.1 Spectrum Sensing	53
4.1.2 Spectrum Database	54
4.2 Priority Methodology	55
4.3 Soft radio resource sharing	56
4.4 Carrier Aggregation using the TD-LTE Band and TV White Space Band	59
4.5 Coexistence solutions for TD-LTE to deploy in WS	61
4.6 Backhaul Capabilities of TD-LTE Standard with White Space Deployment	63
4.6.1 Spectrum allocation	64

4.6.2	Robust to the Long Delay Spread	64
4.6.3	Cognitive Plane Support	64
4.6.4	Dynamic Spectrum management and QoS Guarantee	64
5.	Performance Evaluation	64
5.1	Evaluation methodology description	65
5.2	RF performance for TV protection when TD-LTE Backhaul over TVWS	66
5.2.1	Scenario	66
5.2.2	Simulation assumptions	68
5.2.3	Simulation results	70
5.2.4	TV projection suggestions	72
6.	Commercialization Study	72
6.1	Market category	72
6.2	Market places	73
6.3	Capacity analysis of white space	74
6.3.1	USA	74
6.3.2	Europe [12]	75
6.4	Market demands	76
7.	Conclusion, next steps and future vision	78
8.	Appendix A: Acronym List	80
9.	Appendix B: References	82

List of Figures

Figure 2-1	Canadian band plan for the bands 698-756 MHz and 777-787 MHz	7
Figure 2-2	General band plan for BRS in the band 2500-2690 MHz	8
Figure 2-3	Overview of GAS protocol	11
Figure 2-4	RLQP for GDB Access in 802.11af	12
Figure 2-5	Coexistence system architecture	14
Figure 2-6	Reference model of Coexistence Enabler	14
Figure 2-7	Reference model of Coexistence Manager and Coexistence Discovery and Information Server	15
Figure 2-8	IEEE 802.22 Wireless Regional Area Network (WRAN) with multiple base stations (BSs) for coexistence mode within the coverage of a TV Broadcasting Station	16
Figure 2-9	Potential Application Scenarios of ECMA-392	18
Figure 2-10	Organization of the ETSI Technical Committee on RRS	19
Figure 2-11	Example of Intra-RAT reconfiguration	20
Figure 2-12	Existing Certification Framework, e.g. SW components are provided through FOTA Mass-upgrades	21
Figure 2-13	New Certification Framework, e.g. SW components are installed on a per-Device level and thus per-Device Certificates are required	21
Figure 2-14	Mid-/long range wireless access over white space frequency bands	22
Figure 2-15	PAWS use cases – Hotspot	25
Figure 2-16	PAWS use cases – Offloading	26
Figure 2-17	PAWS use cases - Backhaul	26
Figure 2-18	PAWS use cases – Indoor networking	28

Figure 2-19 PAWS use cases – Machine-to-machine.....	29
Figure 2-20 LTE time-domain structure	31
Figure 2-21 LTE time-domain structure	31
Figure 2-22 Uplink/downlink time/frequency structure in case of FDD and TDD	32
Figure 2-23 Uplink-downlink asymmetries supported by the TD-LTE	32
Figure 2-24 Definition of Channel Bandwidth and Transmission Bandwidth Configuration for one E-UTRA carrier.....	35
Figure 2-25 Definition of Aggregated Channel Bandwidth for Contiguous Carrier Aggregation.....	35
Figure 3-1 Land Mobile Connectivity	42
Figure 3-2 High Speed Vehicle Broadband Access.....	44
Figure 3-3 Transportation Logistics.....	45
Figure 3-4 Utility Grid Networks	47
Figure 3-5 Emergency and Public Safety	48
Figure 3-6 Broadcasting services.....	49
Figure 3-7 Carrier Aggregation in the TD-LTE Band and TV White Space Band	49
Figure 3-8 Wireless backhaul access	50
Figure 3-9 Wireless backhaul using TVWS	51
Figure 3-10 TD-LTE Works on 700MHz White Space.....	52
Figure 4-1 TD-LTE shares spectrum with broadcasting system using spectrum sensing	53
Figure 4-2 TD-LTE shares spectrum with broadcasting system using spectrum database	54
Figure 4-3 Prioritized connectivity	55
Figure 4-4 Secondary License Spectrum Sharing.....	56
Figure 4-5 Multiple RAT frequency allocation	57
Figure 4-6 Soft Frequency reuse GSM/LTE.....	57
Figure 4-7 Database Guided Power Control.....	58
Figure 4-8 Spectrum Sensing for Resource Sharing.....	58
Figure 4-9 Data Aggregation at the MAC Layer in the TD-LTE Bands and TV White Space Bands.....	59
Figure 4-10 eNB Transmitter with Carrier Aggregation	60
Figure 4-11 UE Receiver with Carrier Aggregation.....	61
Figure 4-12 Coexistence control entities located in the internet.....	62
Figure 4-13 Coexistence control function.....	63
Figure 5-1 General Topology of LTE Backhaul Link	66
Figure 5-2 Co-channel TV Protection Scenario.....	67
Figure 5-3 Co-channel Scenario	67
Figure 5-4 Adjacent Channel TV Protection Scenario	68
Figure 5-5 Adjacent Channel Scenario	68
Figure 5-6 TV TX Emission Mask	69
Figure 6-1 TV band in China	73
Figure 6-2 TVWS availability in US	74
Figure 6-3 TVWS availabilities in EU and US.....	76
Figure 6-4 Compare the GDP generated by mobile broadband and digital broadcasting	77
Figure 6-5 Mobile subscribers' growth in China.....	77

List of Tables

Table 2.A: Transmission bandwidth configuration NRB in E-UTRA channel bandwidths.....	34
Table 2.B: Definition of F_{offset}	36
Table 2.C: Base Station rated output power	36
Table 2.D: Base Station ACLR in unpaired spectrum with synchronized operation	38
Table 2.E: Minimum requirements for Relative Carrier Leakage Power	39
Table 2.F: Minimum requirements for in-band emissions.....	40
Table 5.A: TV system parameters	69
Table 5.B: TDD-LTE BH system parameters.....	70
Table 6.A TVWS in typical cities in US (source: “Measuring the TV ‘White Space’ Available for Unlicensed Wireless Broadband” New America Foundation and Free Press).	74
Table 6.B TVWS availability in Europe and in the USA	75
Table 6.C Link budget comparison.....	78

Executive Summary

Given the worldwide scarcity of radio frequency spectrum a White Space (WS) task group was created by the proponents of the Time Division Duplex (TDD) implementation of the Long Term Evolution (LTE) i.e. the TD-LTE system. The purpose of this group was to investigate at a high level the possibility for the deployment TD-LTE in White Space (WS) spectrum in areas of location, time or frequency where the primary user is not active. That is to say, in spectrum that has been licensed to sectors for example, broadcasting, but is not being currently used by the broadcaster. The task group looked at the North American and European regulatory environment for WS and determined that although a clear policy on WS had not been finalized, the trend was to support any system deployment in WS as long as it was done such that interference created by these system operations would not harm the incumbents of that WS spectrum.

Regarding the standardization effort to accommodate the operation of White Space Devices (WSD) in white space spectrum, all related standards organizations for WLAN have endorsed the FCC requirement for access to WS spectrum. To this end a number of task groups within the various standards organizations in North America and Europe have been formed to address the implementation of procedures and protocol to enable WS access by the various WSD to WS spectrum. A similar process is required to allow for the TD-LTE system to have access to this spectrum on and also to coexist with other TD-LTE systems in the same WS.

For TD-LTE systems to operate in WS spectrum, the existence of the incumbent to the spectrum, the existence of other TD-LTE operators and also the existence of other WS users must be accounted for. To this end several tools (spectrum sensing, geo-location etc.) have or are being developed to enhance the awareness of the TD-LTE system to other operations in the WS band. The challenge for TD-LTE systems is to design a protocol to employ these tools such that the WS spectrum being used is managed such that the incumbent is not harmed with no penalty in the event of coexistence and at the same time guarantee the Quality of Service the their end users expects.

Several application scenarios for the TD-LTE in TV Whitespace have been introduced such as, Land Mobile Connectivity, High Speed Vehicle Broadband Access, Transportation and Logistics, Utility Grid Networks, Emergency and Public Safety and Local Broadcasting. The essential driving force behind these applications is that the mobile communication networks in the TV Whitespace is capable of providing wider converge area, for the excellent properties of the radio propagation. From the network operators' perspective, wireless services, exploiting TV Whitespace, are key to their success due to low CAPEX and OPEX. Therefore, it is generally believed that TD-LTE in Whitespace is a promising technology which can be utilized, but not limited, to the applications presented in this chapter/section.

Enabling technologies and techniques such as cognitive radio, spectrum sensing, geo-location database access, carrier aggregations, radio resource sharing etc. make it technically feasible to deploy TD-LTE systems in TVWS such that incumbent broadcasters won't be penalized by TD-LTE operation in their WS spectrum. Also, the coexistence mechanism inherent in the TD-LTE

technology ensures that in addition to ensuring no harmful interference to incumbents, harmful interference to other TD-LTE systems sharing the same WS spectrum can be avoided. The carrier aggregation mechanism inherent in the TD-LTE standard for systems operating in S-Band may be extended to operate in the VHF/UHF (TVWS) bands where better propagation and additional spectrum may be found.

Performance Evaluation is provided to verify the feasibility of TD-LTE system deployed in TVWS from the perspective of protection of incumbent user. And the evaluation is based on the technical radio aspects of existing TD-LTE techniques that are defined in 3GPP.

Commercially, there are huge market requirements and benefits to accrue for TD-LTE technology deployed on TVWS which could yield opportunities to provide both cellular market and public safety market services. From a Technology & Performance Evaluation perspective, it can be seen that TD-LTE technology is feasible (i.e. protection of the incumbent user is possible) for TVWS deployment. Moreover, the current TD-LTE standard can be largely reused with only a few enhancements to support its deployment in TVWS spectrum.

The task group showed that the deployment of TD-LTE in white space spectrum is possible. It is now the work of the Standardization bodies to move this work closed to implementation by making the appropriate enhancements to the standard documents such that implementation of TD-LTE in White Space becomes a reality.

TD – LTE in White Space

1. Introduction

This document reports the results of an extensive research project performed by the members of the Wireless Innovation Forum (WinnF) on exploiting the use of White Space spectrum for deploying TD-LTE on a [no-interference-no-protection] basis. The intent of this report is to document the impact of introducing TD-LTE to neighboring systems, the corresponding interference mitigation methodologies and also business possibilities.

1.1 Motivation

Driven by the advanced services offered by mobile operators and the trends of transition to mobile broadband connections via smart phones and laptops, the total traffic required by the mobile communication industry is increasing faster than ever. However, spectrum scarcity poses a major challenge in meeting such user requirements given that there will be no additional global spectrum allocation before the World Radio Conference in 2015. Under this circumstance, exploiting available White Space on a limited-interfering basis is an opportunity to mitigate the spectrum scarcity challenge.

Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) is the latest standard in the mobile network technology, focusing on enhancing the Universal Terrestrial Radio Access (UTRA). LTE has wide industry support and there are already some networks deployed commercially. This report specifically addresses TD-LTE, which operates in TDD mode and allows flexibility for bandwidth allocation.

1.2 Scope of Project

This report addresses aspects of deploying TD-LTE system specifically in white space as a secondary spectrum user. It includes possible application scenarios, use cases, and impacts and most importantly the impact to neighboring broadcasting systems and other wireless broadband systems utilizing the same white space, and vice versa. The project includes both the licensed usage and unlicensed usage. Licensed usage refers to TD-LTE system as the exclusive secondary spectrum user, and unlicensed usage refers to TD-LTE system as one of multiple secondary spectrum users.

Particular attention is given to the following considerations of TD-LTE throughout this project:

- The operators' perspectives on TD-LTE in White Space
- Standardization and regulations required in dynamic spectrum access
- The restrictions on spectrum and bandwidth that impact TD-LTE in White Space
- New techniques and testing required to support a TD-LTE White Space solution
- The requirements on baseband processing imposed by TD-LTE in TV White Space (TVWS)
- The options that exist for TD-LTE in White Space in Europe, Asia and North America
- Assessment of TD-LTE in White Space.

The design of TD-LTE system itself was not a part of this project.

1.3 Organization of the Contents

This report first synthesizes the possible scenarios of using White Space spectrum in different regions of the world by reviewing the relevant regulations and broader input from industries, academics and business communities. Then the performance of TD-LTE in such scenarios is analyzed based on a certain set of assumptions on enabling technologies, interfering mitigation methodologies and regulatory conditions. In order to facilitate the development of engineering solutions, test and measurement requirements are given in a separate section. To provide readers a context of the research, the document also summarizes the latest progress of relevant standards and regulations. The commercialization possibilities are also studied to address the motivation of this report. Finally, this document concludes with a consideration of steps to be taken that pave the way to deploying TD-LTE in White Space and the future vision. The acronym list and cited technical publications are summarized in Appendix A and Appendix B respectively.

1.4 Definition of Terms

For the purposes of this report, the members of the Forum have adopted the following definition of white space:

In areas where the spectrum that has been assigned by a regulatory authority for licensed services (for example broadcasting) is not in use, that spectrum is then deemed as White Space. White Space spectrum may be used by an Unlicensed Device as long as it creates interference which is not harmful to a licensed incumbent and it does not claim any right to protection from the incumbent. The designation of any spectrum as White Space is mandated by the regulatory authority in the specific country in which the spectrum being considered resides.

2. Regulation and Standardization

2.1 Regulatory issues

2.1.1 Federal Communications Commission (FCC)

General

The US administration is committed to the development of services using Cognitive Radio technologies in TV White Space (TVWS). The FCC started the discussion on the use of unused TV frequencies for unlicensed devices on a non-interference basis in 2002. Work has progressed consistently with several reports, opinions and NPRMs (Notice of Proposed Rulemaking) since then.

An FCC final opinion on cognitive devices in TV White Spaces was made available in 2010, and the Commission has adopted rules to allow unlicensed radio transmitters to operate in the TVWS [1] [2].

The FCC requirements on incumbent protections are tightly coupled with the fact that TVWS is a license exempt scheme with a device-centric solution. In regards to incumbent protection, the FCC made it mandatory for White Space Device (WSD) to access one of the geo-location databases if such a device does not rely on sensing and excludes “de-facto” a “radio network controlled” architecture. It shaped the adaptive power control mechanism, the maximum transmission power for base stations and WSD devices, and also the protection contours of the incumbent.

In 2011 the FCC selected ten companies (Comsearch, Frequency Finder, Google, KB Enterprises, LS Telcom, Key Bridge, Microsoft, Neustar, Spectrum Bridge, and Telcordia) as the administrators of the TVWS geo-location database. Each database administrator will undergo a 45-day trial period before being allowed to operate for a five-year term. Several experimental municipal licenses have been assigned by the FCC for testing in the recent years. A geo-location database system public trial was recently established to test the Spectrum Bridge database administrator capabilities. The public was given access to the system to verify the system’s correct identification of the available channels and the proper registration of users entitled to protection. A public comment period was followed before the FCC made a final decision on the Spectrum Bridge launch of commercial services.

In Dec. 2011, the Federal Communications Commission issued a Public Notice announcing that the Office of Engineering and Technology (OET) has approved Spectrum Bridge Inc.’s television white spaces database system, which may provide service to devices beginning January 26, 2012. OET has also approved a WSD manufactured by Koos Technical Services, Inc. (KTS). This is the first product to be deployed for use in fixed operations system that may serve any broadband data applications, on an unlicensed basis over WS in the TV bands. The KTS device will operate in conjunction with the Spectrum Bridge TV band database.

U.S. TV Whitespace Regulations

- FCC rules governing use of TV Band Devices (TVBDs) are governed by subpart H of the Part 15 rules.
 - Reference title 47 of: <http://ecfr.gpoaccess.gov>
 - Following information is current as of Dec 8th, 2011
- Goal of regulations to ensure that incumbent TV band users are not hampered.
- Rules require implementation of the following to prevent interference to incumbent TV broadcasters also using these bands:
 - Device type classification
 - Maximum transmission power limitations
 - Interference protection requirements
 - Use of geo-specific frequency database to assess where TV spectrum is being utilized
 - Spectrum sensing
 - FCC does not regulate modulation type or technology to be used in TVWS.

Device Type Classification

- **Fixed**
 - Location of device is fixed in position
 - May select TVWS channels for operation itself from a database providing a list of available channels
 - Can initiate and operate a network by sending signals to one or more fixed and/or personal/portable TVBDs
 - May pass along a list of available channels to Mode I TVBD devices
 - Can utilize 54 - 60,76 - 88,470 - 512 MHz
 - Max antenna height is 30 meters
- **Mode II personal/portable device**
 - Has internal geo-location sensing capability and access to TV bands database either directly or via fixed or another Mode II TVBD
 - Can provide a list of available TV channels to Mode I TVBD
 - Restricted from using channels below 21 (512 MHz) due to interference prevention consideration with respect to wireless microphones
 - Max antenna height is 3 meters
- **Mode I personal/portable device**
 - Has no internal geo-location sensing capability
 - Must obtain list of available TVWS channels from a fixed or Mode II TVBD
 - Also restricted from using channels below 21 (512 MHz)
 - Max antenna height is 3 meters

Maximum Transmission Power

- Covered in section 15.709
- TV band devices (TVBDs) have maximum Tx power limitations, which are dependent on whether device type is fixed or portable/portable.
 - Fixed TVBDs have max Tx power of 1W which, given a maximum antenna gain of 6dBi, results in a max Effective Isotropic Radiated Power (EIRP) of 4W
 - For personal/portable TVBDs, the maximum EIRP will depend on separation between LTE system and occupied TV channel
 - Max EIRP of 40mw if adjacent channel
 - Max EIRP of 100mW if 2nd or greater adjacent channel
- Above limits are over 6MHz channel bandwidth

Interference Protection Requirements

- Covered in section 15.712(a)
- Example: below provides minimum separation requirements between TVBDs and existing TV systems.
 - TVBDs may operate within adjacent channel separation limit

Unlicensed Device Ant Ht (m)	Co-channel (km)	Adjacent channel (km)
Less than 3 meters	6.0	0.1
3 – less than 10 meters	8.0	0.1
10 – 30 meters	14.4	0.74

Use of Geo-specific Database

- Database requirements
 - maintains records of all authorized services in TV frequency bands
 - is able to determine available channels for a given specific geographic location
 - considering aforementioned interference prevention requirements
 - is capable of providing lists of these channels to TVBDs
 - Including information covering scheduled changes in channel availability over next 48 hours
 - is able to verify FCC ID of TVBD seeking channel information

Spectrum Sensing

- Is a process whereby a TVBD monitors a television channel to detect whether the channel is occupied by a radio signal or signals from authorized services.
- A TVBD with ability to perform spectrum sensing is not required to have access to geo-specific database, but will have maximum transmission power restricted to 50 mW/6 MHz.
- Detection thresholds
 - 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 signals, such as those from wireless microphones: -107 dBm, averaged over a 200 kHz bandwidth
 - In-service monitoring – TVBD must perform in-service monitoring of an operating channel at least once a minute
- Channel move time – once a signal from a TV or other low-power auxiliary device is detected by the TVBD on a channel which it is currently using, all transmissions on that channel by the TVBD must cease within 2 seconds.

2.1.2 Canada

At the time of preparing this document, the White Space regulations in Canada were under development. Industry Canada launched consultation processes on the use by White Space and non-White Space Radio communication Services, of spectrum that will be made available due to the transition from analog to digital television (TV). Below is summary on the potential introduction of new wireless telecommunications applications into the TV broadcasting bands below 698 MHz, 698 - 806 MHz, and in the band 2500 - 2690 MHz.

In August 2011, Industry Canada released Notice SMSE-012-11 “Consultation on a Policy and Technical Framework for the Use of Non-Broadcasting Applications in the Television Broadcasting Bands below 698 MHz”, which initiates a process on the introduction of wireless telecommunications application into the television (TV) broadcasting bands using TV White Spaces.

TV broadcasting spectrum below 698 MHz is already shared with licensed Low-Power Apparatus (LPA) such as wireless microphones¹. In January 2010, Industry Canada issued a Spectrum Advisory Bulletin (SAB-001-10)², which restricted the licensing and certification of LPA in the band 698-806 MHz

In addition, in June 2006, Industry Canada established rules for the use of licensed subscriber-based broadband Internet systems in remote rural areas on TV channels 21 to 51 (512-698 MHz) except channel-37³. These systems, called Remote Rural Broadband Systems (RRBS), are unique to Canada and are established on a no-protection, no-interference basis with respect to all TV broadcast stations, including low-power and very low-power TV (refer to Radio Systems Policy RP-0 at <http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf08664.html>).

RRBS licenses are authorized by Industry Canada, on a case-by-case basis, to make use of radio spectrum that is currently un-allotted and unassigned to TV broadcasters provided that:

- the RRBS be located at sufficient distance from major population centers, TV broadcasting facilities and their service contours so as not to cause them interference; and
- the RRBS not constrain the provision of current and future TV broadcasting services.

Although TV broadcasting bands are already shared with LPA and RRBS, many TV channels in many locations remain unassigned and unused by LPA, RRBS or broadcasting. This Consultation Paper considers how this unused spectrum could be put to use.

Notice SMSE-012-11 can be found at <http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf10058.html>. The deadline for submitting comments on this Notice is November 4, 2011 and reply to comments from other parties will be accepted until December 2, 2011.

In March 2012, Industry Canada⁴ announced its decisions on the use of the band 698-806 MHz (known as the 700 MHz band) for Commercial Mobile Services and Public Safety applications, and also on the use of the band 2500-2690 MHz (known as the 2500 MHz) for Broadband Radio Service (BRS).

Details of the Industry Canada decisions are given in the “Policy and Technical Framework: Mobile Broadband Services (MBS) – 700 MHz Band Broadband Radio Service (BRS) – 2500 MHz Band” (<http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf10125.html>). Part A of this document outlines the general policy decisions on both the 700 MHz band and the 2500 MHz. Parts B and

¹ Low-power apparatus consists of wireless microphones, cue and control communications, synchronization of video camera signals and video cameras.

² SAB-001-10, Low-power Licensed Radio communication Devices, Including Wireless Microphones, in the Band 698-806 MHz, is available at <http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf09777.html>.

³ Channel 37 is allocated to the radio astronomy service, and is not available for broadcasting or RRBS.

⁴ Industry Canada is the radio spectrum regulator in Canada.

C set out specific decisions regarding the 700 MHz and 2500 MHz bands. Part D outlines Industry Canada's determination with respect to auction timing for both of the bands.

In summary, Industry Canada has decided to harmonize with the U.S. band plan in the 700 MHz.

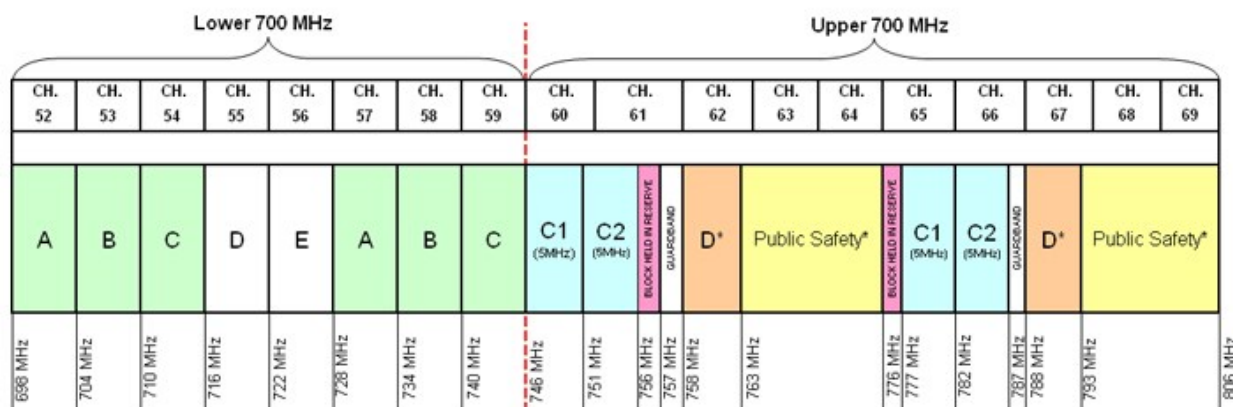


Figure 2-1 Canadian band plan for the bands 698-756 MHz and 777-787 MHz

The following frequency blocks will be available for the 700 MHz auction:

Block	Frequency	Pairing	MHz
A	698-704 MHz/728-734 MHz	Paired	6+6 MHz
B	704-710 MHz/734-740 MHz	Paired	6+6 MHz
C	710-716 MHz/740-746 MHz	Paired	6+6 MHz
D	716-722 MHz	Unpaired	6 MHz
E	722-728 MHz	Unpaired	6 MHz
C1	777-782 MHz/746-751 MHz	Paired	5+5 MHz
C2	782-787 MHz/751-756 MHz	Paired	5+5 MHz

The bands 763-768 MHz and 793-798 MHz are designated for public safety broadband use and will not be part of the 700 MHz auction.

Industry Canada has adopted the ITU-R band plan for BRS licensing in the band 2500-2690 MHz and the mapping of incumbents into the new band plan. The 2500 – 2570 MHz and 2620 – 2690 MHz are the paired FDD spectrum, and the 2570 – 2620 MHz (including 5 MHz guard bands on each side) is the unpaired TDD spectrum. Three geographic regions are considered (Region-A where the MDS spectrum has not been licensed, Region-B where both the MCS and MDS spectrum have been licensed, and Region-C (Manitoba Province)).

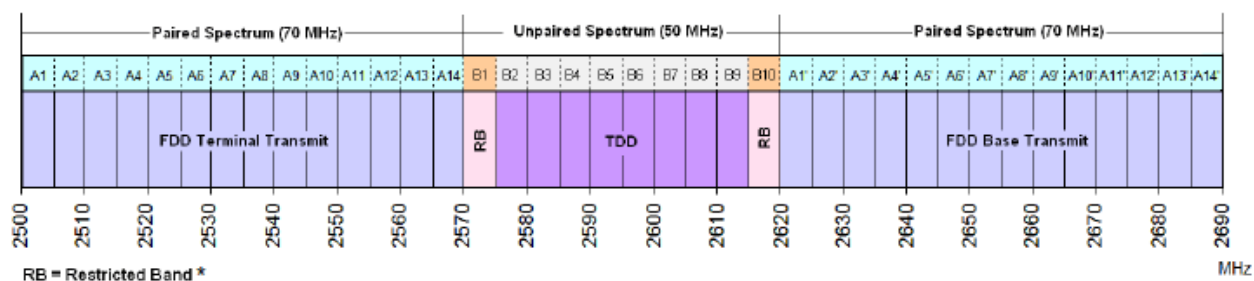


Figure 2-2 General band plan for BRS in the band 2500-2690 MHz

Industry Canada will proceed with an auction process for the 700 MHz band in the first half of 2013, followed by an auction process for the 2500 MHz band in early 2014. Copies of the relevant Gazette Notices and documents are available electronically on the [Spectrum Management and Telecommunications](http://www.ic.gc.ca/spectrum) Web site at www.ic.gc.ca/spectrum.

