IEEE P802.19
Wireless Coexistence

Coexistence mechanism and its algorithm

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Abstract

This document contains a submission that is a response to call for proposals of 802.19 Task Group 1 (TG1). This document contains a text proposal for coexistence mechanism and algorithms clause of the 802.19.1.

Contents

1. Overview

TBD.

2. Normative references

[1] “Technical and operational requirements for the possible operation of cognitive radio systems in the ‘white spaces’ of the frequency band 470-790MHz,” DRAFT ECC Report 159, http://www.ero.dk/D9634A59-1F13-40D1-91E9-DAE6468ED66C?frames=no&, October 2010
[2] “19-10-0101-00-0001-expectation-for-ieee-p802-19-1-system-from-a-primary-protection-viewpoint.pptx”, IEEE mentor, July 2010.
[3] “Measurements on the performance of DVB-T Receivers in the presence of interference from the mobile service,” DRAFT ECC Report 148, 2010.
[4] “Second report and order and memorandum option and order”, FCC 08-260, 2008
[5] “Second memorandum option and order”, FCC 10-174, 2010
[6] “Part 10: Application procedures and Rules for Digital Television (DTV) Undertakings”, BPR-10, August 2009
[7] “Method for point-to-area predictions for terrestrial services in the frequency range 30MHz to 3000MHz”, Recommendation ITU-R P.1546-4, October 2009

3. Definitions, acronyms and abbreviations

3.1 Definitions

In-block	co-channel
Out-of-block	adjacent channel

3.2 Abbreviations and acronyms

CDIS	Coexistence Discovery and Information Server
CM	Coexistence Manager
CE	Coexistence Enabler
TVBD	TV Band Device
EIRP	Effective Isotropic Radiated Power

4. System architecture

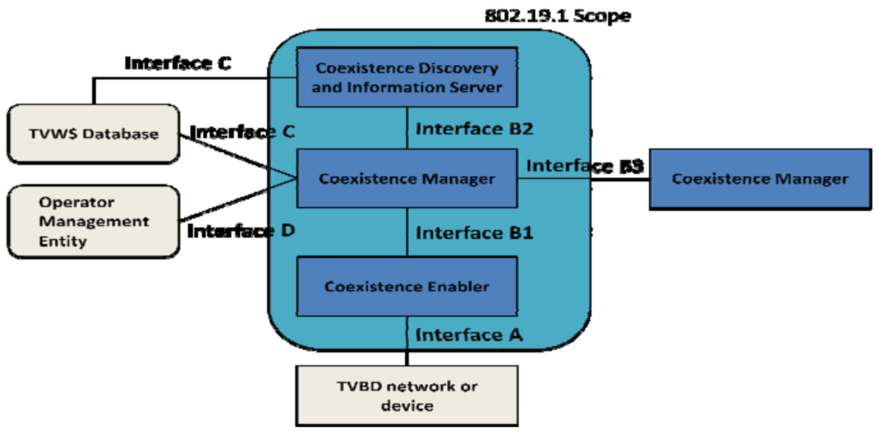

Figure 4.1 System architecture.

This proposal content as shown in Figure 4.1 is referred to the system architecture in System Design Document (SDD) of IEEE P802.19.1.

(IEEE P802.19.1 internal entities)

CM

- Coexistence decision making
  - This includes generating and providing corresponding coexistence requests/commands and control information to Coexistence Enabler(s)
- Discovery of and communication with other Coexistence Managers
- Assist network operators in management related to TVWS coexistence

CE

- Communication between Coexistence Manager and TVBD network or device
- Obtaining information, required for coexistence, from TVBD network or device
- Translating reconfiguration requests/commands and control information received from the Coexistence Manager into TVBD-specific reconfiguration requests/ commands

CDIS

- **Providing coexistence related information to Coexistence Managers**
- Supporting discovery of Coexistence Managers and opening interfaces between Coexistence Managers
- Collecting, aggregating information related to TVWS coexistence.
- Coexistence Discovery and Information Server may connect to TVWS database to obtain primary users information.

(IEEE P802.19.1 external entities)

TV Band Device or TV Band Device Network

- Unlicensed operation in the broadcast television spectrum at locations where that spectrum is not being used by licensed services.

TVWS Database

- Provides list of channels occupied by primary users.