2.1.3 European Union (EU)

The European Commission and Radio Spectrum Policy Group (RSPG) are assessing the potential behind this WS model with a number of significant initiatives.

RSPG “report on cognitive technologies” from February 2010 had the merit of informing European regulators on the Cognitive Radio potential and the possible critical areas for further investigation. Following a public consultation, RSPG adopted an Opinion on the matter on February 2011 which explored the regulatory and standardization implications related to possible implementation of Cognitive Radio including the following: applicability to Cognitive Radios of the current Radio and Telecommunications Terminal Equipment (R&TTE)-Directive, areas to be addressed by ETSI Harmonized Standards, and responsibilities of Member States Administrations with reference to the database management. The current draft of the Radio Spectrum Policy Program has more than one reference to the importance of further exploring Cognitive Radio in White Spaces and geo-location databases.

RSPG “Report on Collective Use of Spectrum (CUS) and other spectrum sharing approaches” from October 2011 draw up the conclusions that will assist the European Commission on a way forward to implement spectrum sharing approaches. The RSPG Report concludes that a great part of spectrum is already shared between different applications, and at the moment there is no need for more dedicated spectrum. Nevertheless, there is a need to progress further on appropriate regulatory mechanisms in regard to sharing of spectrum and to foster more efficient use of it, both for the commercial and public sector. Additionally, in this way forward, it introduces a new concept called “licensed shared access”. Licensed Shared Access could provide new sharing opportunities on a European scale under a licensing regime, while safeguarding national current spectrum usages which cannot be re-farmed. However, further investigations

would be required to identify how Member States would implement a Licensed Shared Access (LSA) concept based on existing licensing regimes. Further analysis would also be required in order to determine more detailed considerations, such as, for example, the number of LSA licensees with a similar QoS requirement that could successfully utilize an LSA band, how competition rules would apply, and to what extent the introduction of LSA might inhibit future flexibility of spectrum utilization for existing users.

The European Commission may develop a mandate to ETSI to develop harmonized standards in this area and to evaluate how the R&TTE Directive essential requirements could be implemented where a database determines the spectrum usage conditions for a given terminal equipment.

More details on the mandate are as follows:

Harmonized standard for cognitive radio devices (CRD) and geo-location databases (GDB) for defining:

- Parameters and other information to be exchanged between a CRD and a GDB
- Procedures for such information exchange including security and reliability aspects
- Discovery and access to GDB

Other European standards, e.g. Information exchange between GDBs. There was comment from the Office of COMmunications (OFCOM), that this may also affect the radio parameters, even if not directly and thus should be considered if it should be a harmonized standard or not.

Scope of mandate – commercial

- To allow CR devices to comply with EU and national legislation on placing on the market and the use of radio equipment
- To ensure that the standardization of CR and SDR technologies do not create barriers on single market
- To ensure that the standardization of CR and SDR happens in timely in Europe compared to global development

Issues related to the utilization of Cognitive Radio have been on the agenda of TCAM (Telecommunications Conformity Assessment and Market Surveillance Committee) for a number of years.

CEPT

ECC WG SE Project team 43, tasked to investigate and define technical and operational requirements for the operation of cognitive radio systems in the White Spaces in the 470-790 MHz frequency band in 2009, delivered the ECC Report 159 in January 2011. The report provides technical and operational (potential) requirements for cognitive radio systems operating in the TVWS to ensure protection of the incumbent radio services. Geo-location is identified as the most feasible approach while a number of practical questions, such as how Programme Making and Special Events (PMSE) users will enter data into the system, what information should be stored, and how often WSD must consult the database, still require resolution.

The group was recently assigned a new work item for the medium term addressing: the impact of TVWS Devices on the adjacent bands, approaches combining geo-location DB and spectrum sensing and the identification of a common set of parameters to calculate location-specific power levels of devices.

EU Member States

UK – OFCOM has been consistently working on unlicensed cognitive radio applications in the TVWSs since 2007 according to feedback to the 5th consultation on CR, while ETSI Harmonized Standards might be ready in a few years, the UK will try in the mean time to prepare its national TVWS regulation (with the involvement of stakeholders) to be superseded by EU standards when they become available. Thanks to OFCOM work is certainly the most active European regulator on this topic investigating CR in TVWS for rural WLL applications as of 2013 after the analogue broadcasting switch-off with several consultations performed and an on-going trial. OFCOM is working on unlicensed CR applications in general and in TVWS in particular.

The first European trial on Cognitive Radio in the TVWS started in June 2011 in Cambridge and involved the participation of important stakeholders including British Telecom, BSkyB, BBC, and Microsoft. The aim is to understand how the unused spectrum in the TV band can be used for mobile and fixed wireless access especially for extension of rural broadband coverage or for urban hotspot “Wi-Fi on steroid”. In late April 2012, the testing consortium has announced trials of white-space radio spectrum in the UK over the past 10 months have been successful. The consortium explored and measured a range of applications -- rural wireless broadband, urban pop-up coverage and the emerging "machine-to-machine" communication -- and found TV white spaces can be successfully utilized. The consortium members recommend that the UK regulator OFCOM complete its development of the enabling regulatory framework in a manner that protects licensees from harmful interference and encourages innovation and deployment.

2.2 Standardization analysis

2.2.1 IEEE 802.11af

IEEE 802.11af is the IEEE Task Group (TG) responsible for specifying the Physical (PHY) and Medium Access Control (MAC) amendment in Wireless Local Area Network (WLAN) system for operation in the TV white space. TV white space is the spectrum allocated to TV broadcasting services, but is unused by the service locally and temporarily. The main focus of TGaf is to modify the existing 802.11 specification to comply with the regulations related to TV white space utilization, frequency re-banding to meet the TV spectrum and necessary MAC/PHY alterations required by operation in TV white space. In the US, the Federal Communications Commission (FCC) required WLAN devices to obtain permission from a primary user Geo-location Database (GDB) before operating in a specific TV channel. In the WLAN configuration, the Access Point (AP) will be responsible of obtaining the accessible TV channels from the GDB. The connectivity from a WLAN AP to the GDB may be through the wired or wireless medium.

In TGaf, there are several specifications inherited from existing 802.11 standards. The base standard of 802.11-2007 provides most of the basic system design. The chosen primary modulation method is the orthogonal frequency division multiplexing (OFDM), a popular method implemented in the widespread 802.11 a/g/n systems. The supported channel spacing are 5, 10, 20 and 40MHz. The maximum achievable data rate is 600Mbps, assuming 4 parallel Multiple-Input Multiple-Output (MIMO) streams with 150Mbps per stream.

Conventional WLAN is a well-proven system operating within the range of several tens to several hundreds of meters. The first ever long range WLAN is normally referred to the IEEE 802.11y, targeting up to 5km or more. Towards realizing the long range WLAN, the MAC design in legacy 802.11 standard has undergone several key enhancements such as Enhanced Contention Based Protocol (CBP), Channel Power Management (CPM), Channel Schedule Management (CSM) and Dependent Station Enablement (DSE) Employing the MAC enhancements coupling with higher allowable transmit power. In order to enable operation in the TV white space, 802.11af devices need to be able to access the GDB. From the perspective of connectivity to the outside world, 802.11u has provided a complete specification on connecting to external networks. Figure 2-3 gives an overview illustration on the Generic Advertisement Protocol (GAS) to enable connectivity to external networks. GAS provides the functionality that enables 802.11 devices to discover the availability of information related to desired network services. GAS uses a generic container to advertise network services information over an 802.11 network. The specifications of network services are beyond the scope of 802.11u, as depicted by the dotted lines in Figure 2-3. The following description is based on Figure 2-3. Note that a requesting STA may be a non-Access Point (AP) device and a responding STA may be an AP device. First, a requesting STA send an initial query to the responding STA, inquiring on the networks that are available. The responding STA will then send a query to the Advertisement Server (AdS) that advertises the services provided. Upon receiving the response from the AdS, the responding STA will reply to the requesting STA with the information. Mapping the information exchange model in Figure 2-3 to the scenario in 802.11af operation in TV white space, the requesting STA is a non-AP STA from the 802.11 perspective and a mode I TVBD from the FCC regulation perspective. The responding STA is an AP STA from the 802.11 perspective and a mode II personal/portable TVBD or a fixed TVBD from the FCC regulation perspective. The AdS is the GDB from the FCC regulation perspective.

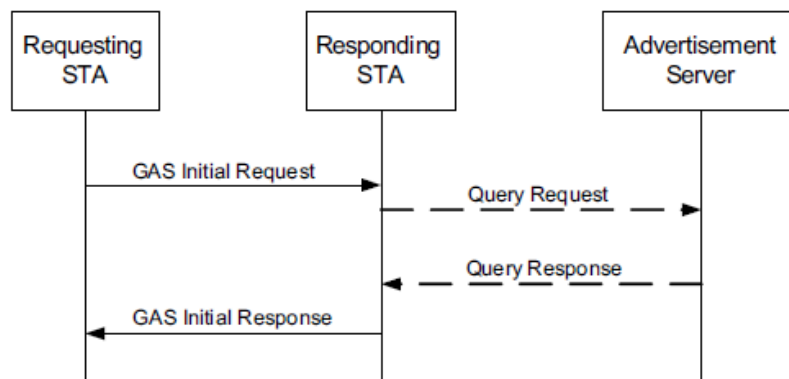


Figure 2-3 Overview of GAS protocol

As shown in Figure 2-4, the requesting STA requests the available list of channels from the responding STA. The message exchanges are similar to that specified in 802.11u. The responding STA then connects to the RLS through the Distribution System (DS). The DS may be formed by any of connectivity from wired to wireless solution. Thus, the RLS may be an entity that resides within the responding STA. The RLS may also be a centralized server physically separated from the responding STA through wired or wireless means. Then, the RLS is connected to the GDB to obtain the information on the available list of channels. Note that it is also possible that the RLS is residing physically within the GDB. Introducing the RLS into 802.11af specification provides flexibility of implementing the existing communication framework in the TV white space.

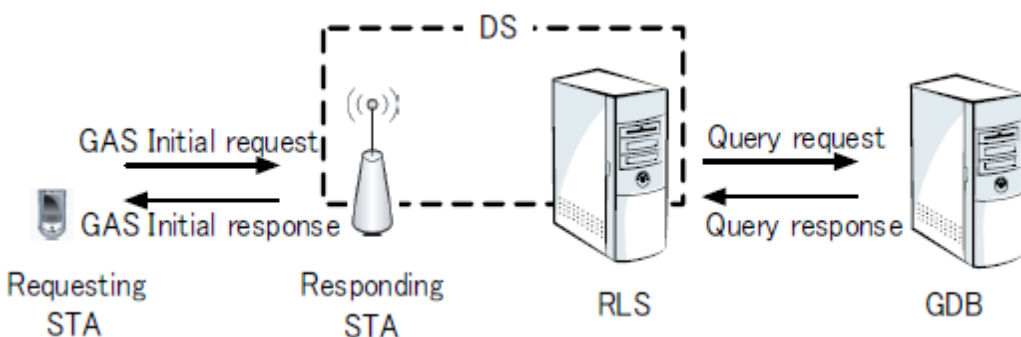


Figure 2-4 RLQP for GDB Access in 802.11af

In the past, IEEE802.11af has decided to use IEEE802.11ac as a baseline in PHY so as to meet international requirements and facilitate the use of multiple contiguous or non-contiguous channels. The Task Group has also decided to modify it in order to provide a scalable high throughput PHY and allow modifications to satisfy the requirements to operate in the various TV bands.

2.2.2 IEEE 802.19

Cognitive radio systems operating in white space frequency bands shall be capable of protecting primary users. This is typically mandatory as required by radio regulations since cognitive radio system, as a secondary user, may only be allowed to operate on a temporary basis in white space spectrum. However, the problem is that, coexistence with other cognitive radio systems is not required by radio regulations. FCC regulations state how licensed networks and devices should be protected in TVWS, but the solution for coexistence between unlicensed networks is left to industry. Since any cognitive radio system that satisfies radio regulations for primary user protection can use white spaces, consequently, more than one cognitive radio system can select the same white space for its operation. Thus, several dissimilar cognitive radio systems, operating in the same white space may create interference to each other which may lead to performance degradation or even to an inability to continue operation. So a mechanism that allows cognitive radio systems to avoid such situation is required herein, referred as “coexistence mechanisms”. The protocol to realize a “coexistence mechanisms” is thus called “coexistence protocol”.

To solve this second user coexistence problem, the IEEE 802.19 TG1 was set up. In March 2009, the 802.19 TAG received an assignment from the Executive Committee Study Group (ECSG) to develop coexistence scenarios and possible coexistence metrics in TV white spaces. A Study Group (SG) within the 802.19 TAG was resultantly initiated. In September 2009, the 802.19 TAG SG began work on a new Project Authorization Request (PAR) to form a new IEEE Task Group (TG), 802.19.1 focusing on coexistence methods in TV white spaces. The 802.19.1 TG approaches coexistence enablement through layers above the PHY and MAC layers. The first meeting for 802.19.1 TG was held in January 2010. The PAR scope and purpose [3] are as below:

PAR Scope: The standard specifies radio technology independent methods for coexistence among dissimilar or independently operated TV Band Device (TVBD) networks and dissimilar TV Band Devices.

PAR Purpose: The purpose of the standard is to enable the family of IEEE 802 Wireless Standards to most effectively use TV White Space by providing standard coexistence methods among dissimilar or independently operated TVBD networks and dissimilar TVBDs. This standard addresses coexistence for IEEE 802 networks and devices and will also be useful for non IEEE 802 networks and TVBDs.

In March, 2010, the 802.19 TG1 distributed the call-for-proposal, and after 8 months of work proposals were provided by Nokia (Finland), NICT (Japan), LG (Korea), ETRI (Korea) , AmeriSys(Canada), and InterDigital(USA) and 1 technical contribution was provided by Sony (Japan). Currently the group is working towards a merging proposal.

The group has generally agreed on the coexistence system architecture [4] as shown in Figure Figure 2-5 with three entities and five interfaces.

The three entities are:

- Coexistence Manager (CM)
- Coexistence Enabler (CE)
- Coexistence Discovery and Information Server (CDIS).

The CM is responsible for coexistence decision making related to reconfiguration of TVBD networks or devices to solve coexistence problems between them. The CM obtains all necessary information for this decision making. After making decision, the CM sends reconfiguration requests to TVBD networks or devices via their CEs. Different CMs may negotiate with each other during decision making.

The CE is the interface entity that enables all communication between TVBD network or device and coexistence system.

The CDIS is responsible for coexistence decision making related to discovery of neighboring TVBD networks or devices. The CDIS receives all necessary information for this decision

making during registration of TVBD networks or devices. The CDIS provides updates status of the neighbors each time any change occurs.

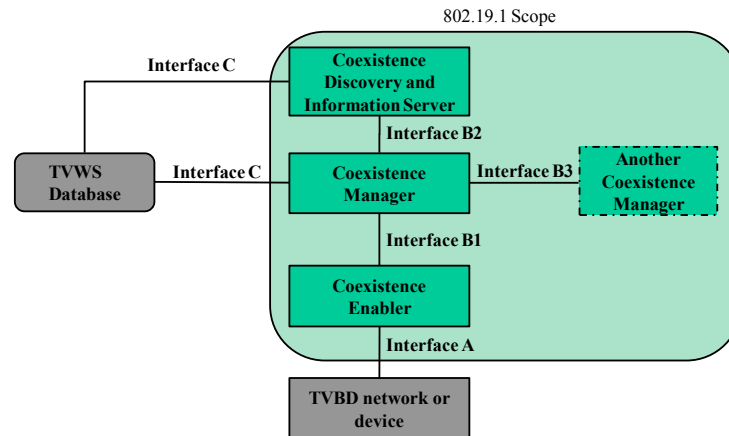


Figure 2-5 Coexistence system architecture

The Five interfaces are:

- Interface A between CE and TVBD network or device. Interface A is media dependent interface enabling communication between CE and TVWS network or device.
- Interface B1 between CE and CM though which CM provides coexistence related information to CE, and CE provides TVWS network or device information to CM.
- Interface B2 between CM and CDIS though which information needed for discovery and coexistence flows both ways
- Interface B3 between different CMs for CM to exchange information
- Interface C between CDIS and TVWS database or between CM and TVWS database. Interface C is used mainly by 802.19.1 entities to obtain data related to available channels

Figure 2-6 illustrates reference model of Coexistence Enabler.

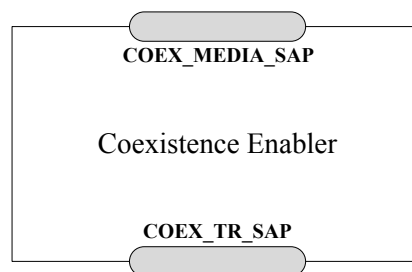


Figure 2-6 Reference model of Coexistence Enabler

The Coexistence Enabler has two service access points:

- Coexistence Media SAP (COEX_MEDIA_SAP)
- Coexistence Transport SAP (COEX_TR_SAP)

Figure 2-7 illustrates reference model of Coexistence Manager and Coexistence Discovery and Information Server.

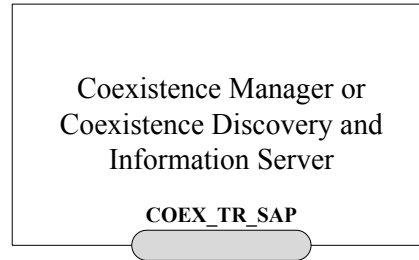


Figure 2-7 Reference model of Coexistence Manager and Coexistence Discovery and Information Server

The Coexistence Manager and Coexistence Discovery and Information Server have one service access point:

- Coexistence Transport SAP (COEX_TR_SAP).

In IEEE 802.19.1 standard, it may also include coexistence procedure and protocol, coexistence mechanisms and algorithm, with all these functionalities, a good coexistence performance is expected for the applications in TV white space.

2.2.3 IEEE 802.22 [9]

IEEE 802.22 wireless regional area network (WRAN) is a Point-to-Multipoint (PMP) network architecture. An IEEE 802.22 WRAN system consists of one Base Station (BS) and a number of Customer Premises Equipment (CPEs) with outdoor directional antennas. A network can have multiple BSs sharing the available resources in the coexistence mode. IEEE 802.22 WRAN also provides a coexistence mechanism for such a deployment. There are coexistence windows that are defined in the superframe structure of IEEE 802.22 for such a purpose. The goal of IEEE 802.22 WRAN is aimed at using cognitive radio techniques to allow sharing of geographically used spectrum allocated to TV broadcast service, on a non-interfering basis, to bring broadband access to hard-to-reach low population density areas of rural environment.

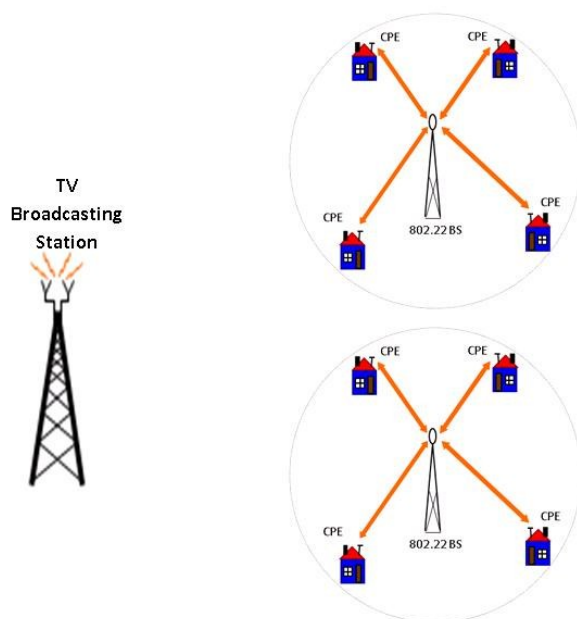


Figure 2-8 IEEE 802.22 Wireless Regional Area Network (WRAN) with multiple base stations (BSs) for coexistence mode within the coverage of a TV Broadcasting Station

The network of IEEE 802.22 WRAN is designed to operate in the TV broadcast bands while ensuring no harmful interference is caused to the incumbent operation (i.e., digital TV and analog TV broadcasting) and low-power incumbent devices such as wireless microphones. There are two methods used for spectral awareness: geo-location database and spectrum sensing. For geo-location database, the knowledge of the location of the cognitive radio devices combined with a database of incumbent transmitters can be used to determine which channels are locally available for reuse by the cognitive radio network. There are two ways to determine Geo-location in WRAN: the mandatory Satellite-based geo-location which requires GPS antenna at each terminal and optional Terrestrially-based geo-location using the characteristics and capabilities of the IEEE 802.22 PHY.

Spectrum sensing consists of observing the spectrum and identifying which channels are occupied by licensed transmission via the use of quiet periods. Flexible quiet periods range from 1 symbol (approx. 1/3 ms) to one superframe (160 ms). The IEEE 802.22 network modifies its operating frequency so as to operate on channels unused by incumbent transmissions. If the current operating channel becomes occupied by an incumbent transmission, the IEEE 802.22 network must quickly identify which channels are allowed for use and move to a new unused channel.

The application of IEEE 802.22 can be in rural areas of typically 17-30 km in radius up to a maximum of 100 km, where a BS can be serving up to 512 fixed units of CPEs with outdoor directional antennas located nominally 10 m above ground level.

The minimum peak throughput delivered to the CPE at the edge of the coverage is 1.5 Mbps in the DownStream (DS) direction (BS to CPE) and 384 kbps in the upstream direction (CPE to

BS). The frequency range used is in the very high frequency/ultra high frequency (VHF/UHF) TV broadcast bands ranges from 54 to 862 MHz. Orthogonal frequency division multiple access (OFDMA) is used as the air interface at the physical (PHY) layer.

IEEE 802.22 medium access control (MAC) provides mechanisms for flexible and efficient data transmission. It also supports cognitive capabilities for reliable protection of incumbent services in the TV band and self-coexistence among IEEE 802.22 systems. A superframe is transmitted by a BS on its operating channel beginning with a special preamble and contains a superframe control header (SCH) and 16 MAC frames. Each MAC frame is 10 ms. Each MAC frame comprises a DS subframe and an US subframe with an adaptive boundary in between. In the DS direction, data is scheduled over consecutive MAC slots. In the US direction, the channel capacity is shared by the CPE units based on a demand-assigned multiple access (DAMA) scheduling. A frame may also contain a Self-Coexistence Window to send out Coexistence Beacons for self-coexistence and Geo-location. IEEE 802.22 WRAN also has Security Features for secured transmissions.

2.2.4 ECMA-392

ECMA-392[7] is a Cognitive Radio (CR) networking standard for personal/portable devices operating in TV white space (TVWS). The standard defines the physical (PHY) and the medium access control (MAC) layer specifications for personal/portable devices operating in TVWS[8]. ECMA-392 aims at in-home, in-community, and in-campus applications including high definition video streaming, real-time video telephony, and high-quality community- or campus-wide wireless internet services, as depicted in Figure 2-9. ECMA-392 offers a number of benefits such as enhancing coverage and quality of service (QoS) of wireless internet access across campuses and communities, as well as improving range and reliability for public service communication networks.

1) PHY Layer Designs

In the ECMA-392 standard, the PHY design adopts an orthogonal frequency division multiplexing (OFDM) based transceiver with 128 subcarriers. ECMA-392 supports multiple cyclic prefixes to accommodate different channel conditions, and supports flexible channel bandwidth with three possible options 6 MHz, 7 MHz, and 8 MHz, and multiple data rates to enable different applications. In the ECMA-392 standard, multiple antenna transmission schemes such as frequency interleaved transmit diversity (FITD), Alamouti space time block coding (STBC), and spatial multiplexing (SM) are supported. ECMA-392 uses two types of physical layer convergence procedure (PLCP) preambles, normal preamble and burst preamble, for synchronization and channel estimation.

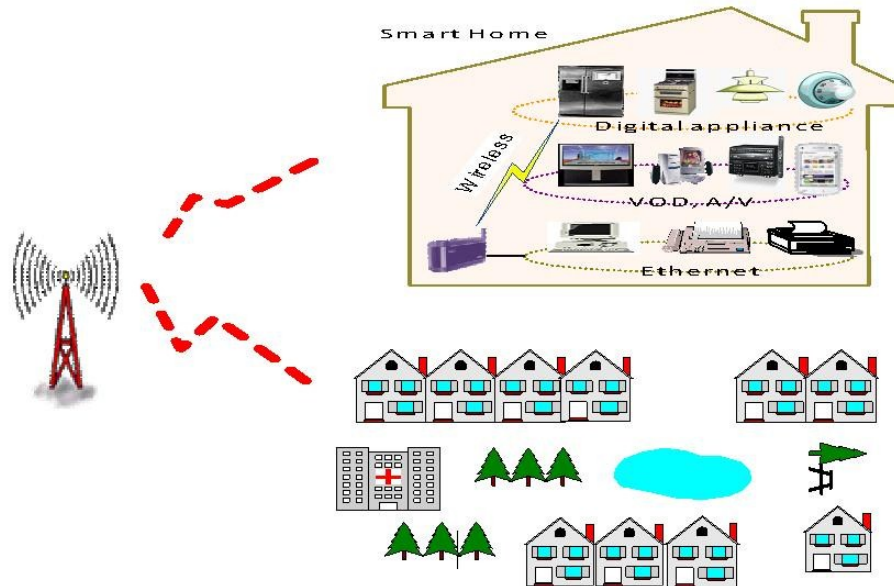


Figure 2-9 Potential Application Scenarios of ECMA-392

2) MAC Layer Designs

ECMA-392 supports networks with flexible formation. ECMA specifies three possible devices: master devices, slave devices, and peer devices, which can form master-slave or peer-to-peer, or mesh-networks. ECMA-392 has one unified superframe structure that consists of 256 medium access slots (MASs). Each superframe consists of beacon period (BP), data transfer period (DTP), contention signaling window (CSW), and possibly reservation signaling window (RSW). ECMA-392 supports both reservation based access and contention based access. Reservation based access is essential for a master-slave mode but it is optional for a peer-to-peer mode. Contention based access is based on prioritized carrier sensing multiple access (CSMA). ECMA-392 provides incumbent protection and dynamic frequency selection mechanisms. To protect incumbent users, both spectrum sensing and geo-location/database approaches are supported. In particular, ECMA-392 supports regular quiet period (QP) schedule and on-demand QP schedule. Regular QP is mandatory and has predetermined duration scheduled right before CSW. On-demand QP schedule is flexible and is activated by the detection of abnormal channel use. ECMA-392 also supports transmit power control that considers incumbent protection and fast channel evacuation and connect establishment.

2.2.5 ETSI TC-RRS

ETSI (European Telecommunications Standards Institute) is recognized as an official European Standards Organization by the European Union, enabling valuable access to European markets. The Technical Committee (TC) on Reconfiguration Radio Systems (RRS) is part of ETSI, which was established on 65th board meeting of ETSI in 2008. Reconfigurable Radio Systems are based on technologies such as SDR (Software Defined Radio) and CR (Cognitive Radio) whose systems exploit the capabilities of reconfigurable radio and networks for self-adaptation to a dynamically-changing environment with the aim of ensuring end-to-end connectivity. The ETSI

TC-RRS received its mandate to start standardization at the end of 2009 following a 2 year technical and study phase. The committee's activities include studies on the feasibility of RRS standardization, collecting and defining RRS requirements, identifying gaps where existing standards do not fulfill those requirements and proposing solutions to fill those gaps.

ETSI's TC-RRS has four working groups, which are organized as shown in Figure 2-10. WG1 mainly focuses on functional architecture of Reconfigurable radio systems which includes functional blocks, interfaces and protocol messages; WG2's work is to standardize the SDR architecture, access interfaces, application interfaces and RF interfaces of mobile device; The standards of cognitive pilot channel (CPC) is the concern of WG3; Defining and specifying system architecture of Cognitive Radio Networks in the Public Safety domain is the responsibility of WG4. Based on those work above, TC-RRS is going to develop standards for the White Space in the UHF frequency TV-band and the spectrum-refarming in GSM/IMT band.

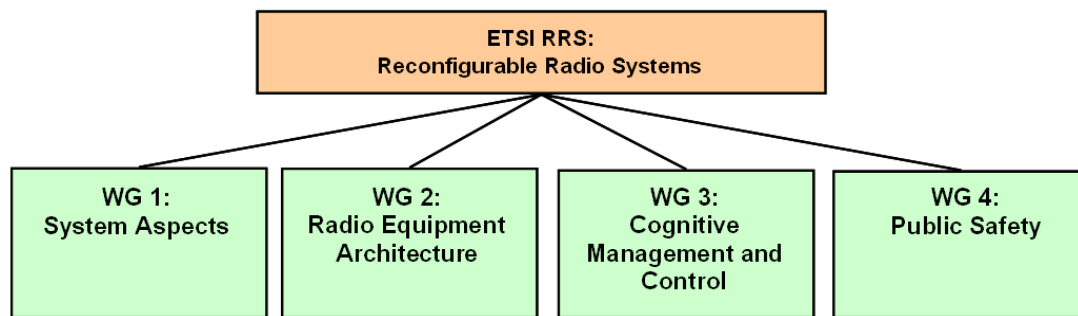


Figure 2-10 Organization of the ETSI Technical Committee on RRS

The TC-RRS follows the ETSI three-step process for creating standards. This begins by creating technical report on key study items and defining generic use cases. These reports then are used to define system requirements and architecture specifications. Lastly, the requirements specifications are used to define standard specifications for protocols and interfaces.

The general cognitive radio framework functionality (observing the environment, learning, orienting, planning, deciding and acting) has three aspects relevant to RRS activities:

(1) Heterogeneous radio framework management, including, for example, 3GPP, WiFi, WiMax, etc. (SDR is an “enabling technology” for this).

(2) Opportunistic spectrum access in which additional users dynamically accesses “white space spectrum” in areas of location, time or frequency where the primary user is not active. This additional access leads to dramatically higher spectrum utilization (e.g. TV White Space access).

(3) Flexible spectrum management in which a wireless network operator may deploy RATS dynamically (over frequency/time/location) and acquire/exchange Spectrum Usage Rights with other users.

In all three aspects, the mobile devices may autonomously adapt to diverse heterogeneous radio framework.

Finalized and published deliverables of the ETSI RRS committee are available at
<http://www.etsi.org/WebSite/technologies/RRS.aspx>.

The RRS WG1 has investigated use cases for reconfigurable radio systems in licensed spectrum usage and shared/opportunistic spectrum usage. One of the scenarios considered for dedicated spectrum (licensed bands) use is illustrated as Figure 2-11 from TR 103 063. This example illustrates a reconfigurable deployment with different allotments to various Radio Access Technologies (RATs) in a multi-cell deployment. This configuration enables the network operator to match the spectrum availability and RAT performance to the user traffic conditions.

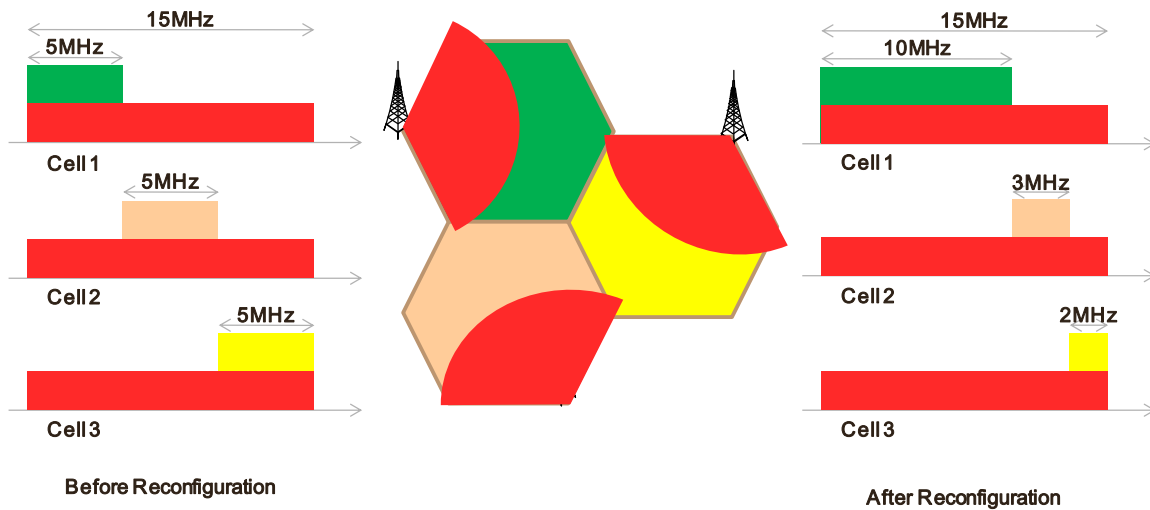


Figure 2-11 Example of Intra-RAT reconfiguration

To facilitate the reconfiguration of certified radio equipment after initial sale and deployment, the ETSI TC RRS WG1 also has ongoing activities related to the European Radio and Telecommunications Terminal Equipment (R&TTE) directive which governs the sale of equipment (including reconfigurable equipment used for TV White Space in general). In the draft TR 102 967, use cases are being identified for the introduction of mechanisms to enable, for reconfigurable radio systems, the dynamic declaration of conformity with the essential requirements of the R&TTE Directive. In particular, this work is tailored to accommodate reconfigurable radio systems and their accommodation in future versions of the R&TTE Directive. These Use Cases involve the dynamic reconfiguration of reconfigurable radio equipment after its initial certification. Such reconfiguration must ensure the continued compliance to the essential requirements in the new configuration. It is expected that some of the new mechanisms will enable reconfigurable devices to dynamically declare their conformity. Examples of existing and expected certificates are illustrated in the Figure 2-12 and Figure 2-13 (from draft TR 102 967 – “Use Cases for Dynamic Declaration of Conformity”).

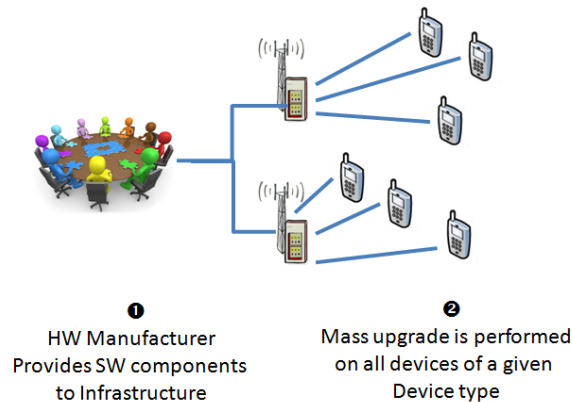


Figure 2-12 Existing Certification Framework, e.g. SW components are provided through FOTA Mass-upgrades

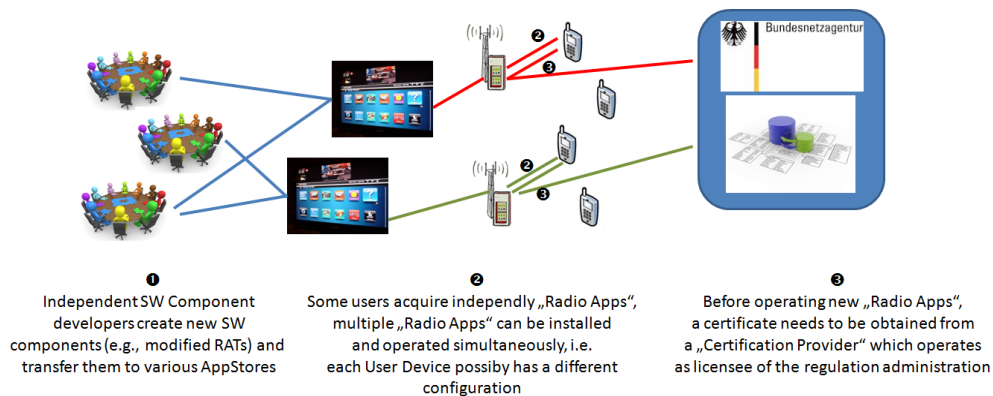


Figure 2-13 New Certification Framework, e.g. SW components are installed on a per-Device level and thus per-Device Certificates are required

TC RRS WG1 is in the progress of early drafting a technical standard (TS 102 946) which is going to standardize the system requirements for operation in UHF TV Band White Space. In this draft functional requirements and performance requirements are proposed, to indicate to users how to operate as a secondary user in UHF TV Band without interfering the primary users. The requirements are stemming mostly from the use cases described in Technical Report 102 907 “Use cases for Operation in White Space Frequency Bands”. The stable version of the TS is supposed to be provided by September, 2012.

The technical report TR 102 097 on use cases for operation in White Space frequency band has been completed and published. TC RRS proposed 4 use cases as shown below:

1. Wireless access over TVWS

According to the range between end users and base station/access point, this use case is divided into two specific scenarios described as mid/long range (0-10km) and short range (0-50m) access over TVWS. The first mentioned scenario can be divided into three sub-scenarios as shown in figure 2.2-12 according to the mobility of the end-users. This differentiation is made because the constraints for detecting incumbent users or other secondary users as well as on retrieving the geographical position may differ dependent on the mobility of the users. Another scenario named short range access over TVWS focuses on how the white space frequency access is handled between different networks and how the coexistence of the networks in the white space frequency bands between the secondary networks.

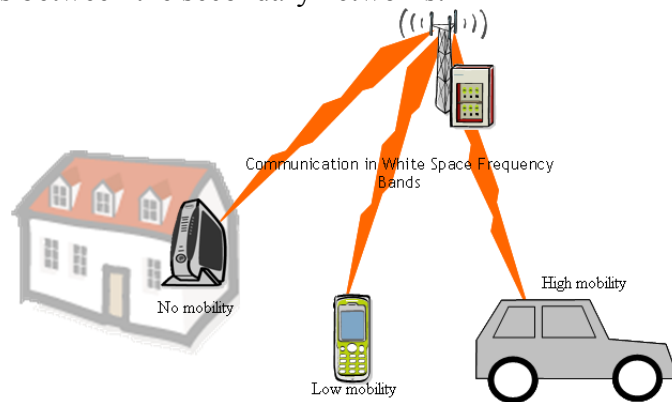


Figure 2-14 Mid-/long range wireless access over white space frequency bands

2. Ad-hoc networking and combined ad-hoc and wireless access over TVWS

The use case presents an ad hoc network operating on white space frequency bands and a combined networking over TVWS. The second scenario contains an ad-hoc network where one node of the network has also access to a base station. Both the communication inside the ad-hoc network as well as towards the base station is over white space frequency bands.

3. Backhaul link using TVWS frequency bands

In current mobile network, there are many access points which have different capability, e.g. they can support different coverage. These access points can be connected with wireless backhaul link. In 3GPP LTE for example, the backhaul link between eNB and relay is wireless. The wireless backhaul link operated on the TVWS can obtain many advantages such as improving the access link capacity, providing a simple wireless environment, improving the capacity of the backhaul link, etc.

4. Multimedia Broadcast Multicast Service(MBMS) operating in TVWS frequency bands

Broadcasting services are widely used when transmitting the same content to a group of users at the same time in many telecommunication systems (e.g., UMTS/LTE). The utilization of TVWS to transmit broadcasting services could meet the requirements for more radio resources. Another TS, numbered 102 908 “Coexistence Architecture for Cognitive Radio Networks on UHF White Space Frequency Bands” is also in the drafting stage. Currently, the normative system

requirements are being defined and to be approved; meanwhile, there's the informative discussion on the different options for coexistence system architecture.

Now another work item which is responsible for TR 103 067 is ongoing. This Technical report is mainly about radio frequency performance for cognitive radio system operating in UHF TV band white space. In this TR, co-existence between cognitive radio systems in UHF TVWS, advanced incumbent protection techniques and implementations such as cooperative sensing and additional RF attributes for advanced geo-location database, Coexistence studies in UHF TVWS in regions outside of CEPT responsibility and White Space device classification are also under discussing. The stable version is supposed to be provided at May, 2012.

2.2.6 IETF PAWS

General

The Internet Engineering Task Force (IETF) Protocol to Access White Space database (PAWS) standardizes the interface between the White Space Device (WSD) and the White Space DataBase (WSDB): how the WSD discovers and accesses a WSDB anywhere. The charter is available at <http://datatracker.ietf.org/wg/paws/charter/>. The two clear deliverables are 1) A description of the relevant use cases and requirements (Informational) and 2) A specification of the mechanism for discovering a white space database, the method for accessing a white space database, and the query/response formats for interacting with a white space database (Standards Track). The PAWS BOF is held at IETF80 in Prague on March 2011, WG approved on June 2011. Currently, the Draft Problem statement, Use Case and Requirements I-D have been prepared and work is on track. The protocol specification work is also starting. The group is scheduled to Submit Use Cases and Requirements I-D to the IESG by Apr. 2012 and Submit the proposed standard for Accessing Radio White Space Database to the IESG for publication by Dec. 2012.

Problem Statement

The use of white space spectrum is enabled via the capability of a device to query a database and obtain information about the availability of spectrum for use at a given location. The databases may be country specific since the available spectrum and regulations may vary, but the fundamental operation of the protocol should be country independent. A messaging interface between the white space devices and the database is required for operating a network using the white space spectrum.

The following four items are to be considered in the use of White Space Spectrum:

✧ Global applicability

The use of TV white space spectrum is currently approved by the FCC in the United States. However regulatory bodies in other countries are also considering similar use of available spectrum.

✧ Database discovery

Since the spectrum and databases are country specific, the device will need to discover the relevant database. The device needs to obtain the IP address of the specific database to which it can send queries in addition to registering itself for operating and using the available spectrum.

✧ Data model definition

The contents of the queries and response need to be specified. A data model is required which enables the white space device to query the database while including all the relevant information such as geo-location, radio technology, power characteristics, etc. which may be country and spectrum and regulatory dependent. All databases are able to interpret the data model and respond to the queries using the same data model that is understood by all devices.

✧ Protocol

A protocol that enables a white space device to query a database to obtain information about available channels is needed.

Use Cases

The following use cases are based mostly on the FCC regulation [2010] that allows WSD's to access TV band on an unlicensed basis as long as those WSD's fulfill the FCC ruling and regulations (see FCC, "Federal Communications Commission, "Unlicensed Operation in the TV Broadcast Bands; <http://edocket.access.gpo.gov/2010/pdf/2010-30184.pdf>", December 2010).

Hotspot: Urban Internet connectivity

Master/AP devices use a TDD radio technology and transmit at or below a relatively low transmit power threshold shown in

Figure 2-15. The operation is as follows:

1. The Master/AP powers up (WS Radio in idle mode)
2. Master/AP discovers a database and registers with it
3. Master/AP queries the database requesting a list of available channels at its current location
4. Database responds with a list of available channels
5. Master/AP selects a channel(s) and activates the WS radio interface
6. Slave devices scans the WS bands and detects the Master/AP and attaches to it
7. Slave devices have Internet connectivity over WS radio channels

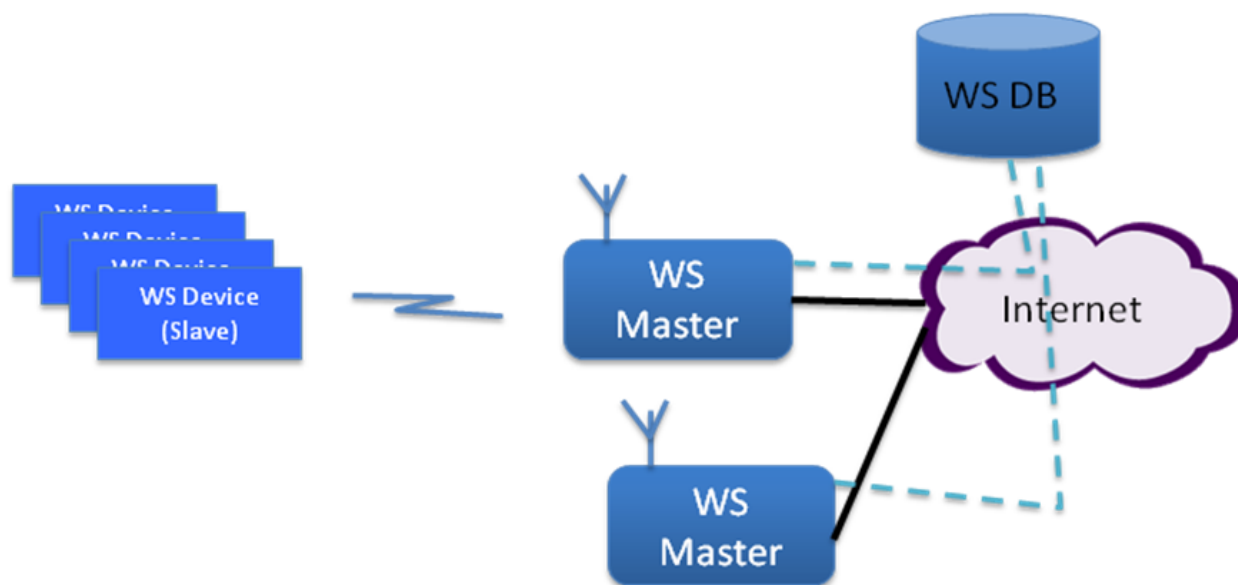


Figure 2-15 PAWS use cases – Hotspot

Rural internet broadband access

Internet access is provided as a WAN or Wireless Regional Area Network (WRAN).

Typically characterized by one or more fixed master(s)/BS(s), cells with relatively large radius (tens of kms, up to 100 km), and a number of available radio channels.

The BS in this scenario use a TDD radio technology and transmit at or below a transmit power limit established by the local regulator.

Each base station has a connection to the internet and provides internet connectivity to multiple slave/end-user devices which can be fixed or mobile.

Offloading: Moving traffic to a WS network

Mobile devices using 3G/4G Cellular networks for data can offload the session to a WS network if a network is available as shown in Figure 2-16.

A device attached to a 3G/4G cellular network has an ongoing video streaming session.

The policy on the device is configured to use an alternate access network such as WS when one is available for use.

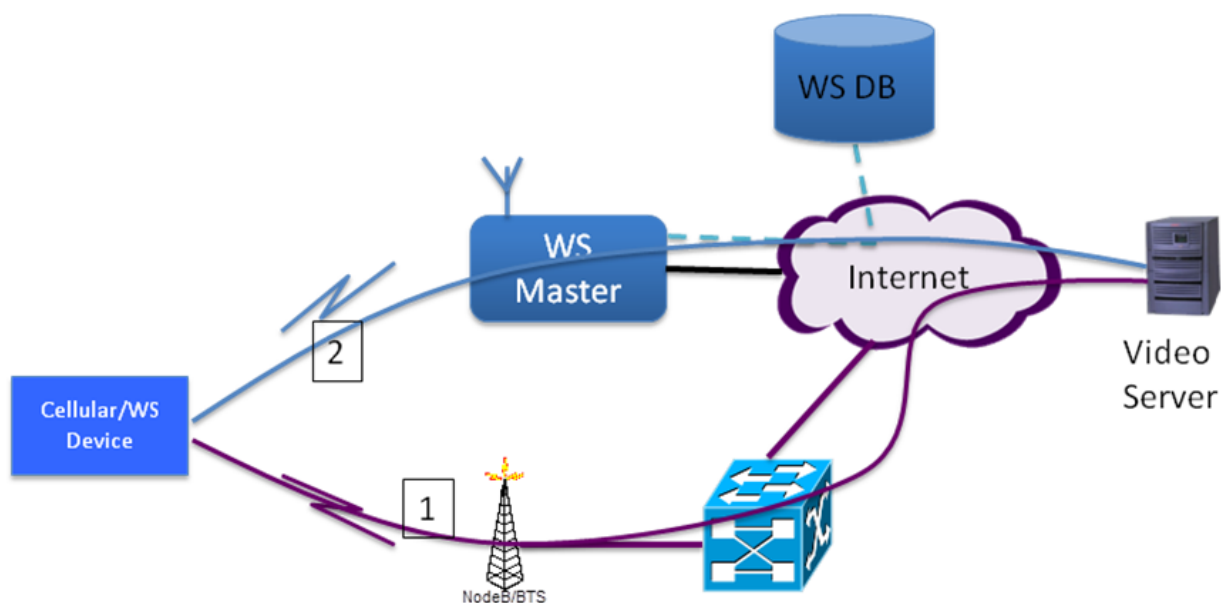


Figure 2-16 PAWS use cases – Offloading

Backhaul

WS spectrum can be used as a backhaul and thus enable various types of network deployments (mesh, Muni WiFi etc.) as shown in Figure 2-17.

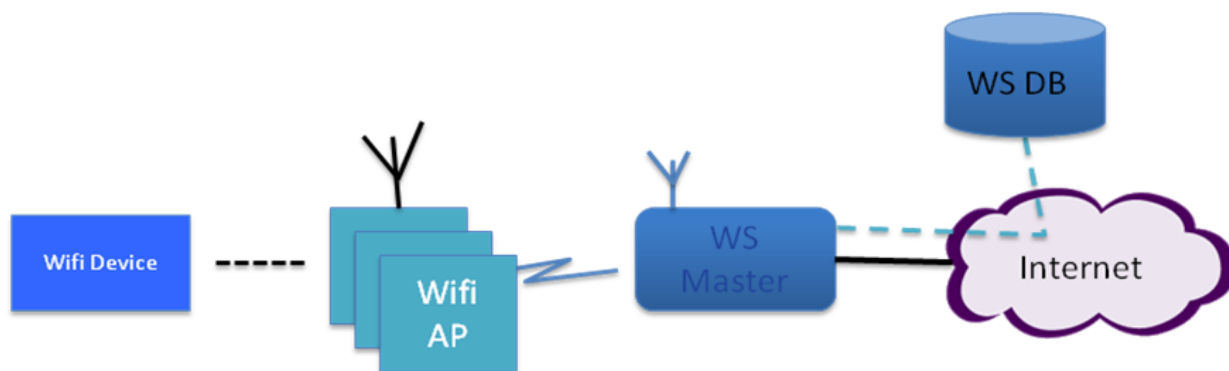


Figure 2-17 PAWS use cases - Backhaul

Rapid deployed network for emergency scenario

Emergency spectrum can be made available for the establishment of a rapid response network.

WS Master Devices can be deployed or existing ones use the freed spectrum in such scenarios.

Mobility in white space (sub scenario)

Operation

1. The master/AP powers up (WS Radio in idle mode)
2. Master/AP discovers a database and registers with it
3. Master/AP queries the database requesting a list of channels that are available at its current location and also a future location.
4. Database responds with a list of available channels that are available at all locations identified in the request.
5. Master/AP selects a channel(s) and activates the WS radio interface
6. Master/AP may use channels from the list while moving within the predicted area without requirement to query the database due to mobility (i.e. moving more than 100 m). Time based restrictions are still applicable

Indoor networking use case

User devices are inside a house or office, requiring connectivity to the Internet or to equipment in the same or other houses/offices.

Database query from the master device includes geolocation and location uncertainty and optional additional information such as device ID.

Response is list of channels available, and optional additional information such as channel validity time and maximum radiated power.

The master authenticates the response and selects one or more channels from the list.

The user device scans the TVWS bands to locate the master device transmissions, and associates with the master.

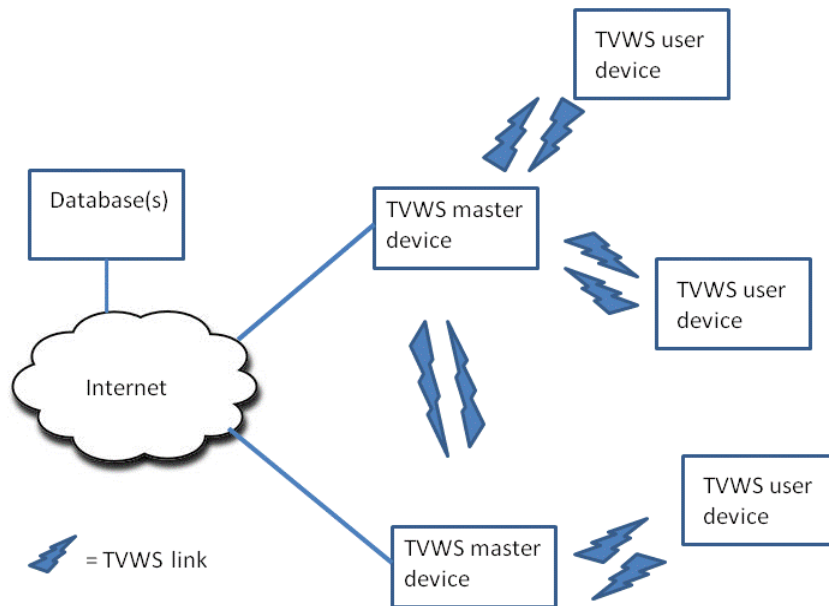


Figure 2-18 PAWS use cases – Indoor networking

Machine to machine (M2M) use case

Machines including a whitespace device and can be located anywhere, fixed or on the move. Each machine needs connectivity to the internet and/or to other machines in the vicinity.

A database query from the master device includes geolocation and location uncertainty and optional additional information such as device ID.

The response is list of channels available, and optional additional information such as channel validity time and maximum radiated power.

The master authenticates the response and selects one or more channels from the list.

The slave devices fitted to the machines scan the TV bands to locate the master transmissions, and associate with the master device.