Operator Management Entity

- Provides operator provided information such as policies/ limitations.

5. Reference model

TBD.

6. Protocol and procedure

TBD.

7. Coexistence mechanism and algorithms

7.1 General

The following two items are proposed.

- ✓ Output power management for TVWS network coexistence (Section 7.2)
- ✓ Resource management for TVWS network coexistence (Section 7.3)

7.2 Output power level management

7.2.1 Service models

This section introduces proposed service models on output power level management for TVWS network coexistence.

Service model #1: Maximum output power allocation service

This service provides the maximum output power allocation for TVDBs to protect the incumbent service, such as TV broadcasting and wireless microphone service, from the aggregated interference [1] due to simultaneous transmission of neighbor TVWS networks which are independently operated each other. The mechanisms and algorithms to realize this service are described in the section 7.2.2.

Service model #2: Information service on aggregated interference power level

This information service provides the interference power level on each operable TVWS channel for each TVBD. This interference level shows the aggregated interference power level from the other TVBDs' in-block and out-of-block emission effects in their TVWS operation, and the information is specified for each TVBD. The mechanism and algorithm to realize this information service model are described in the section 7.2.3.

7.2.2 Mechanism and algorithm #1 for service model #1

7.2.2.1 Preface

This section explains the basic criterion to specify the maximum output power of TVBDs. Let us first form the aggregated interference signal level from multiple TVBDs. When one can set maximally allowed interference level ($I_{acceptable}$)[2] to the incumbent service (i.e. broadcasting and wireless microphone and so on) receiver for a frequency channel in an interfere-victim reference point, the criterion to specify the maximum permitted EIRP for a single TVBD can be simply written in the following simplified anti-logarithmic form:

$$I_{acceptable}(i, f_j) \geq P_{tx}(f_j, k) \cdot L_p(i, f_j, k). \tag{7.1}$$

The parameters are summarized in Table 1. Subsequently, the criterion to specify the maximum permitted EIRP for multiple TVBDs without considering the aggregated mutual interference power from the adjacent channel usage among TVBDs can be also written in the following simplified anti-logarithmic form:

$$I_{acceptable}(i, f_j) \geq \sum_{k=1}^{M_j} P_{tx}(f_j, k) \cdot L_p(i, f_j, k). \tag{7.2}$$

Moreover, if the aggregated mutual interference power level from the adjacent channel usage among TVBDs is considered in the equation (7.2), it can be also written as follows:

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[1] The topics on aggregated interference problems from multiple WSDs in-block and out-of-block emission in TVWS operation have been discussed in CEPT SE43[1]. In an operation where fixed output power level approach in FCC is adopted, the TVBDs should also care about this problem from a viewpoint of incumbent service protection[2].

[2] Please refer to (*1) "Definition of maximally allowed interference level" in page 7.

$$I_{acceptable}(i, f_j) \geq \sum_{k=1}^{M_j} P_{tx}(f_j, k) \cdot L_p(i, f_j, k) \cdot G\left(f_j, k\right)$$
$$+ \sum_{jj=1,\, jj \neq j}^{O_j} \left(\sum_{kk=1}^{N_{jj}} \left(P_{tx}(f_{jj}, kk) \cdot L_p(i, f_{jj}, kk) \cdot G\left(f_{jj}, kk\right) / \left(H(f_j, f_{jj}, kk)\right)\right)\right). \tag{7.3}$$

The first term of this equation (7.3) shows the aggregated mutual interference power in a co-channel operation among TVBDs for target channel # j. The second term of this equation (7.3) shows the aggregated mutual interference power level from neighbor channel operation of TVBDs for the target channel # j in the interfere-victim reference point # i.

Table 1. Parameters.