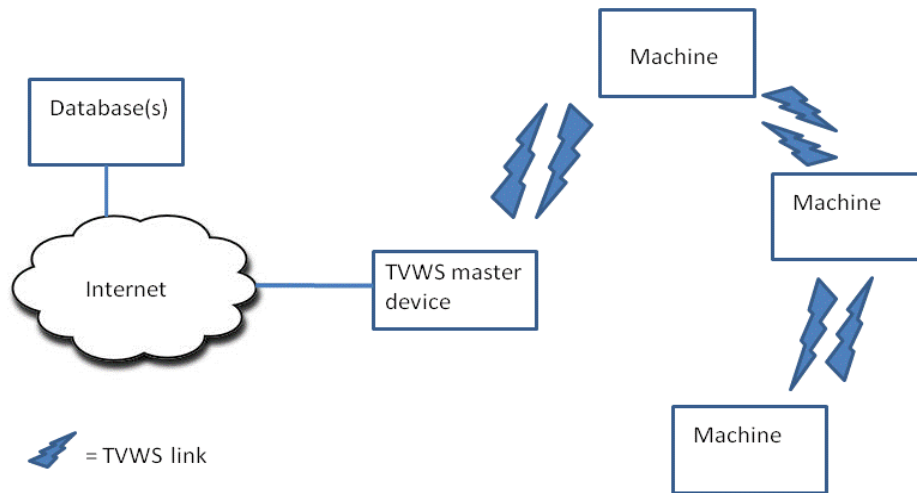


Figure 2-19 PAWS use cases - Machine-to-machine

Note: Further signalling can take place (outside the scope of PAWS) to establish direct links among those slave devices that have associated with the master device. Machine communication over a TVWS channel, whether to a master device or to another machine (slave device), is under the control of a master device.

2.3 Challenges of deploying TD-LTE in White Space

2.3.1 Overview of 3GPP TD-LTE

Third Generation partnership Project (3GPP) Long Term Evolution (**LTE**) [5] is the latest standard in the mobile network technology, focusing on enhancing the Universal Terrestrial Radio Access (UTRA). The TDD part of LTE, also known as TD-LTE, uses Time-Division Duplex operation and therefore is applicable for operation with unpaired spectrum. TD-LTE provides flexibility in terms of downlink-uplink resource allocation by supporting multiple uplink-downlink resource-allocation configurations that can be used to match different traffic scenarios. It is also designed to exploit the more extensive channel reciprocity inherent in case of TDD operation, e.g. for beamforming, and facilitates coexistence with TD-SCDMA as well as other TDD-based IMT-2000 technologies. The downlink transmission scheme is based on conventional OFDM to provide a high degree of robustness against frequency selective fading while still allowing for low-complexity receiver implementations also at very large bandwidths.

The uplink transmission scheme is based on DFT-spread OFDM (DFTS-OFDM). The use of DFTS-OFDM transmission for the uplink is motivated by the lower Peak-to-Average Power Ratio (PAPR) of the transmitted signal compared to conventional OFDM. This allows for more efficient usage of the power amplifier at the terminal, which translates into an increased coverage and/or reduced terminal power consumption. The uplink numerology is aligned with the downlink numerology.

Channel coding is based on rate-1/3 Turbo coding and is complemented by Hybrid-ARQ with soft combining to handle decoding errors at the receiver side. Data modulation supports QPSK, 16QAM, and 64QAM for both the downlink and the uplink.

TD-LTE supports bandwidths from approximately 1.4 MHz to 100 MHz. Carrier aggregation, i.e. the simultaneous transmission of multiple component carriers in parallel to/from the same terminal, is used to support bandwidths larger than 20 MHz. Component carriers do not have to be contiguous in frequency and can even be located in different frequency bands in order to enable exploitation of fragmented spectrum allocations by means of spectrum aggregation. Channel-dependent scheduling in both the time and frequency domains is supported for both downlink and uplink with the base-station scheduler being responsible for (dynamically) selecting the transmission resource as well as the data rate. The basic operation is dynamic scheduling, where the base-station scheduler takes a decision for each 1 ms Transmission Time Interval (TTI), but there is also a possibility for semi-persistent scheduling. Semi-persistent scheduling enables transmission resources and data rates to be semi-statically allocated to a given User Equipment (UE) for a longer time period than one TTI to reduce the control-signaling overhead.

Multi-antenna pre-coding with dynamic rank adaptation supports both spatial multiplexing (single-user MIMO) and beam-forming. Spatial multiplexing with up to eight layers in the downlink and four layers in the uplink is supported. Multi-user MIMO, where multiple users are assigned the same time-frequency resources, is also supported. Finally, transmit diversity based on Space-Frequency Block Coding (SFBC) or a combination of SFBC and Frequency Switched Transmit Diversity (FSTD) is supported.

2.3.1.1 Network Architecture

The LTE radio-access network has a flat architecture as shown in Figure 20 with a single type of node, the *eNodeB*, which is responsible for all radio-related functions in one or several cells. The *eNodeB* is connected to the core network by means of the S1 interface, more specifically to the *Serving Gateway* (S-GW) by means of the user-plane part, S1-u, and to the *Mobility Management Entity* (MME) by means of the control-plane part, S1-c. One *eNodeB* can interface to multiple MMEs/S-GWs for the purpose of load sharing and redundancy.

The X2 interface, connecting *eNodeBs* to each other, is mainly used to support active-mode mobility. This interface may also be used for multi-cell *Radio Resource Management* (RRM) functions such as ICIC. The X2 interface is also used to support lossless mobility between neighboring cells by means of packet forwarding.

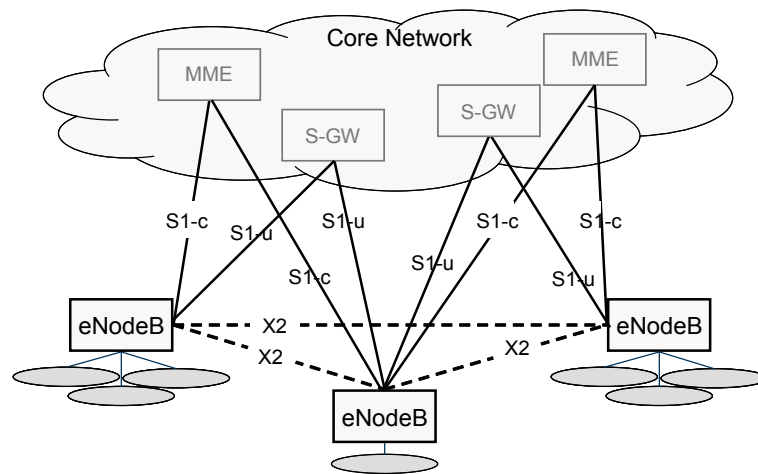


Figure 2-20 LTE time-domain structure

2.3.1.2 Time-domain structure and duplex schemes

Figure 2-21 illustrates the high-level time-domain structure for transmission, with each (*radio*) *frame* of length 10 ms consisting of ten equally sized *subframes* of length 1 ms. Each subframe consists of two equally sized *slots* of length $T_{\text{slot}} = 0.5$ ms with each slot consisting of a number of OFDM symbols including cyclic prefix.

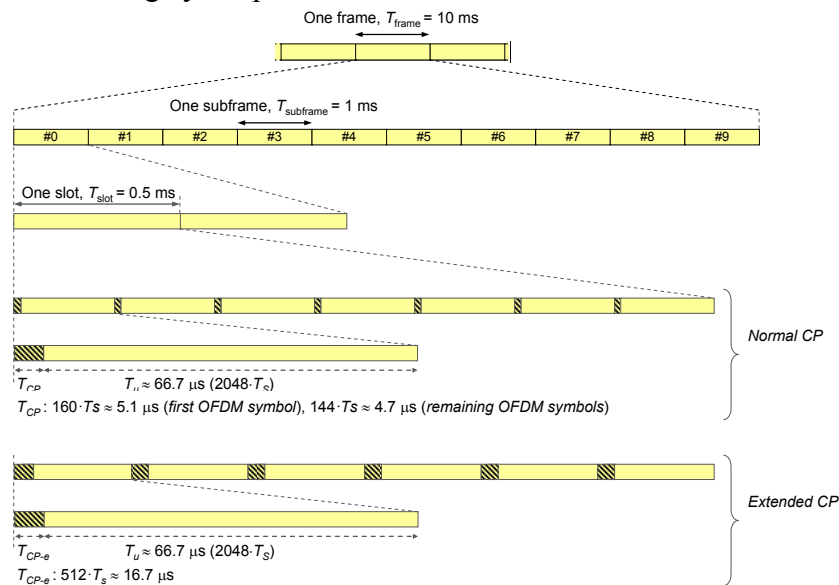


Figure 2-21 LTE time-domain structure

LTE can operate in both FDD and TDD as illustrated in Figure 2-22. Although the time-domain structure is, in most respects, the same for FDD and TDD there are some differences between the two duplex modes, most notably the presence of a *special subframe* in case of TDD. The special subframe is used to provide the necessary guard time for downlink-to-uplink switching.

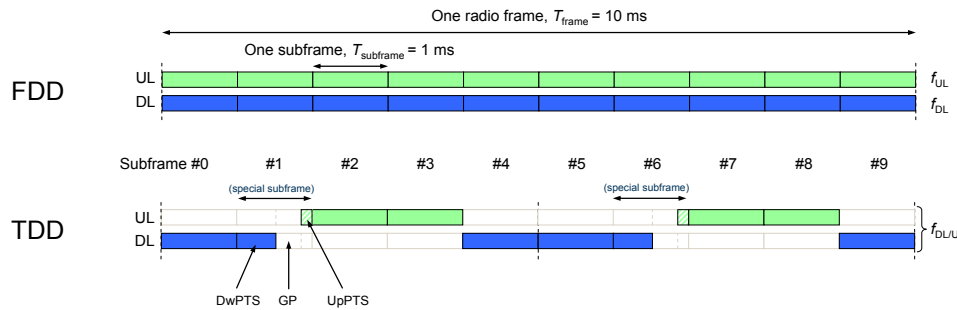


Figure 2-22 Uplink/downlink time/frequency structure in case of FDD and TDD

In case of FDD operation (upper part of Figure 2-22), there are two carrier frequencies for each component carrier, one for uplink transmission (f_{UL}) and one for downlink transmission (f_{DL}). During each frame, there are thus ten uplink subframes and ten downlink subframes and uplink and downlink transmission can occur simultaneously within a cell. Half-duplex operation at the UE side is supported by the scheduler ensuring non-simultaneous reception and transmission at the UE.

In case of TDD operation (lower part of Figure 2-22), there is only a single carrier frequency per component carrier and uplink and downlink transmissions are always separated in time also on a cell basis. As seen in the figure, some subframes are allocated for uplink transmissions and some subframes for downlink transmission with the switch between downlink and uplink occurring in the *special subframe*. The special subframe is split into three parts: a downlink part (DwPTS), a guard period (GP) where the switch occurs, and an uplink part (UpPTS).

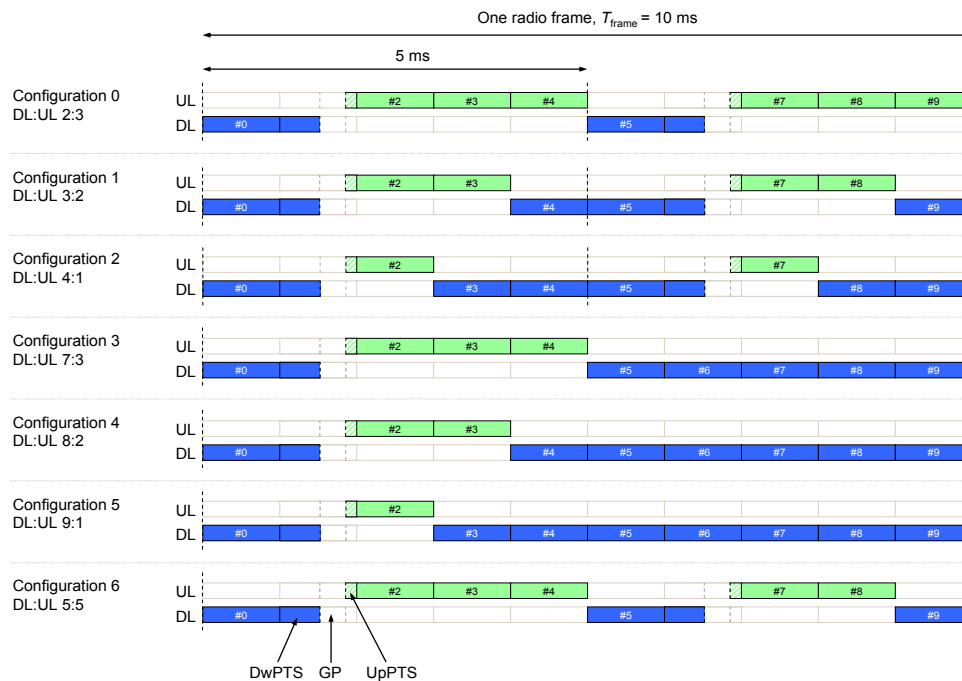


Figure 2-23 Uplink-downlink asymmetries supported by the TD-LTE

The UpPTS can be used for channel sounding or random access. The DwPTS, GP, and UpPTS have configurable individual lengths to support different deployment scenarios, and a total length of 1 ms.

Different asymmetries in terms of the amount of resources allocated for uplink and downlink transmission, respectively, are provided through seven different downlink/uplink configurations as shown in Figure 2-23. In the case of carrier aggregation, the downlink/uplink configuration is identical across component carriers.

Coexistence between the TDD RIT and other (IMT-2000) TDD systems such as TD-SCDMA is catered for by aligning the switch points between the two systems and selecting the appropriate special subframe configuration and uplink-downlink asymmetry.

2.3.1.3 Physical layer processing

To the transport block(s) to be transmitted on a DL-SCH or UL-SCH, a CRC is attached, followed by rate-1/3 Turbo coding for error correction. Rate matching is used not only to match the number of coded bits to the amount of resources allocated for the DL-SCH/UL-SCH transmission, but also to generate the different redundancy versions as controlled by the hybrid-ARQ protocol. In case of spatial multiplexing, the processing is duplicated for the two transport blocks. After rate matching, the coded bits are modulated (QPSK, 16QAM, 64QAM). In case of multi-antenna transmission, the modulation symbols are mapped to multiple layers and pre-coded before being mapped to the different antenna ports. Alternatively, transmit diversity can be applied. Finally, the (pre-coded) modulation symbols are mapped to the time-frequency resources allocated for the transmission.

Downlink transmission is based on conventional OFDM with a cyclic prefix. The subcarrier spacing is $\Delta f = 15$ kHz and two cyclic prefix lengths are supported: normal cyclic prefix ≈ 4.7 μ s and extended cyclic prefix ≈ 16.7 μ s. In the frequency domain, the number of resource blocks can range from 6 to 110 per component carrier (for channel bandwidths ranging from 1.4 to 20 MHz respectively), where a resource block is 180 kHz in the frequency domain. There can be up to five component carriers transmitted in parallel implying an overall bandwidth up to 100 MHz.

Uplink transmission is based on DFT-spread OFDM (DFTS-OFDM). DFTS-OFDM can be seen as a DFT precoder, followed by conventional OFDM with the same numerology as in the downlink. Multiple DFT precoding sizes, corresponding to transmission with different scheduled bandwidths, can be used.

The remaining downlink transport channels (PCH, BCH, MCH) are based on the same general physical-layer processing as DL-SCH, although with some restrictions in the set of features used.

2.3.1.4 Multi-antenna transmission

A wide range of multi-antenna transmission schemes are supported in the downlink:

- Single-antenna transmission using a single cell-specific reference signal.
- Closed-loop spatial multiplexing, also known as codebook-based beam-forming or precoding, of up to four layers using cell-specific reference signals. Feedback reports from the terminal are used to assist the eNodeB in selecting a suitable precoding matrix.
- Open-loop spatial multiplexing, also known as large-delay cyclic delay diversity, of up to four layers using cell-specific reference signals.

- Spatial multiplexing of up to eight layers using UE-specific reference signals. The eNodeB may use feedback reports or exploit channel reciprocity to set the beam-forming weights.
- Transmit diversity based on space-frequency block coding (SFBC) or a combination of SFBC and Frequency Switched Transmit Diversity (FSTD)
- Multi-user MIMO where multiple terminals are assigned overlapping time-frequency resources.

The following multi-antenna transmission schemes are supported in the uplink:

- Single-antenna transmission
- Pre-coding supporting rank-adaptive spatial multiplexing with one up to four layers

2.3.1.5 Link adaptation and power control

According to the radio channel conditions, the Modulation and Coding Scheme (MCS) can be adapted flexibly. The same modulation and coding is applied to all resource units assigned to the same transport block within a TTI. Uplink power control determines the average power over a DFTS-OFDM symbol in which the physical channel is transmitted.

2.3.2 Radio Transmission Characteristics

2.3.2.1 Channel bandwidth of LTE

According to 3GPP TS 36.104 [6], following transmission bandwidth is supported by LTE (E-UTRA).

Table 2.A: Transmission bandwidth configuration NRB in E-UTRA channel bandwidths

Channel bandwidth BW_{Channel} [MHz]	1.4	3	5	10	15	20
Transmission bandwidth configuration N_{RB}	6	15	25	50	75	100

Figure 2-24 shows the relation between the Channel bandwidth (BW_{Channel}) and the Transmission bandwidth configuration (N_{RB} : Number of Resource Blocks). The channel edges are defined as the lowest and highest frequencies of the carrier separated by the channel bandwidth, i.e. at $F_C \pm BW_{\text{Channel}}/2$.

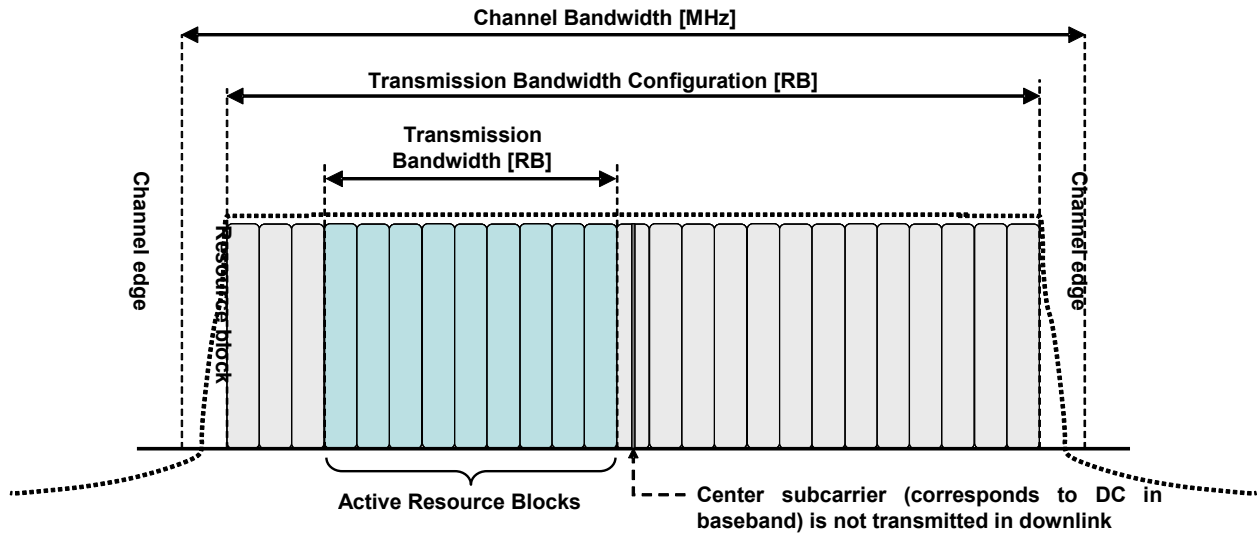


Figure 2-24 Definition of Channel Bandwidth and Transmission Bandwidth Configuration for one E-UTRA carrier

Figure 2-25 illustrates the channel bandwidth for contiguous carrier aggregation.

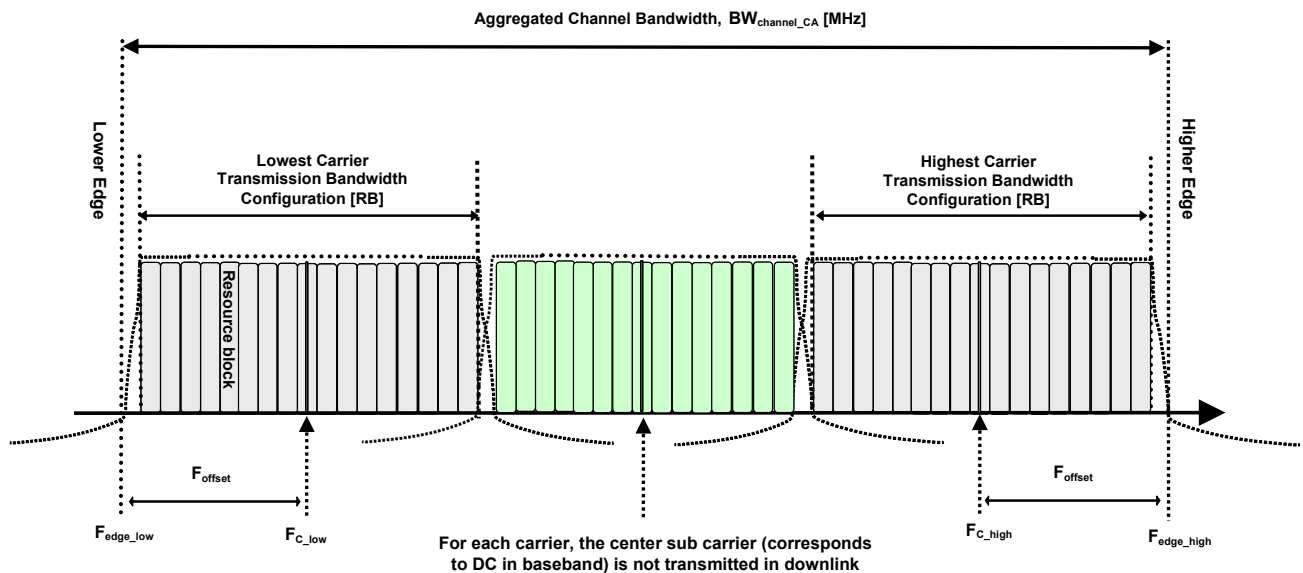


Figure 2-25 Definition of Aggregated Channel Bandwidth for Contiguous Carrier Aggregation.

The lower edge of the Aggregated Channel Bandwidth ($BW_{\text{Channel_CA}}$) is defined as $F_{\text{edge_low}} = F_{C_low} - F_{\text{offset}}$. The higher edge of the aggregated channel bandwidth is defined as $F_{\text{edge_high}} = F_{C_high} + F_{\text{offset}}$. The Aggregated Channel Bandwidth, $BW_{\text{Channel_CA}}$, is defined as follows:

$$BW_{\text{Channel_CA}} = F_{\text{edge_high}} - F_{\text{edge_low}} \text{ [MHz]}$$

F_{offset} is defined in Table 2.B below where BW_{Channel} is defined in Table 2.A.

Table 2.B: Definition of F_{offset}

Channel Bandwidth of the Lowest or Highest Carrier: BW_{Channel} [MHz]	F_{offset} [MHz]
5, 10, 15, 20	$BW_{\text{Channel}}/2$

NOTE: F_{offset} is calculated separately for the Lower Edge and the Higher Edge of the Aggregated Channel Bandwidth.

2.3.2.2 Base Station output power

3GPP defines the output power, P_{out} , of the base station as the mean power of one carrier delivered to a load with resistance equal to the nominal load impedance of the transmitter.

Maximum output power, P_{max} , of the base station is the mean power level per carrier measured at the antenna connector during the transmitter ON period in a specified reference condition.

Rated output power, P_{RAT} , of the base station is the mean power level per carrier for BS operating in single carrier, multi-carrier, or carrier aggregation configurations that the manufacturer has declared to be available at the antenna connector during the transmitter ON period. Different P_{RAT} s may be declared for different configurations

The rated output power, P_{RAT} , of the BS shall be as specified in Table 2.C.

Table 2.C: Base Station rated output power

BS class	P_{RAT}
Wide Area BS	- (note)
Local Area BS	$\leq +24$ dBm (for one transmit antenna port) $\leq +21$ dBm (for two transmit antenna ports) $\leq +18$ dBm (for four transmit antenna ports) $< +15$ dBm (for eight transmit antenna ports)
Home BS	$\leq +20$ dBm (for one transmit antenna port) $\leq +17$ dBm (for two transmit antenna ports) $\leq +14$ dBm (for four transmit antenna ports) $< +11$ dBm (for eight transmit antenna ports)
NOTE: There is no upper limit for the rated output power of the Wide Area Base Station.	

In normal conditions, the base station maximum output power shall remain within +2 dB and -2 dB of the rated output power declared by the manufacturer.

In extreme conditions, the base station maximum output power shall remain within +2.5 dB and -2.5 dB of the rated output power declared by the manufacturer.

In certain regions, the minimum requirement for normal conditions may apply also for some conditions outside the range of conditions defined as normal.

2.3.2.3 Requirements on Base Station Unwanted emission

Out of band emissions are unwanted emissions immediately outside the channel bandwidth resulting from the modulation process and non-linearity in the transmitter but excluding spurious emissions. Spurious emissions are emissions which are caused by unwanted transmitter effects such as harmonics emission, parasitic emission, intermodulation products and frequency conversion products, but exclude out of band emissions.

The out-of-band emissions requirement for the BS transmitter is specified both in terms of Adjacent Channel Leakage power Ratio (ACLR) and Operating band unwanted emissions. The Operating band unwanted emissions define all unwanted emissions in the downlink operating band plus the frequency ranges 10 MHz above and 10 MHz below the band. Unwanted emissions outside of this frequency range are limited by a spurious emissions requirement.

For a BS supporting multi-carrier or contiguous CA, the unwanted emissions requirements apply to channel bandwidths of the outermost carrier larger than or equal to 5 MHz.

Occupied bandwidth

The occupied bandwidth is the width of a frequency band such that, below the lower and above the upper frequency limits, the mean powers emitted are each equal to a specified percentage $\beta/2$ of the total mean transmitted power. See also ITU-R Recommendation SM.328.

The value of $\beta/2$ shall be taken as 0.5%. The requirement applies during the transmitter ON period.

The occupied bandwidth for one E-UTRA carrier shall be less than the channel bandwidth as defined in Table 2.A

Adjacent Channel Leakage power Ratio (ACLR)

Adjacent Channel Leakage power Ratio (ACLR) is the ratio of the filtered mean power centered on the assigned channel frequency to the filtered mean power centered on an adjacent channel frequency.

The requirements shall apply whatever the type of transmitter considered (single carrier or multi-carrier). It applies for all transmission modes foreseen by the manufacturer's specification. For a multi-carrier BS, the requirement applies for the adjacent channel frequencies below the lowest carrier frequency transmitted by the BS and above the highest carrier frequency transmitted by the BS for each supported multi-carrier transmission configuration or carrier aggregation configurations. The requirement applies during the transmitter ON period.

The ACLR is defined with a square filter of bandwidth equal to the transmission bandwidth configuration of the transmitted signal (BW_{Config}) centred on the assigned channel frequency and a filter centred on the adjacent channel frequency according to the tables below.

- For Category A Wide Area BS, either the ACLR limits in the tables below or the absolute limit of -13dBm/MHz apply, whichever is less stringent.
- For Category B Wide Area BS, either the ACLR limits in the tables below or the absolute limit of -15dBm/MHz apply, whichever is less stringent.
- For Local Area BS, either the ACLR limits in the tables below or the absolute limit of -32dBm/MHz shall apply, whichever is less stringent.
- For Home BS, either the ACLR limits in the tables below or the absolute limit of -50dBm/MHz apply, whichever is less stringent.

Table 2.D: Base Station ACLR in unpaired spectrum with synchronized operation

Channel bandwidth of E-UTRA lowest (highest) carrier transmitted BW_{Channel} [MHz]	BS adjacent channel centre frequency offset below the lowest or above the highest carrier centre frequency transmitted	Assumed adjacent channel carrier (informative)	Filter on the adjacent channel frequency and corresponding filter bandwidth	ACLR limit
1.4, 3	BW_{Channel}	E-UTRA of same BW	Square (BW_{Config})	45 dB
	$2 \times BW_{\text{Channel}}$	E-UTRA of same BW	Square (BW_{Config})	45 dB
	$BW_{\text{Channel}}/2 + 0.8 \text{ MHz}$	1.28 Mcps UTRA	RRC (1.28 Mcps)	45 dB
	$BW_{\text{Channel}}/2 + 2.4 \text{ MHz}$	1.28 Mcps UTRA	RRC (1.28 Mcps)	45 dB
5, 10, 15, 20	BW_{Channel}	E-UTRA of same BW	Square (BW_{Config})	45 dB
	$2 \times BW_{\text{Channel}}$	E-UTRA of same BW	Square (BW_{Config})	45 dB
	$BW_{\text{Channel}}/2 + 0.8 \text{ MHz}$	1.28 Mcps UTRA	RRC (1.28 Mcps)	45 dB
	$BW_{\text{Channel}}/2 + 2.4 \text{ MHz}$	1.28 Mcps UTRA	RRC (1.28 Mcps)	45 dB
	$BW_{\text{Channel}}/2 + 2.5 \text{ MHz}$	3.84 Mcps UTRA	RRC (3.84 Mcps)	45 dB
	$BW_{\text{Channel}}/2 + 7.5 \text{ MHz}$	3.84 Mcps UTRA	RRC (3.84 Mcps)	45 dB
	$BW_{\text{Channel}}/2 + 5 \text{ MHz}$	7.68 Mcps UTRA	RRC (7.68 Mcps)	45 dB
	$BW_{\text{Channel}}/2 + 15 \text{ MHz}$	7.68 Mcps UTRA	RRC (7.68 Mcps)	45 dB
NOTE 1: BW_{Channel} and BW_{Config} are the channel bandwidth and transmission bandwidth configuration of the E-UTRA lowest (highest) carrier transmitted on the assigned channel frequency.				
NOTE 2: The RRC filter shall be equivalent to the transmit pulse shape filter defined in TS 25.105, with a chip rate as defined in this table.				

Operating band unwanted emissions

Unless otherwise stated, the Operating band unwanted emission limits are defined from 10 MHz below the lowest frequency of the downlink operating band up to 10 MHz above the highest frequency of the downlink operating band.

The requirements shall apply whatever the type of transmitter considered (single carrier or multi-carrier) and for all transmission modes foreseen by the manufacturer's specification.

The unwanted emission limits in the part of the downlink operating band that falls in the spurious domain are consistent with ITU-R Recommendation SM.329.

3GPP very detailed requirements on operating band unwanted emission, which can be found in 3GPP TS 36.104, section 6.6.3

2.3.2.4 Requirements on Terminal radio transmission

Carrier leakage

Carrier leakage (The IQ origin offset) is an additive sinusoid waveform that has the same frequency as the modulated waveform carrier frequency. The measurement interval is one slot in the time domain.

The relative carrier leakage power is a power ratio of the additive sinusoid waveform and the modulated waveform. The relative carrier leakage power shall not exceed the values specified in Table 2.E.

Table 2.E: Minimum requirements for Relative Carrier Leakage Power

	Parameters	Relative Limit (dBc)
	Output power >0 dBm	-25
	-30 dBm ≤ Output power ≤ 0 dBm	-20
	-40 dBm ≤ Output power < -30 dBm	-10

In-band emissions

The in-band emission is defined as the average across 12 sub-carrier and as a function of the RB offset from the edge of the allocated UL transmission bandwidth. The in-band emission is measured as the ratio of the UE output power in a non-allocated RB to the UE output power in an allocated RB.

The basic in-band emissions measurement interval is defined over one slot in the time domain. When the PUSCH or PUCCH transmission slot is shortened due to multiplexing with SRS, the in-band emissions measurement interval is reduced by one SC-FDMA symbol, accordingly.

The relative in-band emission shall not exceed the values specified in Table 2.F.

Table 2.F: Minimum requirements for in-band emissions

Parameter Description	Unit	Limit (Note 1)		Applicable Frequencies
General	dB	$\max \left\{ -25 - 10 \cdot \log_{10}(N_{RB} / L_{CRBs}), \right. \\ 20 \cdot \log_{10} EVM - 3 - 5 \cdot (\Delta_{RB} - 1) / L_{CRBs}, \\ \left. -57 \text{ dBm} / 180 \text{ kHz} - P_{RB} \right\}$		Any non-allocated (Note 2)
IQ Image	dB	-25		Image frequencies (Notes 2, 3)
Carrier leakage	dBc	-25	Output power > 0 dBm	Carrier frequency (Notes 4, 5)
		-20	-30 dBm ≤ Output power ≤ 0 dBm	
		-10	-40 dBm ≤ Output power < -30 dBm	

Note 1: An in-band emissions combined limit is evaluated in each non-allocated RB. For each such RB, the minimum requirement is calculated as the higher of $P_{RB} - 30$ dB and the power sum of all limit values (General, IQ Image or Carrier leakage) that apply. P_{RB} is defined in Note 10.

Note 2: The measurement bandwidth is 1 RB and the limit is expressed as a ratio of measured power in one non-allocated RB to the measured average power per allocated RB, where the averaging is done across all allocated RBs.

Note 3: The applicable frequencies for this limit are those that are enclosed in the reflection of the allocated bandwidth, based on symmetry with respect to the centre carrier frequency, but excluding any allocated RBs.

Note 4: The measurement bandwidth is 1 RB and the limit is expressed as a ratio of measured power in one non-allocated RB to the measured total power in all allocated RBs.

Note 5: The applicable frequencies for this limit are those that are enclosed in the RBs containing the DC frequency if N_{RB} is odd, or in the two RBs immediately adjacent to the DC frequency if N_{RB} is even, but excluding any allocated RB.

Note 6: L_{CRBs} is the Transmission Bandwidth (see Figure 5.6-1).

Note 7: N_{RB} is the Transmission Bandwidth Configuration (see Figure 5.6-1).

Note 8: EVM is the limit specified in Table 6.5.2.1.1-1 for the modulation format used in the allocated RBs.

Note 9: Δ_{RB} is the starting frequency offset between the allocated RB and the measured non-allocated RB (e.g. $\Delta_{RB} = 1$ or $\Delta_{RB} = -1$ for the first adjacent RB outside of the allocated bandwidth).

Note 10: P_{RB} is the transmitted power per 180 kHz in allocated RBs, measured in dBm.

2.3.3 Challenges of deploying TD-LTE in White Space

White space, as a license exempt spectrum or as a secondary licensed spectrum, provides more opportunities for the rapid introduction of technical innovations, new applications and much lower service costs to end-users, even when use of the spectrum is limited to specific types of

service. The TD-LTE systems operating in white-space, shall have the following cognitive radio features so that they are capable of assessing the available spectrum, make use of this spectrum when they have information to transmit as well as not to cause harmful interference to the incumbent users.

Geo-location database access

Geo-location database has been approved as a good way to provide the information for operating in white space, and it is especially important for incumbent use protection. A key element in the geo-location database approach is that the TD-LTE terminal will provide coexistence related information (such as ID, geo-location, device type) to the database which will then be used by the database to calculate and provide information containing a list of the available channels, the available time slots and their associated maximum transmit powers to the terminal. A geo-location database is key to realizing the applications for secondary spectrum use by TD-LTE in white space. The question of how to design the interface to access this database, what information is required for coexistence, and what structure the information shall be given, are important tasks for TD-LTE to resolve before deployment in white space.

Spectrum sensing

Although spectrum sensing is currently considered as a problematic approach for the protection of incumbent systems from interference, since when taking into account the range of potential TD-LTE deployment scenarios, there is a great level of variability in the derived sensing thresholds. Temporal fading caused by multipath propagation is likely to be one of the main factors affecting the ability to use sensing as a viable technique to protect incumbent system from interference. In some cases, taking account of this type of fading may lead to a very low detection threshold; it may be far below the receiver noise floor, which would make this technique quite impractical. This points to a need to have a further study on spectrum sensing technology, since in some area where geo-location spectrum database may be impossible to set up, spectrum sensing may be the only potential way to avoid interference to the incumbent and coexisting systems.

Spectrum management

To realize the cognitive radio system in the white space, dynamic spectrum management is a must in system design. Thanks to the design of LTE, some important techniques, such as transmit power control, dynamic spectrum access and spectrum aggregation, are already available in the systems. However some special techniques to support secondary use of the spectrum have to be considered if TD-LTE will operate in white space. These techniques may include primary user detection, dynamic frequency selection, alternative spectrum monitoring, fast spectrum switch and adjacent channel interference etc.

Coexistence technology

TD-LTE has its own coexistence features, which make TD-LTE able to coexist with other systems of the same type, TDD RIT and other TDD systems, such as TD-SCDMA. These coexistence features provides good solutions for the TD-LTE deployment but are very limited for the secondary spectrum usage. Since any cognitive radio system that satisfies radio regulations for primary user protection can use white space, several independent or dissimilar

cognitive radio systems operating in the same white space may create interference to each other. This may lead to performance degradation or even to inability to continue operation. So mechanisms that allow cognitive radio systems to operate on a secondary spectrum usage basis are required.

QoS Guarantee and marketing

A device operating in the white space as a secondary user of the spectrum may lose its operating channel at any time if a primary user starts transmission. Thus, in general, it is very hard to guarantee any quality of service (QoS) for any user operating in white space. However, users of TD-LTE expect a guaranteed QoS since they are paying customers. As a result, for TD-LTE operation in white space, QoS has to be guaranteed to a certain extent in order to maintain a continuous connection with acceptable performance. Therefore, the problem of creating a win-win design in white space is an interesting and potentially difficult topic.

3. Application Scenario

3.1 Land Mobile Connectivity



Figure 3-1 Land Mobile Connectivity

Figure 3-1 illustrates one of the envisioned application genres of mobile connectivity using the TV Whitespace, namely, Land Mobile Connectivity. In this use case, PDA/Smartphones, tablet, and laptop/notebook computer users have wireless broadband access to data communications through air interface operating in the Whitespace. The end user may be stationary at a location,

or moving in a vehicle. Common applications are burst or event based, such as voice telephony, Internet access and web browsing.

The main advantage to be offered by the use of whitespace connectivity is to complement the existing mobile broadband access applications, particularly in the category of wireless broadband technologies. Whitespace is capable of offering bandwidth extension in the order of tens, if not hundreds of MHz to ease the traffic of current lower bandwidth technologies.

Another advantage to be offered by the whitespace connectivity is to complement the existing TD-LTE system in sub-urban, rural area or even urban area. Here, whitespace is capable of offering capacity extension in the order of Mbps to ease the traffic of current TD-LTE systems. For instance, TD-LTE on 698 MHz~806 MHz (700MHz band) may be a good candidate in reducing the network investment and satisfying the user requirement of wide and extensive coverage. TD-LTE on 700MHz can also cooperate with TD-LTE on 2.6 GHz or 2.3GHz in urban area to provide higher capacity and wider area coverage.

3.2 High Speed Broadband Vehicle Access

Figure 3-2 provides an illustration of a High Speed Vehicle Broadband Access application utilizing air interface operating in the TV Whitespace (UHF example, below 1GHz due to high speed requirement). With the increasing demand for higher data rates and constant need for connectivity imposed by the fast paced society of today, wireless broadband connectivity must be ubiquitous. That is to say, it must be available even in the most technologically challenging scenarios, like the one inherent to a high speed bullet train moving with speed approaching a typical 350 km/h, or even higher in the future. Speed in such magnitude causes problems to the end user data communications due to inadequate transition time between adjacent cells and significant Doppler spread. In addition, high voltage machinery in railway transportation creates strong electromagnetic exposure. In order to circumvent such harsh scenarios, the connectivity for high-speed vehicle broadband access in the TV Whitespace can be established by deploying along the railways, an array of fixed stations (*e.g.* base stations). The fixed stations are connected to the intermediate portable relays inside the trains.



Figure 3-2 High Speed Vehicle Broadband Access

Connecting to the network, a businessperson travelling from Tokyo to the remote city of Kyoto will have a handful of possibilities to spend the commuting time. The broadband connectivity in the trains supports a wide range of applications, from low-bandwidth-demanding applications such as browsing the Internet and e-mailing to bandwidth-hungry applications such as video conferencing and real time video streaming. In the vehicles, the connectivity between the intermediate relay and the end users may utilize either the TV Whitespace or other air interfaces (*e.g.* Wi-Fi, Bluetooth, WPAN).

As the application example, TD-LTE on 700MHz may also play an important role for this usage case to avoid the relay on train making handover frequently.

3.3 Transportation and Logistics

Figure 3-3 illustrates a specific implementation of transportation and logistics employing an air interface operating in the white space. This example outlines the networking system facilitating logistics in a transportation system that handles freight and shipping services. The logistic-control center is located at the central office of the transportation company. The control center is connected to the data collector network. A data collector network is formed by interconnected hubs acting as data collectors deployed in the area of interest. These data collectors are further connected to the mobile nodes (*e.g.* delivery trucks) that are distributed within the same area. Through the Whitespace connectivity between data collectors and delivery trucks, information can be exchanged, therefore, giving the ability to the central office to add various functions to the transportation service. These advanced functions include real-time location tracking of cargo and parcels, protection against cargo theft through surveillance of its trucks during delivery,

estimating the best route for delivery based on real-time traffic information collected by its trucks, making predictions on delivery time and others and so on. All aforementioned added functions contribute to reduced delivery time and costs, therefore, leading to increased customer satisfaction.



Figure 3-3 Transportation Logistics

The ability to deploy the connectivity using the white space bands complements existing similar services with a wider accessible bandwidth as well as higher resilience to vehicular mobility. In other words, the use of Whitespace to facilitate connectivity brings positive added values to the existing enabling technologies in the current networking systems for transportation and logistics applications.

In the scenario of transportation and logistics, an existing and still evolving enabling technology is the radio identification (RFID). Currently the frequency bands used for RFID vary depending on national regulatory bodies and institutions. Besides the already-existing enabling features offered by the current RFID technologies, air interface connectivity via the Whitespace could also offer several other complimentary advantages, which enables various applications at transportation centre, such as public transportation management, shipping/freight distribution systems, virtual payment systems, location-based services, information sharing service and medical-related services.

3.4 Utility Grid Networks

Figure 3-4 illustrates the concept of utility grid networks employing air interface operating in the TV Whitespace. Smart electricity, gas, and water meters located at the premises of end users are connected to intermediate hubs and then to the main computing systems of utility providers. The smart meters, intermediate hubs and mainframes are equipped with transceivers capable of operating in the white space in order to establish connectivity. Through the white space connectivity; electricity, gas, and water consumption data of a specific household can be transferred automatically to the utility provider in a precise, fast and cheap manner. Contrary to the most common approach of nowadays, meter readers are not employed in utility data collection, freeing the personnel to other tasks, thus adding new values to human resource. Under special circumstances, however, personnel could be deployed to manually obtain the utility data in a specific region, in case of intermediate hub faulty operation, or in a specific household, in case of end user device faulty operation. From the perspective of the utility providers, other advantages of utility grid networks are the ability to connect/disconnect service to the end-users remotely, the flexibility to adjust load-balancing according to local and timely demands, and the capability to respond to emergency situations more effectively. In addition, the utility grid networks application has a remarkable resilience to white space outage. In the event of instantaneous channel unavailability, utility data could be transferred seconds, or even minutes later since delay is not particularly a major issue.

For establishing connectivity in a utility grid network, radio-wave seems to be the more suitable candidate technology. Among other choices, the TD-LTE in white space offers several inspiring advantages. As compared to the power-line cable and optical fiber solutions, network connectivity employing air interface operating in the white space offers larger coverage with lower cost of installation and maintenance. Since the required transmission rate is low in this application, only partial band or several channels of white space should be enough.



Figure 3-4 Utility Grid Networks

3.5 Emergency and Public Safety

Figure 3-5 illustrates the Emergency and Public Safety Network application utilizing air interface operating in TV white space. The network is composed by end-nodes, *e.g.*, portable devices held by firefighters and paramedics, and the communication hubs installed in the vehicles forming a local mesh network. This network is in turn linked to the command/control unit on-site, and is further connected to the main operational control entity, possibly located in the headquarters. The end-to-end connectivity can be established employing air interface operating in the white space connectivity.

The emergency and public safety network is a communication network used by emergency response and public safety organizations such as police force, fire department and emergency medical team responding to accidents, crimes, natural disasters and other similar events. This network covers connectivity from the command/control entity of the public safety organizations all the way down to the end nodes through several hierarchies of intermediate hubs or relays, via air interface operating in the white space. The command/control entity may be the headquarters or commanding offices of the police and fire department. The end nodes can take any form from fixed surveillance cameras/sensors on the streets and other potential disaster areas, to radios in police patrol cars, to mobile radios carried by rescue teams at disaster sites. End nodes have the ability to be interconnected to form mesh networks, to facilitate coverage extension to places where propagation is naturally limited, such as in reinforced concrete buildings and the underground of buildings. Intermediate nodes can be relays or repeaters to extend the range or widen the effective coverage area of the network. Generally, the network should be easily

initiated, *i.e.* in a plug and play manner, with devices simple in design, so as to allow secure easy operation under stressful situations.



Figure 3-5 Emergency and Public Safety

3.6 Local Broadcasting

Broadcasting services are widely provided to transmit the same content to a group of users at the same time in many telecommunication systems (e.g., GSM/UMTS/LTE). Since the specific radio resources have to be reserved for broadcasting services, such as the live TV program broadcasting, the system radio resource may not be enough if many categories of broadcasting services are provided. Therefore, the several hundred MHz of extra spectrum available in TV white space becomes a good candidate for it.

In LTE, MBSFN (Multimedia Broadcast multicast service Single Frequency Network) mode is realized to support a group of cells to transmit identical waveforms in the same frequency band at the same time in order to improve the spectrum efficiency. The group of cells composes an MBSFN area. A central control entity of an MBSFN area is called MCE (Multi-cell/multicast Coordination Entity) used for admission control and allocation of the radio resource for all the eNBs in the same MBSFN area in order to ensure the MBSFN transmission. Figure 3-6 illustrates a scenario of broadcasting services utilizing air interface operating in TVWS frequency bands.

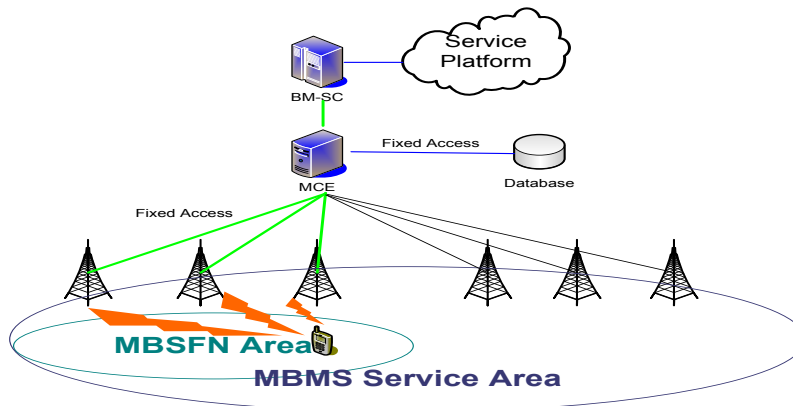


Figure 3-6 Broadcasting services

As a central control point, MCE should manage TVWS resources and allocate these resources to the whole MBSFN area. It should also be aware of the load condition of the whole MBSFN area for admission control. When new broadcasting service is requested in the MBSFN area and makes the TD LTE radio resource insufficient, MCE then decides to allocate services into the TVWS frequency bands. No negotiation is needed between the base stations in this case. As the central control point, MCE contact a database to get the status of TVWS spectrum usage. The database may contain the frequency usage information both of the secondary user and the primary user. The base station in this scenario may be capable of sensing TVWS spectrums and reporting the sensing result to the MCE.

3.7 Carrier Aggregation in the TD-LTE Band and TV White Space Band

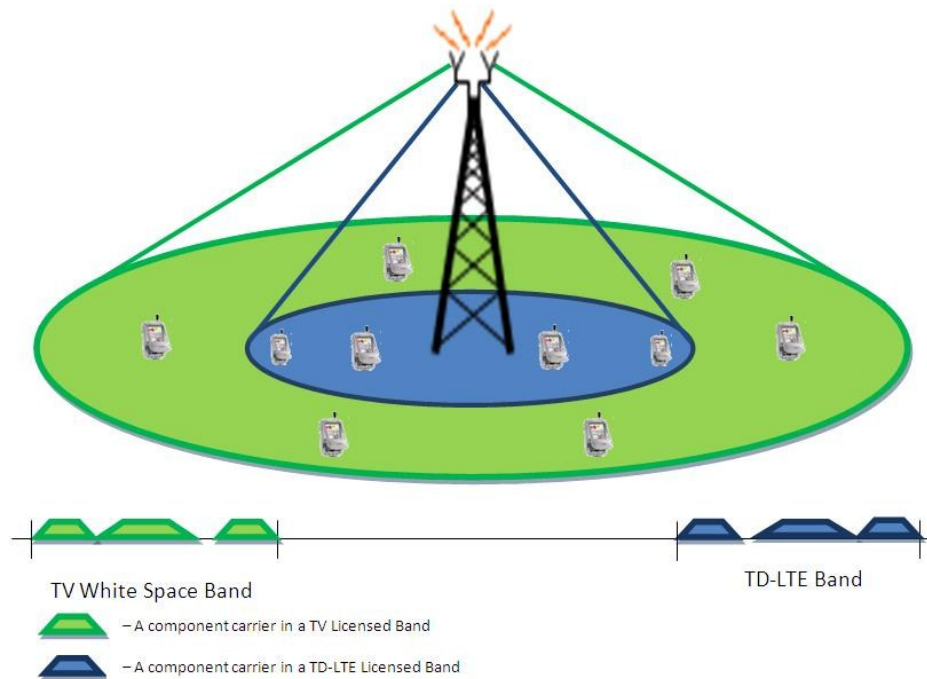


Figure 3-7 Carrier Aggregation in the TD-LTE Band and TV White Space Band

Carrier Aggregation allows multiple component carriers from the same band (TD-LTE Band or TV White Space Band) or different bands (combination of the TD-LTE Band and the TV White Space Band) to be aggregated and jointly used for downlink and uplink transmissions to/from a single user equipment (UE). Different combination of multiple *contiguous* or *non-contiguous* component carriers from the same band or different bands can be aggregated for the downlink and uplink. A carrier-aggregation-capable UE can have *higher data rates* through the total number of aggregated bandwidth. This enables the operators to provide *high data rate services* based on the availability of an overall wide bandwidth, even though a single wideband spectrum is not available.

Figure 3-7 shows the coverage areas for TD-LTE Band (blue region) and the TV White Space Band (green region) as an example where 2.5 GHz band and 700 MHz are assumed for the TD-LTE Band and the TV White Space Band, respectively. The UEs in the blue region can enjoy the *highest aggregated data rates* from the TD-LTE Band and the TV White Space Band. The UEs in the green region can only have *aggregated data rates* from the TV White Space Band.

3.8 Backhaul link using TVWS frequency band

In current mobile networks, wireless backhaul link is widely used by operators in order to enhance cell edge /indoor performance or fill coverage hole. The Figure 3-8 illustrates how to promote outdoor coverage by relay node which connects to a donor BS via wireless backhaul in LTE system. Obvious benefits can be obtained if the wireless backhaul link operates on the TVWS frequency bands as follows: 1) Access link capacity will be improved since interference can be avoided as it operates on the different frequency bands from the backhaul link; 2) Backhaul link capacity can be promoted as well when additional spectrum is utilized; 3) TVWS bands can provide a better channel quality because of the good propagation performance on lower frequency; 4) No impact will be caused to legacy terminals as no change occurs to the access link.

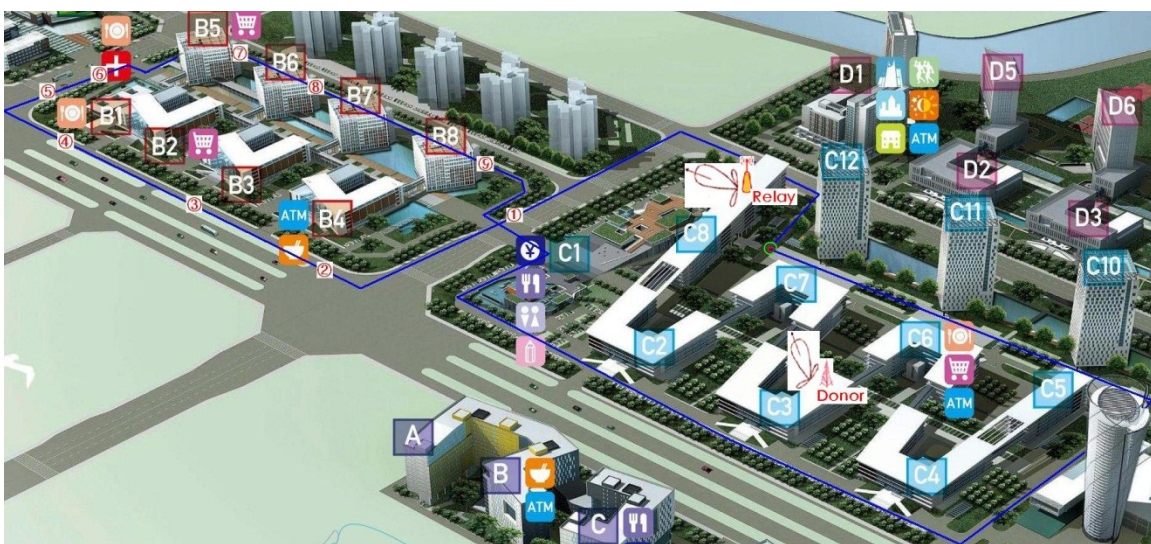


Figure 3-8 Wireless backhaul access

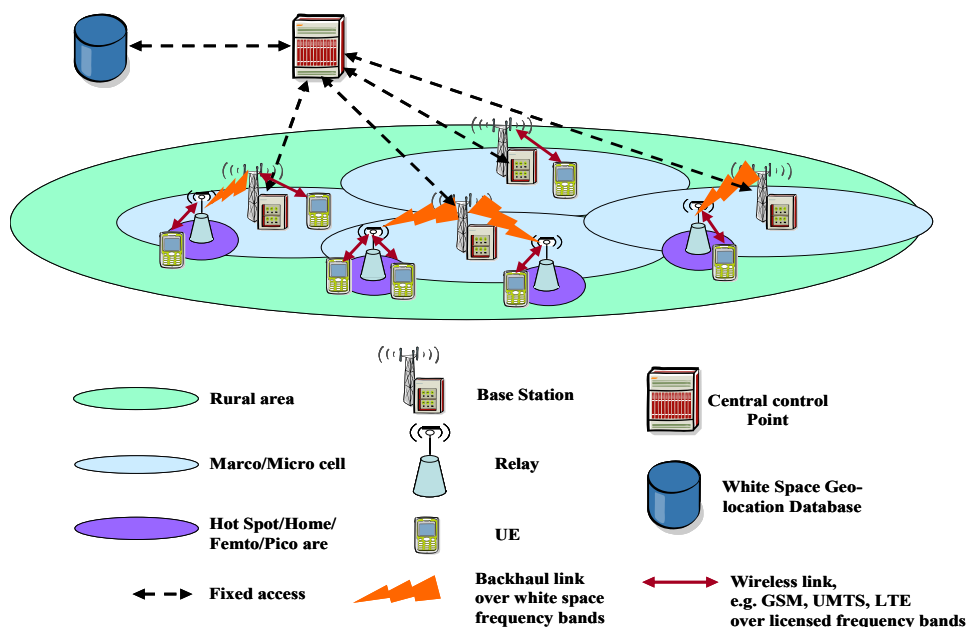


Figure 3-9 Wireless backhaul using TVWS

The Figure 3-9 shows one application to implement backhaul link on TVWS frequency band of relay node in LTE system. In this scenario, a city or a rural area is composed by many macro cells. In a macro cell there are some hotspots or blind areas in which relays can provide the coverage. The relay which has a fixed location e.g. on the roof, could be connected to the macro cell BS with wireless backhaul link. In order to avoid harmful interference to TV system, a central control point is deployed to select a proper TVWS spectrum for backhaul link, e.g., it can obtain available TVWS channel information from a database or through sensing result provided by other network entities, e.g., BS or terminals. Wireless backhaul case can be also deployed by TVWS for macro cell and indoor femto cell or outdoor pico cell as well. The implementation is much similar.