Parameter	Notes
$I_{acceptable}(i, f_j)$	Maximally allowed interference level to the incumbent service (i.e. broadcasting and wireless microphone and so on) receiver in interfere-victim reference point # i [3] for the frequency channel # j
$P_{tx}(f_j, k)$	Maximum permitted EIRP of TVBD # k [4] for frequency channel # j. This maximum value may be different from the other TVBD(s) according to its location. In a case where some fixed output power levels are defined like FCC rule, predetermined value(s) for all the TVBDs may be set in this parameter[5].
$L_p(i, f_j, k)$	Path loss between TVBD # k [6] and interfere-victim reference point # i for frequency channel # j
$P_{tx}(f_{j\,or\,jj}, k\,\mathrm{or}\,kk)$	Maximum permitted EIRP of TVBD #(k or kk) for frequency channel #(j or jj)
$L_p(i, f_{j\,or\,jj}, k\,\mathrm{or}\,kk)$	Path loss between TVBD #(k or kk) and the interfere-victim reference point # i for frequency channel #(j or jj)
$G\left(f_{j\,or\,jj}, k\,\mathrm{or}\,kk\right)$	Total gain of TVBD #(k or kk) for frequency channel #(j or jj). Antenna gain, antenna beam pattern and so on are given in the example parameters
$H(f_j, f_{jj}, kk)$	Total loss of TVBD # kk for adjacent frequency channel # jj for the target frequency channel # j. Adjacent channel selectivity, adjacent channel leakage ratio and so on are given in the example parameters.
M_j	Number of TVBD(s) which may use the target frequency channel #(j)

[3] Please refer to (*2) "Definition of interfere-victim reference point" in page 7.
[4] The system may only have to consider (active) master TVBD(s) coordinate each (active) TVWS network in the selection of this target TVBD.
[5] In this case, the maximum number of TVBD(s), which can simultaneously operate in the target channel, shall be calculated based on the criteria as shown in Eq. (7.3), from a primary protection viewpoint.
[6] The positioning information of the target TVBD may be the one of the closest slave TVBD or virtual slave TVBD in its network coverage area for the protected contour of incumbent service, if the interference signal in the reference point caused by the transmission of the slave TVBD is larger than the interference signal caused by the transmission of the master TVBD according to these transmission parameters. The "virtual" means here that a slave TVBD is assumed to be in the edge of network coverage area of the master TVBD. In these cases, the transmission parameters of the slave TVBD are used for this calculation step, the reference point of the slave node should be each closest point for the protected contour of the incumbent service.

	simultaneously[7]
N_{jj}	Number of TVBD(s) which may use the target frequency channel #(jj) simultaneously[8]
O_j	Number of neighbour channel(s) for the target frequency channel # j being considered in calculating aggregated mutual interference power level[9]

(*1) Definition of maximally allowed interference level ($I_{acceptable}$)

Maximally allowed interference level to the incumbent service (i.e. broadcasting and wireless microphone and so on) receiver could be calculated as follows:

$$I_{acceptable} = P_{rx\_required}\left(f_{BS}\right) \Big/ 10^{\frac{PR(f_{CR}-f_{BS})}{10}} \quad , \tag{7.4}$$

where $I_{acceptable}$, $P_{rx\_required}\left(f_{BS}\right)$ and $PR(f_{CR}-f_{BS})$ show the maximally allowed interference level to the incumbent service receiver in a reference point, the required received signal power of a incumbent service (i.e. broadcasting and wireless microphone and so on) receiver in the referent point, and a minimum required SIR (Signal to Interference Ratio) level of incumbent service receiver, respectively. In a case where the interfere-victim reference point is in a protected contour of DTT service, $P_{rx\_required}\left(f_{BS}\right)$ show the minimum receiver sensitivity level of incumbent service receiver plus 3 [dB] due to the consideration of noise effect [3].

(*2) Definition of interfere-victim reference point

The selection criteria of interfere-victim reference point are one of the important things to calculate the maximum transmission power allocation for multiple TVBDs.

If one considers the mutual in-block/out-of-block interference effects among TVBDs, only one selection criterion, which shall be to choose the closest point for each TVBD in the protected contour of the incumbent service as shown in Figure 7.1, would be.

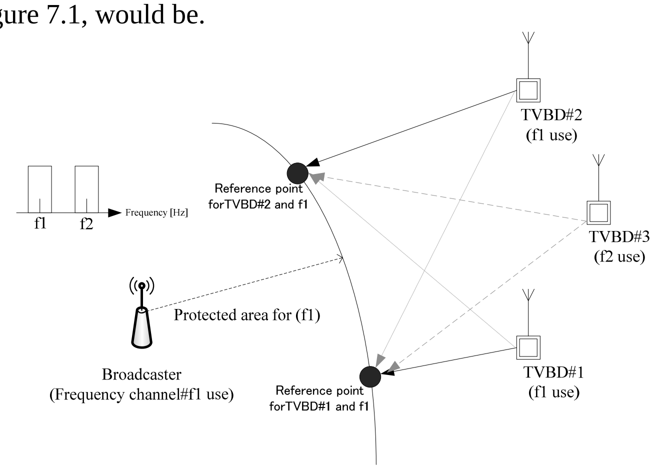

Figure 7.1: Selection criterion of the interfere-victim reference points for the maximum power allocation for multiple TVBDs.