3.9 Asia-Pacific Specific

China Mobile expected that TD-LTE could share the spectrum with other systems (eg. Broadcasting system) on 698 MHz~806 MHz (700MHz band). For the excellent properties of the radio propagation channel, the TD-LTE on 700MHz is proper for wide area coverage to reduce the CAPEX and OPEX, especially in the area with low population density. Three typical scenarios are considered as below.

Rural Area: The telecommunication traffic is exceedingly low in rural areas. TD-LTE on 700MHz will play an important role in reducing the network investment and satisfying the user requirement of wide and extensive coverage.

High Speed Railway: TD-LTE on 700MHz can be used in the network for high speed railway to avoid the relay on train making handover frequently.

Urban Area: TD-LTE on 700MHz could cooperate with TD-LTE on 2.6GHz or 2.3GHz in urban area. TD-LTE on 2.6GHz or 2.3GHz will provide high capacity at those hotspots while TD-LTE on 700MHz provides wide area coverage. This case is useful especially in the initial stage of TD-LTE deployment to provide service quickly with low investment.



Figure 3-10 TD-LTE Works on 700MHz White Space

Besides the white space spectrum of TV band, it is also considered to apply the technology on other IMT or GSM bands for the purpose of sharing the spectrum among the multiple cellular networks of one operator. Since all spectrums belong to one operator, less regulatory conditions will be touched. For the marketing strategies, it is expected that the UE of TD-LTE in white space shall be simple to keep the price reasonable.

We have introduced plenty of application scenarios for the TD-LTE in TV white space, such as Land Mobile Connectivity, High Speed Vehicle Broadband Access, Transportation and Logistics, Utility Grid Networks, Emergency and Public Safety and Local Broadcasting. The essential driving force behind these applications is that the mobile communication networks in the TV white space is capable of providing wider converge area, for the excellent properties of the radio propagation. From the network operators' perspective, wireless services, exploiting TV white space, are key to their success due to low CAPEX and OPEX. Therefore, it is generally believed that TD-LTE in Whitespace is a promising technology which can be utilized, but not limited, to the applications presented in this chapter/section.

4. Enabling Technologies

4.1 Cognitive Information Acquisition

Before utilizing the idle spectrum, TD-LTE should obtain the status of spectrum availability at its location, and should monitor the spectrum status of licensed incumbent during the period of spectrum sharing. Basically, there are two approaches for cognitive radio system to obtain the information of spectrum availability, spectrum sensing and spectrum database. According to the characters and requirements of practical application, a proper approach should be chosen for cognitive information acquisition and an associated solution should be designed.

4.1.1 Spectrum Sensing

Spectrum sensing obtains the cognitive information from the wireless environment by analyzing the wireless signal received at the air interface. As the figure shown below, the TD-LTE detects the spectrum occupancy of the broadcasting system, and then uses the idle spectrum.

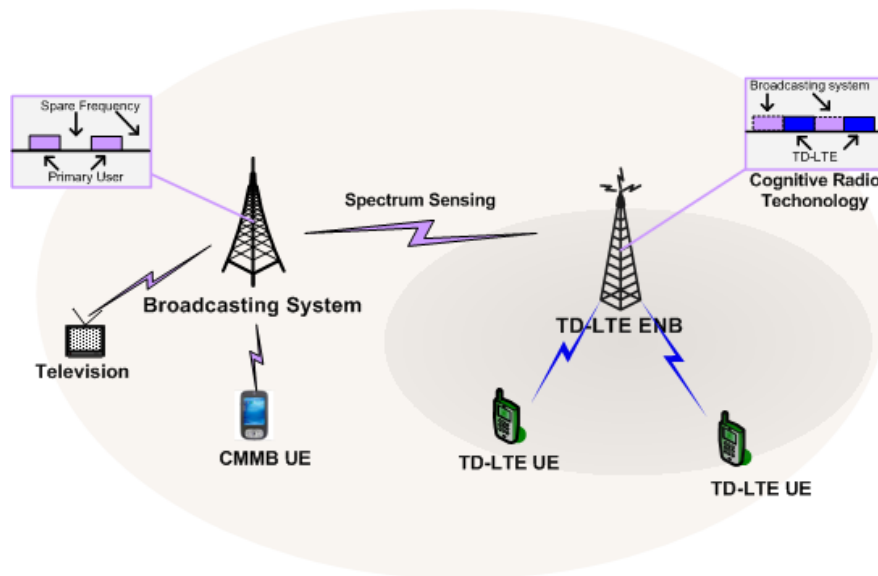


Figure 4-1 TD-LTE shares spectrum with broadcasting system using spectrum sensing

To share the spectrum dynamically and coexist with other radio systems without causing undue interference, the TD-LTE system using spectrum sensing must accommodate a variety of considerations:

- **Continuous spectrum sensing:** During the spectrum sharing, the TD-LTE shall keep sensing the spectrum occupancy of licensed incumbent periodically. Since TD-LTE should vacate the spectrum in time after primary user reoccupies, it is necessary for TD-LTE to conduct the periodical detection at a time interval which shall be short enough for the primary user to bear the interference from TD-LTE.
- **Reliable and efficient detection:** TD-LTE should demonstrate that the licensed system encounters no or minimal interference from the spectrum sharing. So the spectrum sensing must be reliable. At the same time, TD-LTE should maintain the quality of its own transmission. As TD-LTE will track the spectrum status by periodical detection, it will spend considerable resource for the spectrum sensing. Thus, the efficiency of the spectrum sensing will be significant to the transmission quality of TD-LTE network.
- **Monitor for alternative idle spectrum:** In case the primary user reoccupies the spectrum being used, the TD-LTE must switch to other idle spectrum. Thus, TD-LTE should sense the spectrum status in a band much wider than the bandwidth it can occupy and search the alternative idle spectrum.
- **Fast spectrum switch:** When primary user returns, TD-LTE should switch to other idle spectrum in a short period to avoid interfering with primary user and interrupting its own

services. The performance of fast spectrum switch for spectrum sensing is more crucial than that for spectrum database because spectrum sensing cannot notify TD-LTE as to when the primary user will return.

- **Distinguish type of transmission:** It is necessary for the TD-LTE to sense the type of transmission being received. TD-LTE should protect the primary user according to the regulatory rules, thus it should be able to distinguish the transmission of primary user so that spurious transmissions and interference are ignored as well as transmissions made by TD-LTE itself and other system with low priority.

4.1.2 Spectrum Database

Spectrum database gathers the information of spectrum occupancy by certain technology, such as geo-location database which connects with the primary systems and cognitive radio systems directly as shown in Figure 4-2. The primary user will send the information of its spectrum occupancy associated with geographical location to the spectrum database, and spectrum database will inform the cognitive radio system of the available spectrum at its location.

Besides sharing the spectrum information, spectrum database also provides convenience for spectrum trading. The primary user provides its spare spectrum to spectrum database, and spectrum database will sell spectrum to those cognitive radio systems, which can be regarded as a secondary spectrum market using a centralized broker

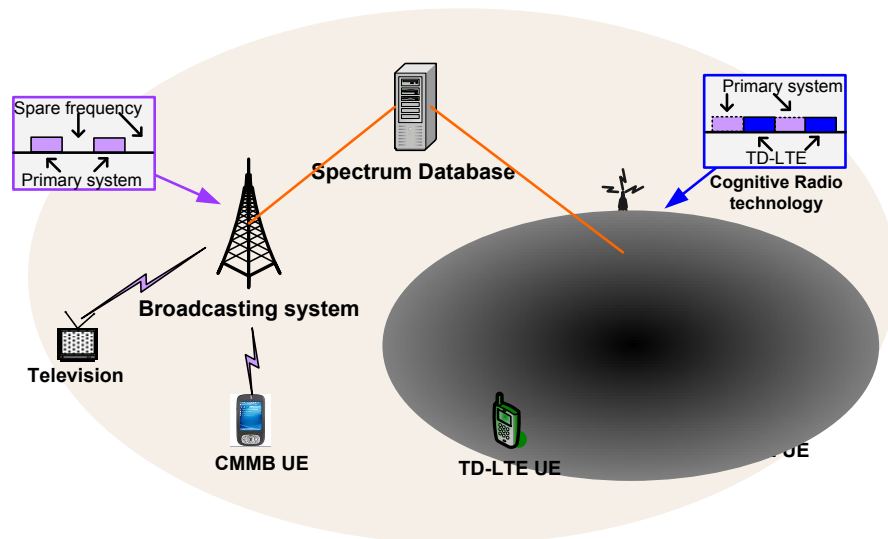


Figure 4-2 TD-LTE shares spectrum with broadcasting system using spectrum database

For a spectrum database, several issues shall be considered for the case of TD-LTE utilizing white space:

- **Availability of spectrum information:** The spectrum database should provide accurate information on the spectrum occupancy of primary users. In some countries, the information on the availability of white space can be determined, for example based on information on DVB-T incumbent's spectrum occupancy in some European countries. Thus, in this case the spectrum database information will be reliable. However, in other countries

without spectrum opening information, the approach of creating a spectrum database will be useless as the data obtained will be unreliable.

- **Time delay for spectrum trading:** It shall take some time for spectrum database to gather the information of idle spectrum from primary user and the spectrum requirements from cognitive radio systems in order to conduct the spectrum trade. Therefore, a WS spectrum database may reduce the time delay in the event that a spectrum trade is needed.
- **Location precision:** To reduce the difficulty to gather the information of the geographical location associated to the idle spectrum, spectrum database is not expected to provide high precision in spectrum location. The actual idle spectrum at certain location may not be consistent with the information provided by spectrum database. This could cause the interference between primary user and TD-LTE. The TD-LTE system must be aware of this possibility and ensure that such an error does not create harmful interference to the incumbent.

4.2 Priority Methodology

When TVWS frequency bands open to other radio systems, secondary users have to compete for the available radio resources. Basically, secondary users can be divided into two categories: (1) Extension of legacy wide area coverage networks (e.g., GSM, UMTS, LTE) (2) Local coverage networks (e.g., Wifi, ad-hoc).

For the first category, operators have invested large amount of money to establish and operate on these networks which serve for millions of users for the past decades. These networks need to provide rigorous, robust and reliable QoS to users and wide area coverage. Compared with the first category, the latter category of network costs less money. It usually provides local coverage and no QoS is required. In other words, the two kinds of networks have different characteristics and performance requirements. Therefore, it is suggested to distinguish the usage priorities for different categories of secondary users.

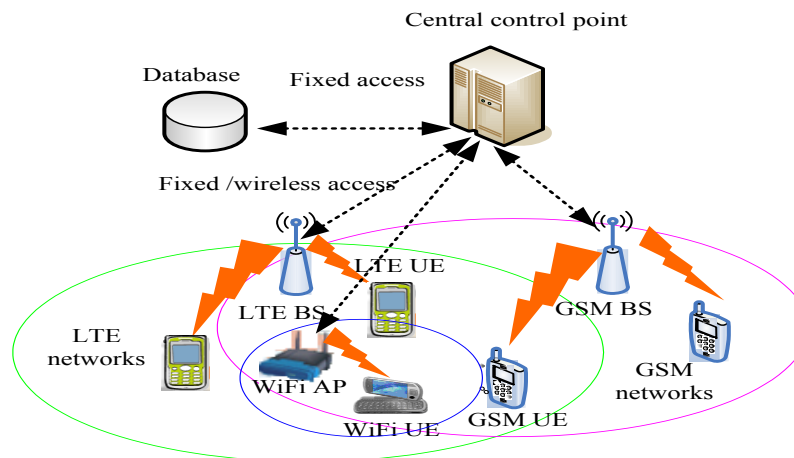


Figure 4-3 Prioritized connectivity

Figure 4-3 illustrates various categories of networks with overlapping coverage. Different networks compete for the limited radio resources as secondary users. In order to utilize these

spectrums effectively and orderly, mechanisms are required to categorize the priorities of the secondary usage in TVWS frequency bands. Two potential methods are provided as follows.

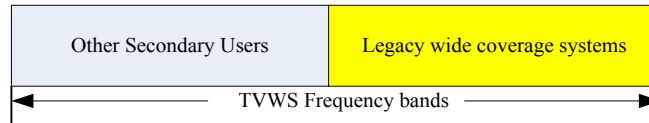


Figure 4-4 Secondary License Spectrum Sharing

1) Secondary license

Secondary license is released by regulators to secondary users in TVWS. An example is shown in Figure 4-4. TVWS frequency bands are divided into two parts: legacy wide coverage systems exclusively occupy fixed TVWS frequency bands while other secondary users share with the rest TVWS radio resources. Such secondary license may be stored in the TVWS database and delivered to decision making entity (e.g., central control point) if necessary. Consequently, the decision making entity should take secondary license into account while allocating TVWS radio resources to the secondary users.

2) Secondary user priorities

Different systems are allocated different priorities to use TVWS frequency bands by the regulators. Similar to the first case, the priority information may be saved in the database and delivered to decision making entity to determine the spectrum sharing of TVWS frequency bands. Additionally, regulators may decide the priority between different operators.

4.3 Soft radio resource sharing

The technology evolution is a continuous process, and it is very common that one operator runs several types and generations of networks in the same geographic area. The operators deploy TD-LTE in white space may also have other systems under their operation, .e.g., WirelessLAN, WiMax, UMTS. The dynamic radio resource allocation works for the operators who

- use at least two radio access technology (RAT) types,
- use different RATs with different QoS support, .i.e., the Primary RAT has higher priority than the Secondary RAT, and
- allow dynamically modifying the radio resource between different RATs.

The following figure is an example of the multiple RATs and their frequency allocation.

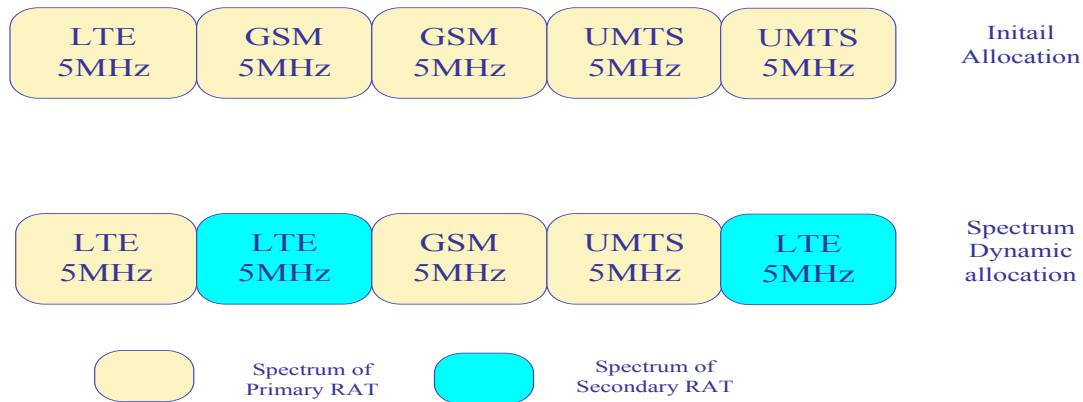


Figure 4-5 Multiple RAT frequency allocation

A more efficient way of sharing spectrum could be to use soft frequency reuse, and an example is shown in Figure 4-6, where there are 3 spectrum bands allocated for GSM, which is the Primary RAT. In each geographic area, one band is used and is different from neighboring area to avoid self-interference. In order to protect the Primary RAT, the LTE system, as a secondary RAT, the LTE system, should limit its transmit power for the band occupied, especially for the band overlapped with GSM system.

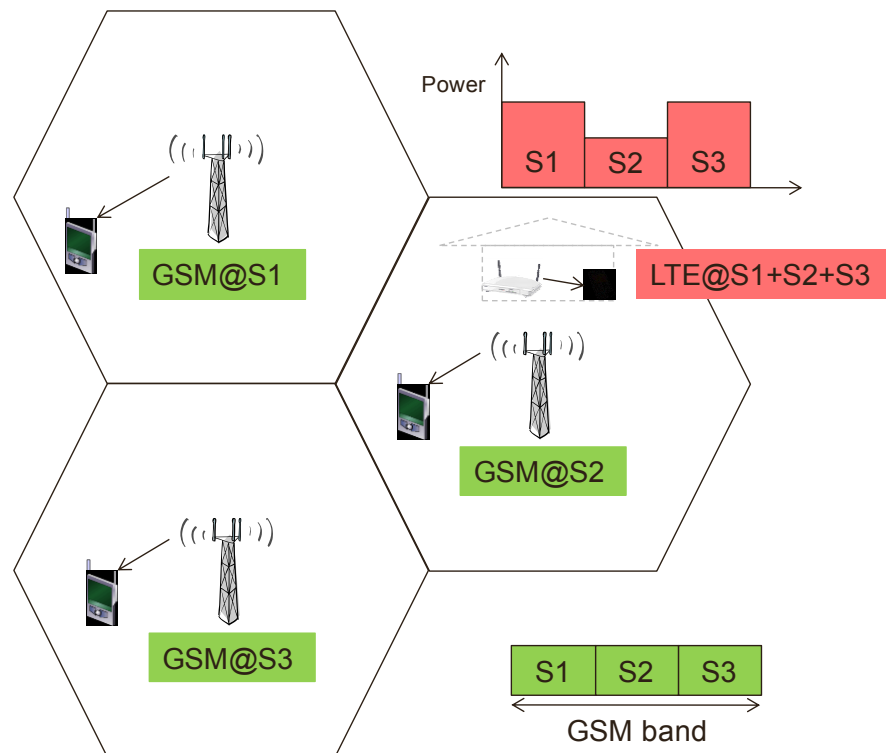


Figure 4-6 Soft Frequency reuse GSM/LTE

The enabling technologies of this soft frequency sharing could be:

- Database guided power control: LTE eNodeB send radio resource request to the database, and then database will calculate the spectrum and corresponding transmit power limit.

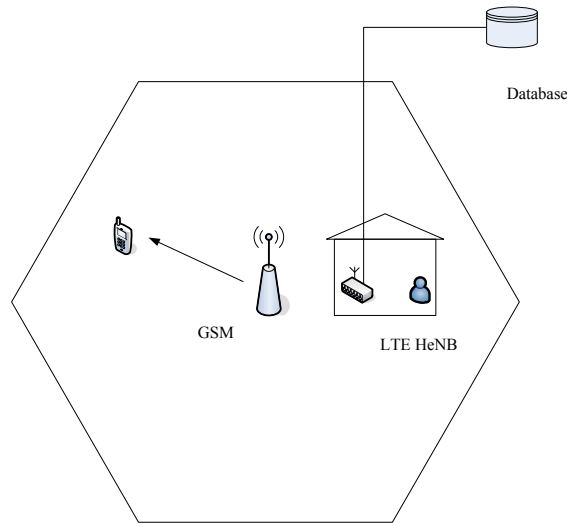


Figure 4-7 Database Guided Power Control

- Spectrum sensing: LTE eNodeB senses the radio environment to get the blank spectrum band, or calculate the maximum transmit power for the band occupied by Primary RAT.

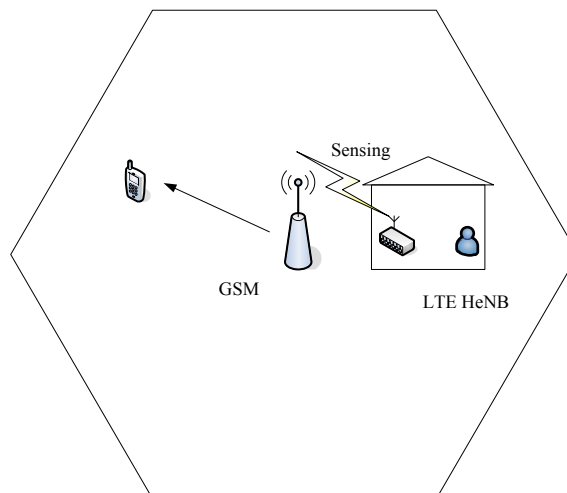


Figure 4-8 Spectrum Sensing for Resource Sharing

4.4 Carrier Aggregation using the TD-LTE Band and TV White Space Band

Conventional TD-LTE operates in its allocated bands (2.3GHz band and 2.6GHz band). It may also operate in 2.0GHz band currently allocated to TD-SCDMA. When TV white space bands are further available, carrier aggregation needs to be designed so that the white space TD-LTE system can operate in high rate transmission. However, the physical layer implementations and MAC layer protocols for white space TD-LTE need to be backward-compatible with the ones in conventional TD-LTE.

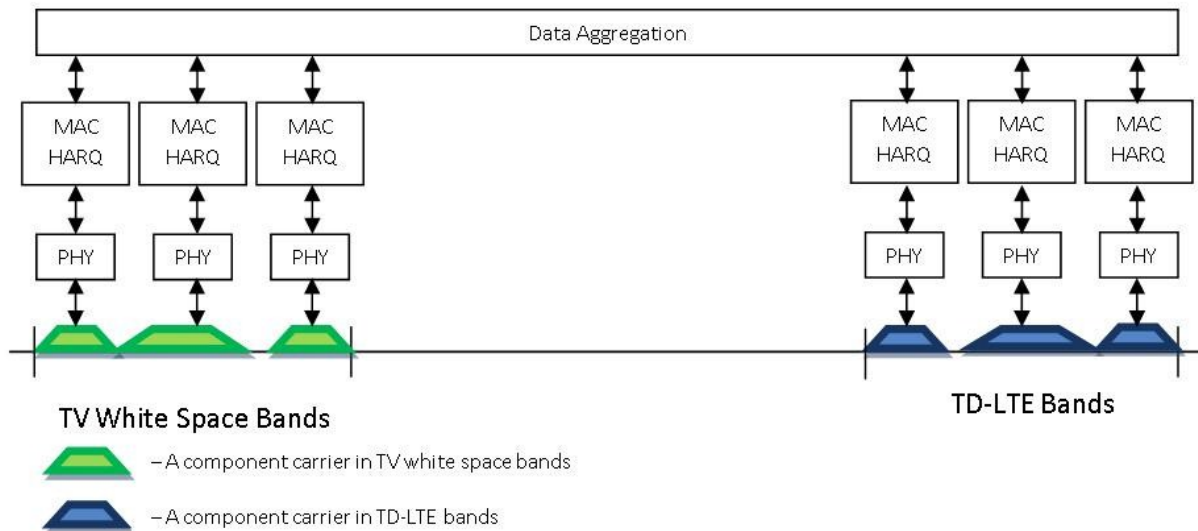


Figure 4-9 Data Aggregation at the MAC Layer in the TD-LTE Bands and TV White Space Bands

Figure 4-9 shows a general scheme for white space TD-LTE with data aggregation at the MAC layer. Each component carrier (either from TD-LTE bands or TV white space bands) has its own physical layer transmission schemes like transmit power, modulation and coding schemes, and multiple antenna configuration as well as an independent hybrid automatic repeat request (HARQ) entity in its MAC layer. The use of multiple control channels supports flexible and efficient transmissions in both uplink and downlink, and ensures backward compatibility.

There are different carrier aggregation scenarios: (1) All component carriers are from TD-LTE bands; (2) all components carriers are from TV white space bands; and (3) some component carriers are from TD-LTE bands, and others are from TV white space bands.

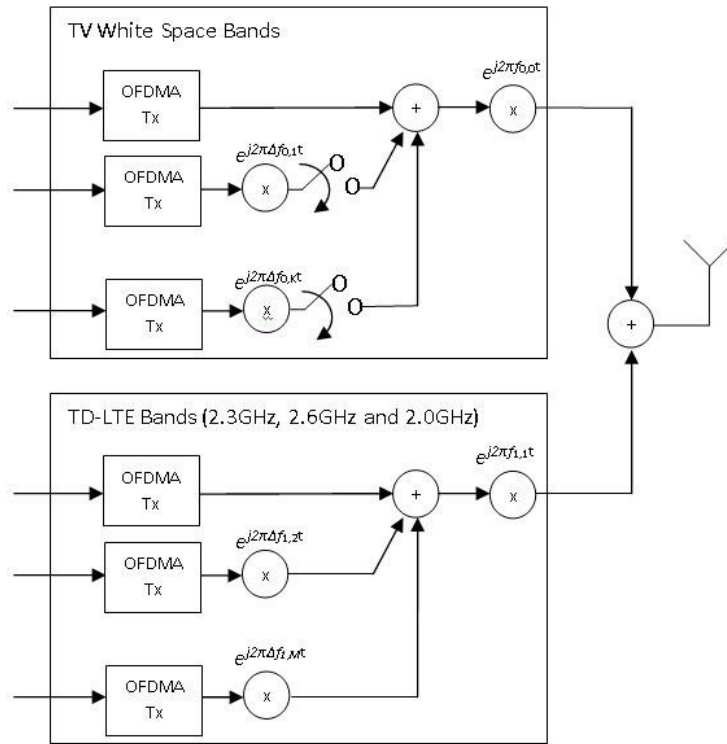


Figure 4-10 eNB Transmitter with Carrier Aggregation

The PHY layer transmitter structure for base station (eNB) supporting carrier aggregation is shown in Figure 4-10. The transmission in the TV white space bands is controlled by switches, which stay in connection mode when the TV white space bands are available. Each of the K -OFDMA blocks for the TV white space bands are first centred at $\Delta f_{0,i} = f_{0,i} - f_{0,0}$, where $f_{0,i}$ ($i > 1$) denotes the carrier frequency of the i^{th} component carrier in the TV white space bands, and $f_{0,0}$ denotes the carrier frequency of the basic component carrier. The summed outputs from $(K+1)$ OFDMA blocks are up-converted to carrier frequency of f_0 to generate the signal output. Note each of the OFDMA blocks may support multiple available TV bands within the bandwidth covered by the OFDMA block.

In a similar manner, each of the M OFDMA blocks in the TD-LTE bands are first centred at $\Delta f_{1,i} = f_{1,i} - f_{1,1}$, where $f_{1,i}$ denotes the carrier frequency of the component carrier in that band. The summed outputs from the M OFDMA blocks are then up-converted to carrier frequency of $f_{1,1}$ to generate the signal output.

The outputs from the two bands are summed together prior to transmission through a wideband antenna as shown in Figure 4-10. Alternatively, each summed output can be transmitted via its own antenna.

The eNB transmit signal is received by UEs via one or more antennas through the receiver unit as shown in Figure 4-11. After the signal is received, it is down-converted to the baseband before processed by parallel OFDMA receiver units. The outputs from each OFDMA receiver units are then sent to the MAC/HARQ units for processing, and further to data aggregation unit.

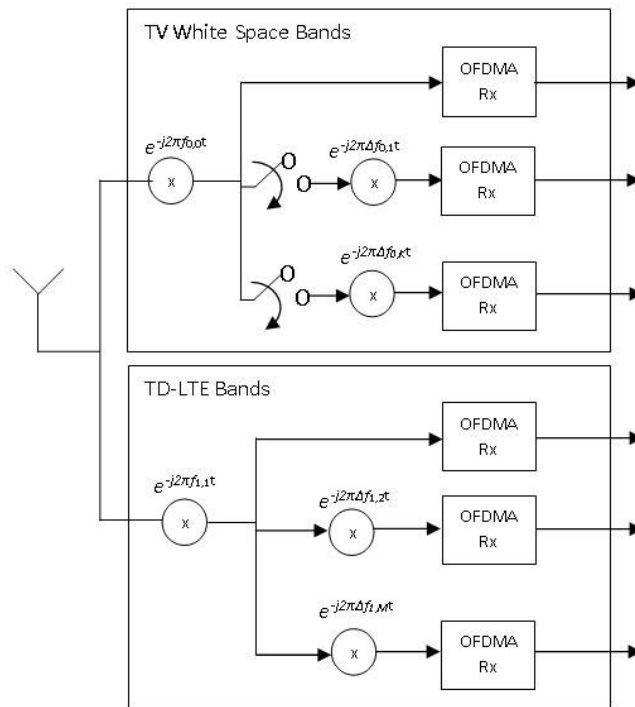


Figure 4-11 UE Receiver with Carrier Aggregation

4.5 Coexistence solutions for TD-LTE to deploy in WS

TD-LTE has its own coexistence features, which makes TD-LTE able to coexist with other systems of the same type in the licensed band, and with TDD RIT and other TDD systems, such as TD-SCDMA. These coexistence features, however, are very limited, and are not specially designed for operation in WS as a secondary user.

Coexistence situations in the widely used unlicensed bands at 2.4 GHz and 5 GHz are not as good as one could imagine. Everybody tries to use the resources carelessly and autonomously which leads to a situation in which no device gets any adequate resources since there is no collaboration on coexistence. The resource exhaustion problem is even more severe in WS for secondary spectrum users. A problem specific to the WS is that availability of WS is very low in heavily populated areas due the existence of primary users. Even among the secondary users, the spectrum is, likely to be scarce if there is no properly coexistence control among them.

For a network operating as a secondary spectrum user in WS of both licensed and unlicensed spectrum use, it is essential to support a set of functions to ensure efficient and fair use of the available spectrum resources. The following functions make it possible for the secondary networks in WS:

- Discover the information of the spectrum use, including the discovery of licensed operation (primary user).
- Discover the neighbor networks with which coexistence is needed.
- Discover the characteristics of the networks and resources needed by each network
- Make coexistence decision to share available resources fairly between the neighboring networks.

Basically there are two ways to provide above functions and to solve the coexistence issues in TD-LTE networks.

Coexistence Control Entities

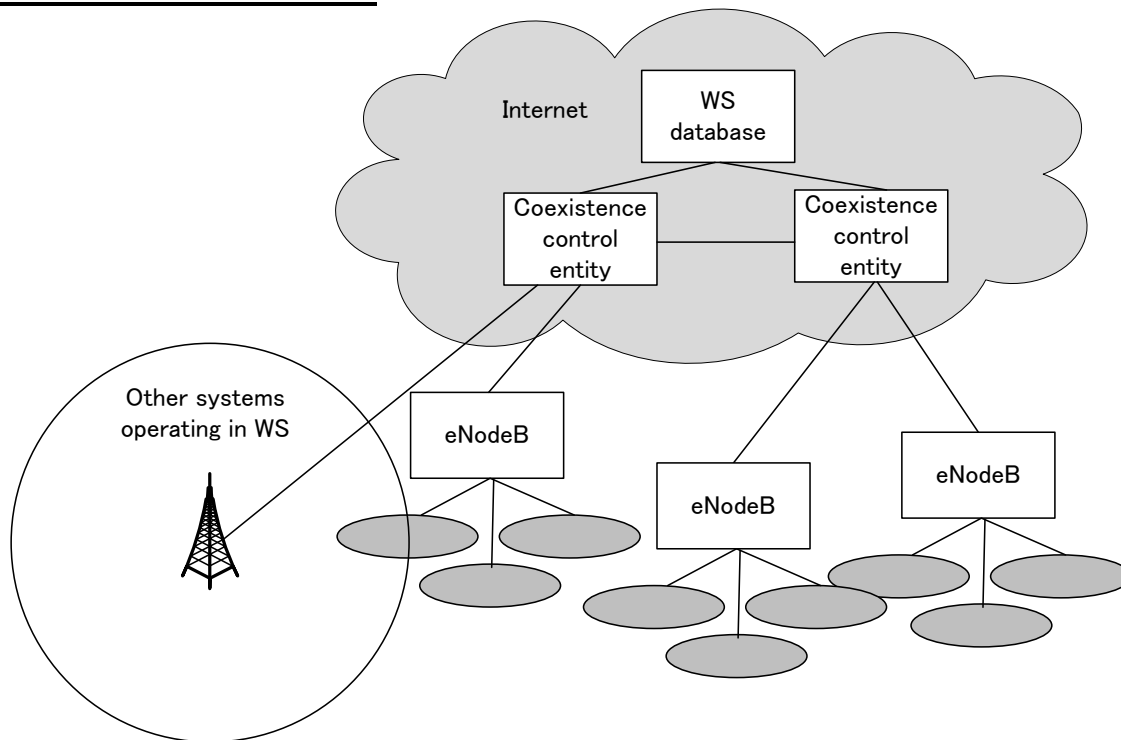


Figure 4-12 Coexistence control entities located in the internet.

Figure 4-12 presents a scenario in which eNodeBs of all the networks connect to coexistence control entities located in the internet. In this scenario, the WS database provide available channel list to all the coexistence control entities. The coexistence control entity may be a physical entity which is able to obtain spectrum information from WS database and provides above functionalities. It may also be a logical entity in the WS database server. The coexistence control entity could be dominated by one eNodeB or shared by several eNodeBs or shared by eNodeBs with other systems operating in WS. There should be an interface between WS database and eNodeBs, as well as an interface these coexistence entities to exchange coexistence related information or to negotiate on the solutions of existence issue which involves several eNodeBs controlled by different coexistence control entities. The resource allocation is done by coexistence control entity as well as eNodeB. This solution is suitable to solve the coexistence in

the license exempt bands with the capability not only to solve the coexistence within TD-LTE systems, but also to solve inter-system coexistence between TD-LTE systems and other dissimilar systems operating in WS.

Coexistence control functions

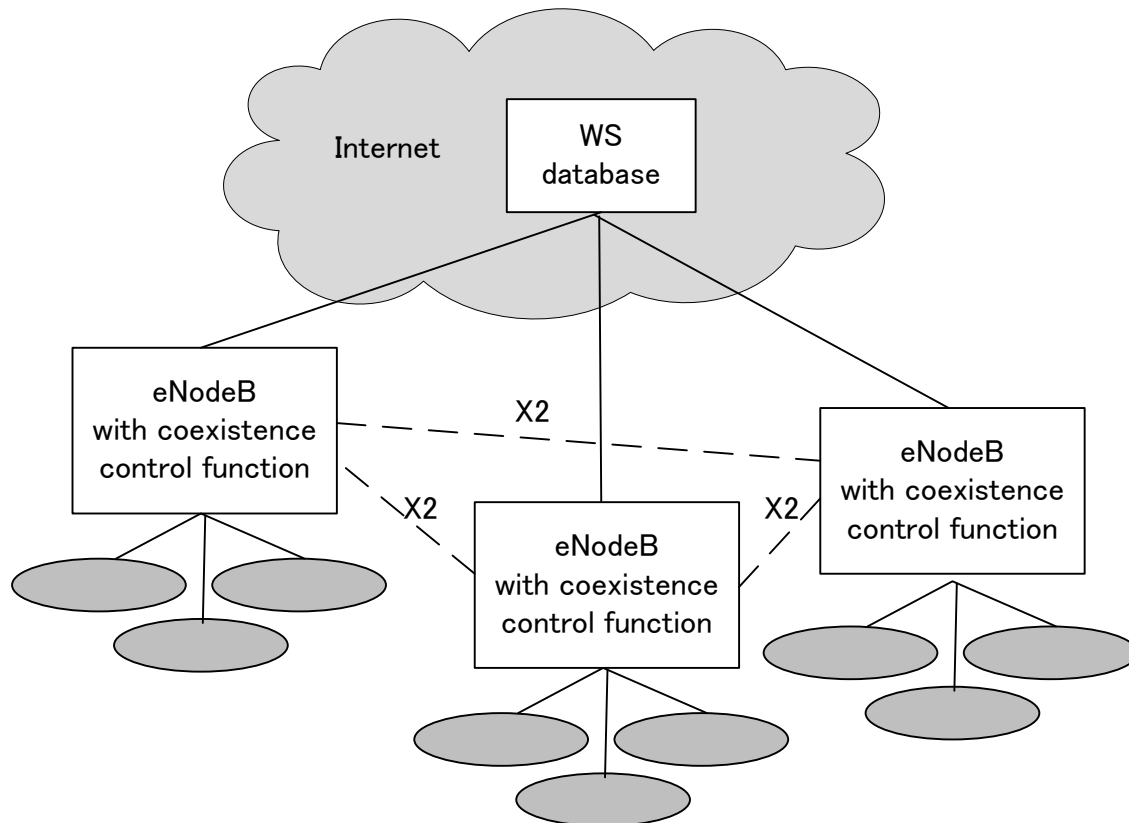


Figure 4-13 Coexistence control function.

Figure 4-13 presents a scenario in which a coexistence control function is installed in side eNodeBs of all the networks. With the help of coexistence control function, the eNodeB is able to perform resource allocation with the coexistence solution. The coexistence related information and the negotiations on coexistence solutions could be exchanged over interface X1. The solution is easily implemented in the currently defined TD-LTE system architecture. However it can only solve the coexistence issues within TD-LTE systems.

4.6 Backhaul Capabilities of TD-LTE Standard with White Space Deployment

Deploying TD-LTE based networks in white space will not have a major impact on the current LTE design. Rather, the potential standard of LTE with white space deployment most likely will keep the current backhaul capabilities, which is a basic requirement for LTE system design. The reasons to keep current backhaul requirements are five fold:

4.6.1 *Spectrum allocation*

Spectrum flexibility is a key feature of LTE radio access and is set out in the LTE design specifications. It consists of several components, including deployment in different spectrum bandwidth allocations and deployment in diverse frequency ranges, both in paired and unpaired frequency bands. Therefore deploying TD-LTE system in white space band using spectrum aggregation technologies in white space are naturally supported by the LTE system design.

4.6.2 *Robust to the Long Delay Spread*

The system design of the possible deployment in TV white space of UHF /VHF band has to take into account a longer delay spread as compared with IMT band. Thanks to the use of OFDM in LTE, additional robustness to radio-channel time dispersion possible, due to the option of a longer cyclic prefix. Furthermore the flexibility to use a guard period to handle the timing uncertainty makes it more likely that TD-LTE can to be deployed in long delay spread environment transmission capabilities.

4.6.3 *Cognitive Plane Support*

To facilitate the TD-LTE deployment in white space as any unlicensed spectrum user or as a secondary licensed user, the cognitive plane shall be introduced into the current LTE system design, for example, to provide the functionalities to access the geo-location database, or inter or intra system coexistence. Since the cognitive plane could be designed inside the core network, from the prospective of LTE RAN, the cognitive functionalities can be considered as a part of MMS. Therefore, the control signaling can be transmitted though S1-C interface and user list, such as the available channel information can be indicated though S1-U interface. Thus the cognitive plan is able to support TVWS deployment without any changes in system architecture.

4.6.4 *Dynamic Spectrum management and QoS Guarantee*

To realize the cognitive radio system in the white space, dynamic spectrum management is a must in system design. The LTE system provides a lot of spectrum management and QoS control techniques, such as transmit power control, dynamic spectrum access and spectrum aggregation in eNodeB. In addition, special techniques to support secondary use of the spectrum including, primary user detection, dynamic frequency selection, alternative spectrum monitoring, fast spectrum switch and adjacent channel interference etc, can be easily facilitated inside eNodeB. The X2 interface is thus able to be used to perform negotiation between different eNodeBs.

In general, we found that almost all techniques defined in current system design, and TD-LTE system can be easily extended to deploy in white space without losing any transmission capabilities.

5. Performance Evaluation

The Performance Evaluation is provided to verify the feasibility of TD-LTE system deployed in TVWS from the perspective of protection of incumbent user. And the evaluation is based on the technical radio aspects of existing TD-LTE techniques that are defined in 3GPP.

5.1 Evaluation methodology description

In order to investigate the mutual interference impact of TD-LTE and TV system through Monte-Carlo approach, a large number of snapshots should be made in which nodes are randomly placed in a predefined deployment scenario; and based on the statistics of the snapshots, the final evaluation results can be obtained.

In this document, an interferer is assumed as the system that causes interference, and a victim is assumed as the system interfered with by an interferer. Here an interferer or victim is not specific to TD-LTE or TV system. Then the general evaluation procedure for coexistence simulation could be described as bellows:

- 1) Evaluate TD-LTE and TV system performance independently as the baseline for each system by using Monte-Carlo [11] method.
- 2) Generate a coexistence layout for both interferer system and victim system, e.g., the distance between the interferer system and victim system, the height of antennas, in urban or in suburban area, .etc.
- 3) Perform a snapshot procedure where the instantaneous RF parameters (such as shadowing, node location, node transmission power, etc.) are used to calculate the actual SIR received by both interferer system and victim system. When calculating the actual SIR, the interference between interferer system and victim system should be considered. Use the actual SIR to throughput/PER/coverage mapping to determine the obtained throughput/PER/coverage for the interferer system or victim system. Note that the number of snapshots should be large enough so that stable average performance can be achieved.
- 4) Adjust parameters (e.g., the separation distance, etc.) of interferer system properly so that its interference to the victim system can be measured. For the adjacent channel coexistence scenario, ACIR (Adjacent Channel Interference Ratio) could normally be adjusted to evaluate the interference caused by interferer system to victim system.
- 5) Compare the performance results of victim system with its baseline results, it will then be seen how victim system performance loss changes as the interference caused by interferer system changes. The performance loss of both TD-LTE and TV system should be evaluated under the condition of coexistence.

For the initial performance simulations, Round Robin scheduler shall be used for TD-LTE system if needed. When using Round Robin scheduler, full buffer traffic shall be simulated. For TV system, there are always signals transmitted over the specific channels.

The TV system performance metrics and TD-LTE system performance metrics could include system throughput, cell-edge user throughput, system coverage, system PER or received SIR, etc.

5.2 RF performance for TV protection when TD-LTE Backhaul over TVWS

5.2.1 Scenario

In current mobile networks, there are many WiFi Access Points (APs) which provides local and/or hotspot coverage. These APs can be back haul TD-LTE user traffic links over TVWS. Use case under section 5.2.3.1 in TR 102 907 [10] shows the same scenario. A TD-LTE CPE is used as backhaul node and can be either integrated into an AP or connected with an AP by wire line as shown in Figure 5-1.

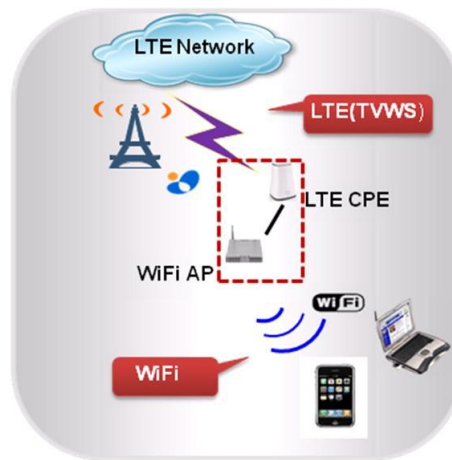


Figure 5-1 General Topology of LTE Backhaul Link

Before discussing the scenario of TD-LTE backhaul link working over TVWS in detail, the following assumptions about the TD-LTE backhaul link are made:

- 1) Terminals can't directly connect with TD-LTE eNB, and each terminal should be connected with one of WiFi APs.
- 2) WiFi will work on different frequency bands (such as ISM band) as compared to TD-LTE backhaul link.
- 3) Since each TD-LTE eNB is laid out to take advantage of AP backhaul independently, TD-LTE cells may not overlap. Thus, interference between LTE cells isn't considered when the cell boundry are sufficiently separated. Otherwise, the interference should be considered.

5.2.1.1 Co-channel TV Protection Scenario

Figure 5-2 shows the co-channel TV protection scenario for the TVWS band. The TD-LTE eNB is located outside the coverage area of the TV Digital Terrestrial Transmitter (DTT). In order not to prevent interference to the Digital Television (DTV) receiver, a minimum offset distance should be kept between TV system (i.e., TV contour) and TD-LTE cell-edge. The interference between TD-LTE system and TV system could be divided into 4 types in general:

- 1) TD-LTE eNB (TD-LTE Downlink) interfere with DTV receiver

- 2) TD-LTE CPE (TD-LTE Uplink) interfere with DTV receiver
- 3) DTT interfere with TD-LTE eNB (TD-LTE Downlink)
- 4) DTT interfere with TD-LTE CPE (TD-LTE Uplink)

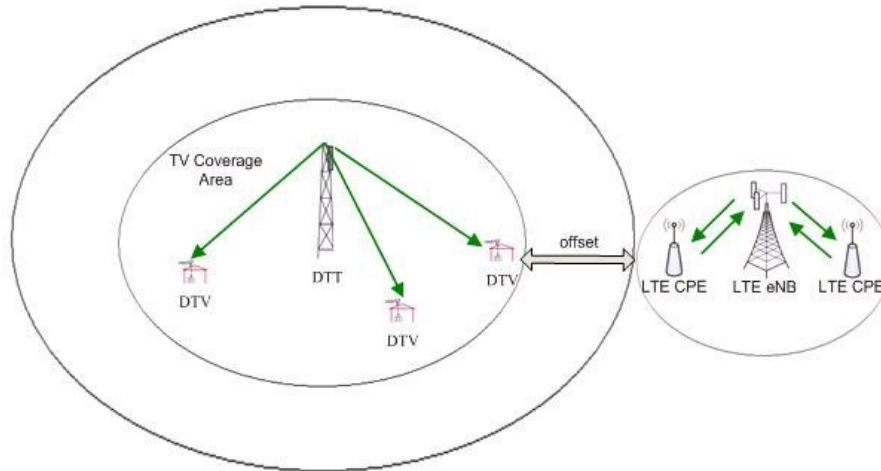


Figure 5-2 Co-channel TV Protection Scenario

Figure 5-3 shows spectrum occupancy of the TDD-LTE system when it coexists with a TV system on a co-channel basis, when the bandwidth of the TV system is 8MHz such as found in DVB and CMMA etc. TDD-LTE system is working at the center of the TV band over a bandwidth is 5MHz. The separation distance between the systems should be such that co-channel interference from TD-LTE system does not create harmful interference to the DTV system.

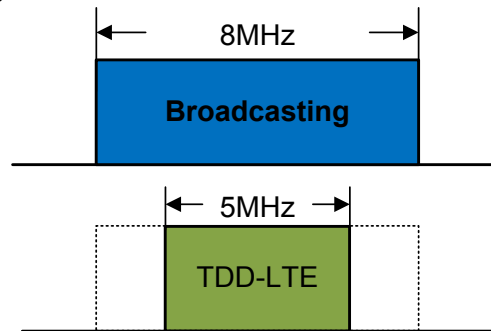


Figure 5-3 Co-channel Scenario

5.2.1.2 Adjacent Channel TV Protection Scenario

When TD-LTE cell is located near the coverage zone of TV transmitter (DTT), a guard band between the TD-LTE system and TV system should ensure that mutual interference to either system is avoided. Figure 5-4 shows the adjacent channel TV protection scenario on the TVWS band. The interference between TD-LTE system and TV system could be divided into 4 types in general:

- 1) TD-LTE eNB (TD-LTE Downlink) interfere with DTV receiver
- 2) TD-LTE CPE (TD-LTE Uplink) interfere with DTV receiver
- 3) DTT interfere with TD-LTE eNB (TD-LTE Downlink)

4) DTT interfere with TD-LTE CPE (TD-LTE Uplink)

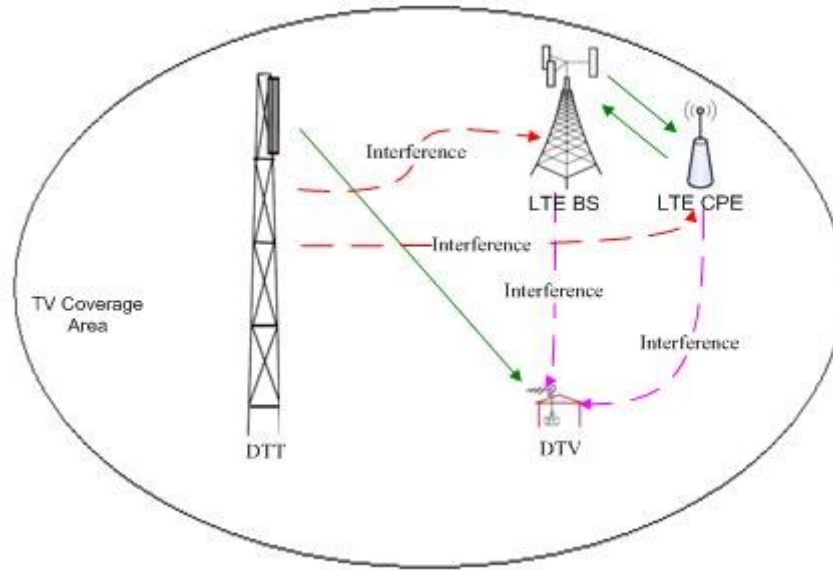


Figure 5-4 Adjacent Channel TV Protection Scenario

Figure 5-5 shows the spectrum for the TDD-LTE system when it coexists with the TV system on an adjacent channel basis. Here, the TDD-LTE system is working on the center of a TV adjacent and the bandwidth is 5MHz, therefore, the frequency isolation between these two systems is 1.5MHz.

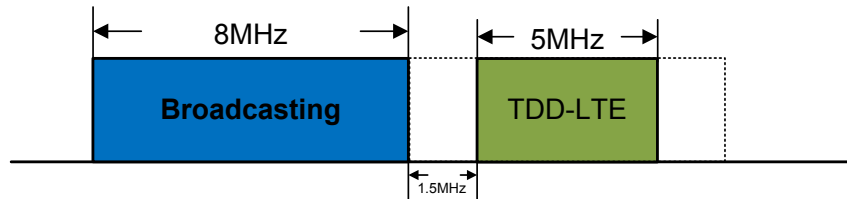


Figure 5-5 Adjacent Channel Scenario

5.2.2 Simulation assumptions

In a general way, the MCL method can be written in the following form:

$$P(\Delta f) = P_{TX} + G_{TX} - ACIR(\Delta f) + G_{RX} - P_{RX_allowed_interf}$$

$$ACIR(\Delta f) = \frac{1}{\frac{1}{ACS_{RX}(\Delta f)} + \frac{1}{ACLR_{TX}(\Delta f)}}$$

where :

Δf : frequency offset between these two coexistence systems;

$P(\Delta f)$: path loss requirement to protect the victim system;

P_{TX} : maximum e.i.r.p. of the interferer;

G_{TX} : antenna gain of the interferer;

G_{RX} : antenna gain of the victim;

$P_{RX_allowed_interf}$: minimum power allowed to be interfered at victim;

$ACS_{RX}(\Delta f)$: Adjacent Channel Selectivity of the victim for a frequency offset Δf ;

$ACLR_{TX}(\Delta f)$: Adjacent Channel Leakage Ratio of the WSD for a frequency offset Δf ;

Some system parameters of the TV and TDD-LTE are described below in Table 5A and Table 5 B respectively:

Table 5.A: TV system parameters

Paratemeter	Value	Comment
Frequency	600MHz	
Link BW	7.6MHz(8 MHz)	
TX Power (EIRP)	72.15dBm	
TX Antenna height	200m	
TX Antenna Peak Gain	0dBi	
RX Antenna height	10m	
RX noise figure	7dB	
RX Noise Floor	-98.17dBm	
RX Antenna Peak Gain	9.15dBi	
Minimum SNR at cell-edge	21dB	Fixed , 64 QAM, 2/3
Cell Size	52.9km	Rec. ITU-R P.1546
TX Emission mask/ACLR	68.53dB	Figure 5.3-6
RX Blocking mask/ACS	53.12dB	CEPT Report 148

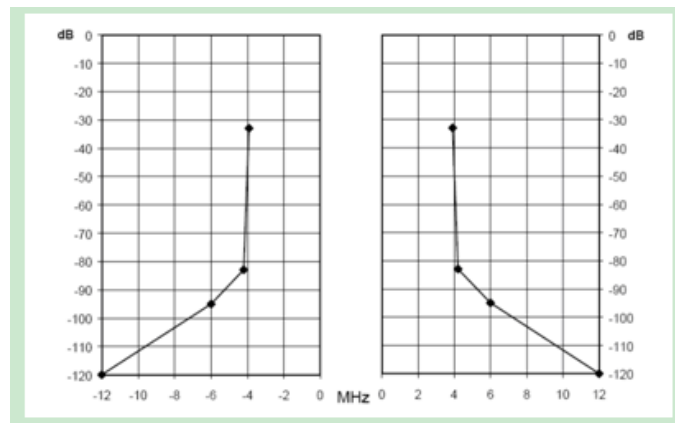


Figure 5-6 TV TX Emission Mask

Table 5.B: TDD-LTE BH system parameters

parameter	value	comment
Frequency	600MHz/608MHz	
System BW	5MHz(4.5MHz)	
eNB		
Receiver Floor noise	-104dBm	Huawei Prototype Test
Antenna Height	32m	
Antenna peak Gain	15dBi	
Maximum transmit power	30dBm	
Emission mask/ACLR	41dB	Huawei Prototype Test in Figure 5.3-5 Scenario
Blocking mask/ACS	54.9 dB	Huawei Prototype Test in Figure 5.3-5 Scenario
CPE		
Antenna Height	5m	
Antenna peak Gain	13.5dBi	
Receiver Floor noise	-102dBm	Huawei Prototype Test
Maximum transmit power	23dBm	
Emission mask/ACLR	50.17dB	Huawei Prototype Test in Figure 5.3-5 Scenario
Blocking mask/ACS	64.33 dB	Huawei Prototype Test in Figure 5.3-5 Scenario

5.2.3 Simulation results

The MCL results including co-channel and adjacent channel will be described respectively below:

a) Co-channel TV Protection Scenario

TD-LTE eNB (TD-LTE Downlink) interfere with DTV receiver						
RX Sensitivity deterioration (dB)	1	2	3	4	5	6
Interfering signal mean power(dBm)	-104.04	-100.5	-98.19	-96.37	-94.82	-93.43
Path loss requirement (dB)	158.19	154.65	152.34	150.52	148.97	147.58
Distance Separation (km)	29.377	24.857	22.273	20.428	18.974	17.753
TD-LTE CPE (TD-LTE Uplink) interfere with DTV receiver						
RX Sensitivity deterioration (dB)	1	2	3	4	5	6
Interfering signal mean power(dBm)	-104.04	-100.5	-98.19	-96.37	-94.82	-93.43
Path loss requirement (dB)	103.3	99.76	97.45	95.63	94.08	92.69

Distance Separation (km)	11.676	9.881	8.869	8.147	7.579	7.104
DTT interfere with TD-LTE eNB (TD-LTE Downlink)						
RX Sensitivity deterioration (dB)	1	2	3	4	5	6
Interfering signal mean power (dBm)	-107.87	-104.33	-102.02	-100.2	-98.65	-97.26
Path loss requirement (dB)	191.52	187.98	185.67	183.85	182.3	180.91
Distance Separation (km)	140.01	123.694	114.209	107.343	101.891	97.29
DTT interfere with TD-LTE CPE (TD-LTE Uplink)						
RX Sensitivity deterioration (dB)	1	2	3	4	5	6
Interfering signal mean power (dBm)	-109.87	-106.33	-104.02	-102.2	-100.65	-99.26
Path loss requirement (dB)	195.02	191.48	189.17	187.35	185.8	184.41
Distance Separation (km)	271.138	243.277	226.214	213.202	202.677	193.525

b) Adjacent Channel TV Protection Scenario

TD-LTE eNB (TD-LTE Downlink) interfere with DTV receiver						
B-eNB ACLR (dB)	41					
TV RX ACS (dB)	53.12					
ACIR (dB)	40.74					
RX Sensitivity deterioration (dB)	1	2	3	4	5	6
Interfering signal mean power (dBm)	-104.04	-100.5	-98.19	-96.37	-94.82	-93.43
Path loss requirement (dB)	117.45	113.91	111.6	109.78	108.23	106.84
Distance Separation (km)	3.592	2.874	2.47	2.192	1.98	1.8
TD-LTE CPE (TD-LTE Uplink) interfere with DTV receiver						
CPE ACLR (dB)	50.17					
TV RX ACS (dB)	53.12					
ACIR (dB)	48.39					
RX Sensitivity deterioration (dB)	1	2	3	4	5	6
Interfering signal mean power (dBm)	-104.04	-100.5	-98.19	-96.37	-94.82	-93.43
Path loss requirement (dB)	103.3	99.76	97.45	95.63	94.08	92.69
Distance Separation (km)	1.013	0.823	0.719	0.646	0.59	0.544
DTT interfere with TD-LTE eNB (TD-LTE Downlink)						
TV ACLR (dB)	68.53					
CPE ACS (dB)	64.33					
ACIR (dB)	62.93					

RX Sensitivity deterioration (dB)	1	2	3	4	5	6
Interfering signal mean power(dBm)	-107.87	-104.33	-102.02	-100.2	-98.65	-97.26
Path loss requirement (dB)	130.63	127.09	124.78	122.96	121.41	120.02
Distance Separation (km)	13.283	10.495	8.919	7.809	6.958	6.26
DTT interfere with TD-LTE CPE (TD-LTE Uplink)						
TV ACLR(dB)	68.53					
B-eNB ACS(dB)	54.9					
ACIR(dB)	54.72					
RX Sensitivity deterioration (dB)	1	2	3	4	5	6
Interfering signal mean power(dBm)	-109.87	-106.33	-104.02	-102.2	-100.65	-99.26
Path loss requirement (dB)	142.34	138.8	136.49	134.67	133.12	131.73
Distance Separation (km)	48.366	42.854	39.462	36.835	34.713	32.782

5.2.4 TV projection suggestions

Both the TV and TD-LTE Back Haul (BH) performance loss is shown to occur when TV system and LTE system are in the co-channel and adjacent scenario.

From the MCL result shown above, in the co-channel scenario LTE performance loss is much greater than TV performance loss, and TDD-LTE BH performance loss is dominated by its UL transmission while there is rarely any impact on its DL transmission. Tus, when LTE and TV systems are deployed on a co-channel basis, the separation distance between LTE and TV system should be larger than 200km.

For the adjacent channel scenario, when DTT interferes with TD-LTE BH, since TV performance loss is much greater, as TV Cell Size is 52.9 km, so eNB and CPE can work in part of TV coverage. However, when TD-LTE BH interferes with TV Receiver, eNB and CPE must work outside of TV coverage, the separation distance between LTE and TV system should be larger than 0.5km.

6. Commercialization Study

6.1 Market category

The commercial markets for wireless technologies are clearly the largest markets for TD-LTE in white space. As a cellular system, the main component of its commercial markets is the cellular market which provides the land mobile service to public. The private mobile networks for high speed vehicle broadband access and transportation and logistics could also be classified as cellular market. TD-LTE on white space could be deployed as the emergency and public safety networks, which belongs to the public safety market.

6.2 Market places

This section will analyze the possible market places in some regions or countries to deploy TD-LTE in white space, such as Asia and Europe. It will analyze the spectrum of white space in these regions which is possible to be utilized by TD-LTE in white space, and will discuss the driving forces, trends and related issues of these market places. This section can also analyze the initiative especial from the standpoint of the regulatory agency of these market places.

In China, since in recent years, the Digital Dividend Band (698MHz~806MHz) has not been allocated to IMT, the requirement of utilizing the white space to compensate for the spectrum shortage of IMT will be more prominent than other countries.

Similar to the situation in other part of the world, the most popular band for cognitive radio application in China is the UHF band or TV band.

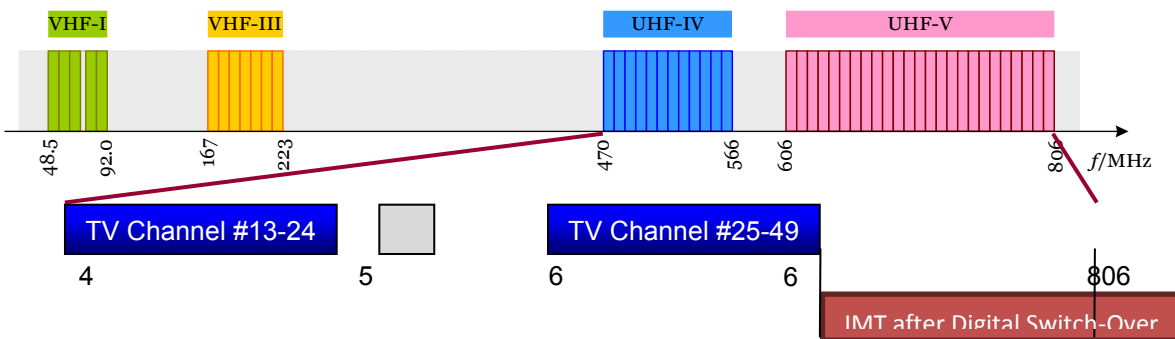


Figure 6-1 TV band in China

The spectrum of broadcasting service is up to 392MHz, which is found in the bands of 48.5-72.5MHz, 76-92MHz, 167-223MHz, 470-566MHz, and 606-806MHz (see Figure 6-1). In 2007, a plan was made to finish the digital switch-over of broadcasting system in 2015, however, this has now been postponed until the year 2020.

China has one of the most significant mobile communication markets in the world. To satisfy the great population demand for mobile services, enough spectrums shall be guaranteed for the cellular system to provide service to the public. However, the allocated bands for TD-LTE deployment in China is limited and are all above 1.9GHz. These bands are much more suitable for hotspot deployment than for wide area deployment. Thus, the Digital Dividend Band is more crucial for TD-LTE in China than other countries.

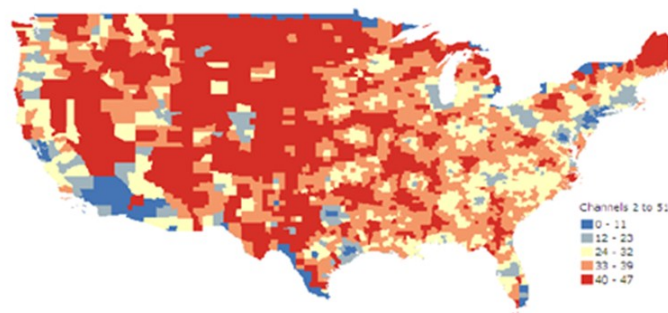
Cognitive radio provides another approach to make use of the Digital Dividend Band for IMT. This could alleviate problems created by the delay digital switch-over of the broadcasting system. As a TDD technology, TD-LTE shows advantages in white space application for it does not require paired frequencies as is the case in FDD. Multiple options on bandwidth from 1.4MHz to 20MHz exist that make TD-LTE able to provide high spectrum efficiency while utilization white space spectrum. Therefore, the mobile operators and regulatory agency of China must now consider deploying the technology of TD-LTE in white space in order to realize a solution for the use of the Digital Dividend Band to fulfill the spectrum shortage. TD-LTE in white space

will then first be applied on 698~806MHz band in China. If the same trend is followed as in the United State and Europe, eg. UK, it could also be extended to the band below 698MHz.

6.3 Capacity analysis of white space

This section will present the capacity that could be provided by the spectrum obtained from white space. Based on the distribution of available idle spectrum in the area, the capacity that TD-LTE in white space is able to provide is analyzed in order to show the great potential to satisfy the market demand.

6.3.1 USA



Source: Rick Tornado, Spectrum Bridge

Figure 6-2 TVWS availability in US

Table 6.A TVWS in typical cities in US (source: “Measuring the TV ‘White Space’ Available for Unlicensed Wireless Broadband” New America Foundation and Free Press).

Market	Post-DTV Transition	
	No. of Vacant Channels Between 2-51	Percent of TV Band Spectrum Vacant
Juneau, Alaska	37	74%
Honolulu, Hawaii	31	62%
Phoenix, Ariz.	22	44%
Charleston, W.V.	36	72%
Helena, Mont.	31	62%
Boston, Mass.	19	38%
Jackson, Miss.	30	60%
Fargo, N.D.	41	82%
Dallas-Ft. Worth, Tex.	20	40%
San Francisco, Calif.	19	37%
Portland, Maine	33	66%
Tallahassee, Fla.	31	62%
Portland, Ore.	29	58%
Seattle, Wash.	26	52%
Las Vegas, Nev.	26	52%
Trenton, N.J.	15	30%
Richmond, Va.	32	64%
Omaha, Neb.	26	52%
Manchester, N.H.	23	46%
Little Rock, Ark.	30	60%
Columbia, S.C.	35	70%
Baton Rouge, La.	22	44%

6.3.2 Europe [12]

A detailed quantitative evaluation of the available TVWSs and their usability in the European market was carried out in our recent paper to be published in IEEE transactions of mobile computing in early 2012. The statistical analysis carried out in this study focuses on 11 European countries (Austria, Belgium, Czech Republic, Denmark, Germany, Luxembourg, The Netherlands, Switzerland, Slovakia, Sweden, and the United Kingdom) and is based on knowledge of the properties of the TV transmitters in those areas. The results show an absolute upper limit on the estimated number of TVWS:

- These results refer to the protected regions of the TV transmitters only, while any realistic scenario has to accommodate an additional protection distance
- The analysis considers TV transmitters only. Constraints due to other applications (e.g., wireless microphones) based on local regulation might further reduce the TVWS availabilities.

In the scenario where the adjacent channel usage is unrestricted, the overall average availability of the TV channels is 56% of the evaluated band (by area) or 49% (by population), compared to USA figures for the 470-806MHz band: 79% (by area) or 63% (by population). In the scenario where the adjacent channel usage is restricted, white space availability is reduced drastically: the average availability of the TV channels is 23% (by area) or 18% (by population) compared to USA figures for the 470-806MHz band: 58% (by area) or 37% (by population).

Table 6.B TVWS availability in Europe and in the USA

	w. unrestricted adjacent channel		w-. restricted adjacent channel	
	Per area	Per population	Per area	Per population
Europe (11 countries)	56%	49%	23%	18%
USA	79%	63%	58%	37%

TVWS availability in Europe and in the USA (as % of the total number of TV channels available).

Our study confirms that there is lower availability of TVWS in Europe in the 470–790MHz band compared to the USA for the 470-806 MHz band.

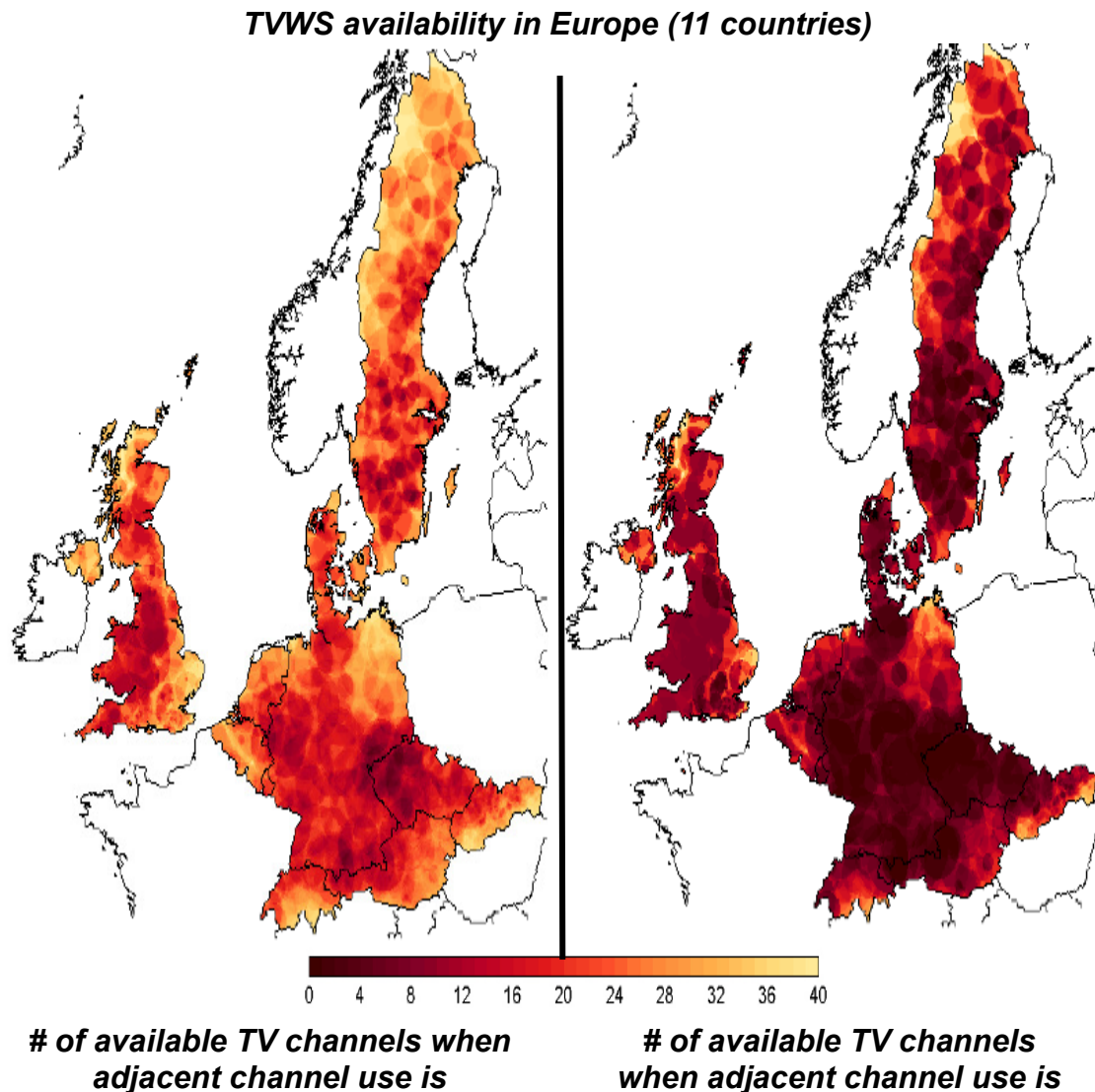


Figure 6-3 TVWS availabilities in EU and US

6.4 Market demands

The white space deployment will bring giant economic and social benefits. TD-LTE in white space will provide telecommunication service for mobile broadband access which is different from other technologies, such as WiFi. The benefits from TD-LTE deployed in white space may be estimated from the similar case of allocating the Digital Dividend Band 698-806 MHz band to mobile broadband.

According to the consulting report “Socio-economic impact of allocating 700 MHz band to mobile in Asia Pacific” from Boston Consulting Group (BCG) (appointed by GSMA in 2010), it will bring great economic benefits and significant social benefits by allocating the 698-806 MHz band to mobile broadband. BCG predicts that allocating this band to mobile broadband would add \$729B to the GDP of Asia Pacific nations by 2020 while Digital Broadcasting would only

generate \$71B (see Figure 6-4). It would also bring significant social benefits, particularly in rural areas of Asia Pacific, by creating new businesses and jobs which are all likely to result from widespread access to high-speed mobile broadband.

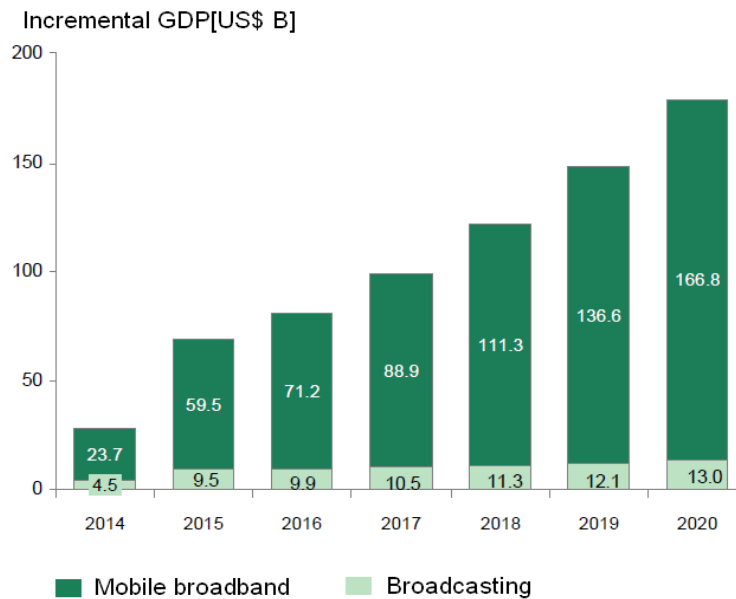


Figure 6-4 Compare the GDP generated by mobile broadband and digital broadcasting

With a huge number of mobile subscribers, China will be a great market for white space. From 2000 to 2011, the mobile subscribers keep growing sustainably although the growth rate is declined to a plateau (see Figure 6-5).

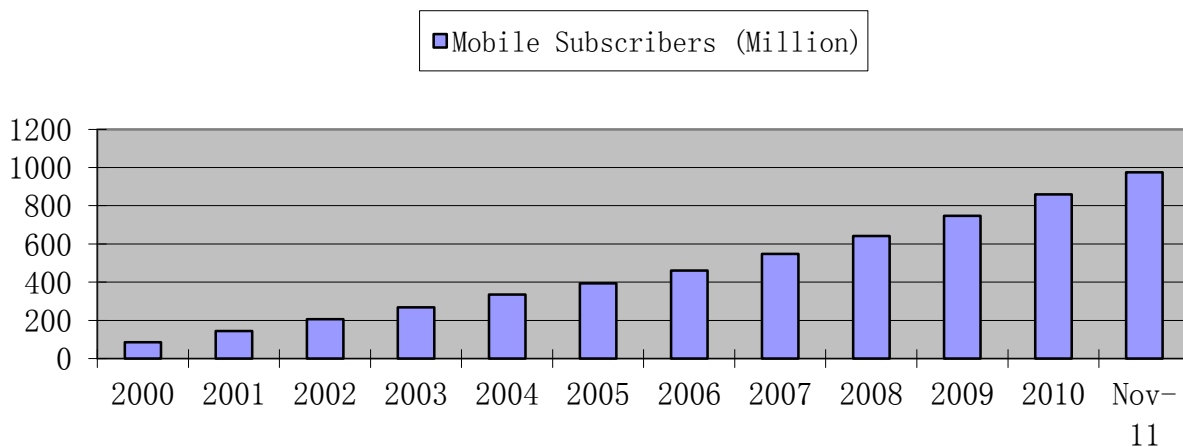


Figure 6-5 Mobile subscribers' growth in China

To meet the requirement of such enormous user groups, white space will play an important role in providing extra spectrum to mobile communication. Furthermore, for the reason of the special

issues on Digital Dividend Band, the mobile operators in China will be the main propeller for the TD-LTE in white space.

The unique propagation characteristics of TV band means a more cost-efficient outdoor and indoor coverage. For example, Table 6.C shows that 700MHz cuts 78% sites in outdoor coverage comparing with 2.6GHz, and cuts 83% sites for indoor coverage which is provided by outdoor BS. It will save the same ratio of investment including CAPEX and OPEX.

Table 6.C Link budget comparison

(Note: data rate 512kbps, 8 path for 2.6G & 1.9G, 2 path for 700M)

Band	700MHz	1.9GHz	2.6GHz
Macro cell radius	2320m	1470m	1080m
cell radius for indoor	710m	420m	290m
Site num ratio	21.7%	54%	100%
Site num ratio for indoor	16.7%	47.7%	100%

7. Conclusion, next steps and future vision

This working report provides the results of an initial study of TD-LTE technology deployed on TVWS. From an Application Scenarios & Commercialization perspective, there are huge market requirements and benefits to accrue for TD-LTE technology deployed on TVWS. This would yield opportunities to provide both cellular market and public safety market services. From a Technology & Performance Evaluation perspective, it can be seen that TD-LTE technology is feasible (i.e. protection of the incumbent user is possible) for TVWS deployment. Moreover, the current TD-LTE standard can be largely reused with only a few enhancements to support its deployment in TVWS spectrum. However, there are some challenges that need to be further studied, besides the RF design to support the corresponding TVWS band and the SDR implementation. With respect to the protection of incumbent users, the TD-LTE system shall be enhanced to allow access to TVWS database and spectrum management functions. Also, the exiting TD-LTE PHY design should implement the spectrum sensing function. Therefore, the main enhancements reside in the architecture design and the high-layer procedure design. With respect to the guarantee of performance of the TD-LTE system itself, it shall consider the coexistence within LTE system and with other system when designing the QoS guarantee. Since the TD-LTE system is designed as “network controlled”, interference control is closely related to

the architecture design. A coordination entity may be introduced to assist in this effort. Therefore, it is proposed that the TD-LTE standard organizations, e.g. 3GPP, discuss and standardize the enhancements to the TD-LTE standard to support the deployment of TD-LTE in TVWS, mainly on the architecture design and high-layer procedure design. Meanwhile, the TD-LTE marketing organizations should push for an industry marketing strategy for its deployment of TVWS e.g. GSMA and NGMN. Because the TD-LTE system is originally deployed by mobile operators, it's reasonable for the mobile operators to deploy the TD-LTE network in TVWS in order to provide data offloading, broader coverage etc. The mobile TD-LTE network deployed in TVWS may enable the land line operators to provide the mobile coverage.

8. Appendix A: Acronym List

Access Points (APs)
 Very High Frequency/ Ultra High Frequency (VHF/UHF)
 Television White Space (TVWS)
 Radio and Telecommunications Terminal Equipment (R&TTE)
 Adjacent Channel Leakage power Ratio (ACLR)
 Advanced Television Systems Committee (ATSC)
 Back Haul (BH)
 Boston Consulting Group (BCG)
 Base Station (BS)
 Customer Premises Equipment (CPE)
 Cognitive Radio (CR)
 Coexistence Manager (CM)
 Coexistence Enabler (CE)
 Coexistence Discovery and Information Server (CDIS)
 DownStream (DS)
 Broadband Radio Service (BRS)
 Canadian Broadcasting Corporation (CBC)
 Canadian Radio-television and Telecommunications Commission (CRTC)
 CAPital Expenditure (CAPEX)
 Channel bandwidth (BW_{Channel})
 Collective Use of Spectrum (CUS)
 DFT-spread OFDM (DFTS-OFDM)
 Digital Terrestrial Transmitter (DTT)
 Effective Isotropic Radiated Power (EIRP)
 eNodeB
 Federal Communications Commission (FCC)
 Frequency Switched Transmit Diversity (FSTD)
 Geo-location Database (GDB)
 Long Term Evolution (LTE)
 Licensed Shared Access (LSA)
 Mobility Management Entity (MME)
 Contention Based Protocol (CBP)
 Generic Advertisement Protocol (GAS)
 Point-to-Multipoint (PMP)
 Medium Access Control (MAC)
 Channel Power Management (CPM)
 Channel Schedule Management (CSM)
 Dependent Station Enablement (DSE)
 NTSC
 Number of Resource Blocks (N_{RB})
 Notice of Proposed Rulemaking (NPRM)
 Multiple-Input Multiple-Output (MIMO)
 Operation EXpenditure (OPEX)

Office of Engineering and Technology (OET)
Office of COMmunications (OFCOM)
Physical (PHY)
Peak-to-Average Power Ratio (PAPR)
Peak-to-Average Power Ratio (PAPR)
Radio access technology (RAT)
Radio Resource Management (RRM)
Radio Spectrum Policy Group (RSPG)
Serving gateway (S-GW)
Space-Frequency Block Coding (SFBC)
Spectrum Utilization Policy SP
Task Group (TG)
Telecommunications Conformity Assessment and Market Surveillance Committee (TCAM)
Third Generation partnership Project (3GPP)
Time Division Duplex – Long Term Evolution (TD-LTE)
Time Division Duplex (TDD)
Transmission Time Interval (TTI)
TV Band Devices (TVBD)
Universal Terrestrial Radio Access (UTRA)
User Equipment (UE)
White Space (WS)
White Space Devices (WSD)
Wireless Innovation Forum (WinnF)
Wireless Local Area Network (WLAN)

9. Appendix B: References

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