[7] This number may count only active TVWS network coordinated by each active master TVBD.
[8] Please find the footnote 6.
[9] Please find the footnote 6.

7.2.2.1 Method

Two kinds of methods are proposed in this section.

1. **Method #1**

An optimized approach to specify the maximum output power of TVBDs is explained in this section. If one considers the mutual interference in-block/out-of-block interference effects among TVBDs, one of the calculation ways could be given in the following steps:

- Step 0:
  The parameters for each TVBD to calculate the equation (7.3) are input.

- Step 1:
  Calculation of local specific maximum output power of TVBD(s) without considering mutual interference effects on in-block/out-of-block interference signal from the other TVBD(s). The criteria for the calculation are summarized as follows:

Criterion #1:

An equal transmission power distribution method in the step 1 is introduced here. It can be written as follows:

$$P_{tx}(f_j,k) = \frac{I_{acceptable}(i,f_j)}{\sum_{k=1}^{M_j}\left(L_p(i,f_j,k)\cdot G\left(f_j,k\right)\right)}. \tag{7.5}$$

This approach will be useful for fairness operation of multiple TVBD networks in co-channel operation.

Criterion #2:

A path-loss based/Unequal transmission power distribution method in the step 1 is introduced here. It can be written as follows:

$$P_{tx}(f_j,k) = \frac{I_{acceptable}(i,f_j)}{\left(L_p(i,f_j,k)\cdot G\left(f_j,k\right)\cdot M_j\right)}. \tag{7.6}$$

This approach will be useful for unfairness operation of multiple TVBD networks in co-channel operation.

Criterion #3:

Extension of the former two approaches with the SM (Safety Margin) value, which will be caused by the interference power level estimation errors in master TVBD of each TVBD network, is introduced here. It can be written as follows:

$$P_{tx}(f_j,k) = \frac{I_{acceptable}(i,f_j)}{\sum_{k=1}^{M_j}\left(L_p(i,f_j,k)\cdot G\left(f_j,k\right)\right)\cdot SM}, \tag{7.7}$$

and

$$P_{tx}(f_j,k) = \frac{I_{acceptable}(i,f_j)}{\left(L_p(i,f_j,k)\cdot G\left(f_j,k\right)\cdot M_j\cdot SM\right)}, \tag{7.8}$$

where SM means here safety margin [10].

[10] *SM* means the margin for some estimation errors such as path loss, interference power level and so on.

Criterion #4:

Network prioritized approach of the former two approaches is introduced here. It can be written as follows:

$$P_{tx}(f_j,k)=\left.\left(\mu_k \middle/ \sum_{kk=1}^{M_j}\mu_{kk}\right)\cdot I_{acceptable}(i,f_j) \middle/ \sum_{k=1}^{M_j}\left(L_p(i,f_j,k)\cdot G\left(f_j,k\right)\right)\cdot SM\right., \quad (7.9)$$

and

$$P_{tx}(f_j,k)=\left.\left(\mu_k \middle/ \sum_{kk=1}^{M_j}\mu_{kk}\right)\cdot I_{acceptable}(i,f_j) \middle/ \left(L_p(i,f_j,k)\cdot G\left(f_j,k\right)\cdot M_j\cdot SM\right)\right., \quad (7.10)$$

where μ_k shows the weight TVBD# k

✧ Step 2:

Recalculation of local specific power for each TVBD with the in-block/out-of-block interference effects from the other TVBD(s), which could be calculated based on the results ($P_{tx}(f_{jj},kk)$) of step 1 for each TVBD, in the following form:

$$P_{tx}^{'}(f_j,k)=\frac{\left(I_{acceptable}(i,f_j)-\sum_{jj=1,\,jj\neq j}^{O_j}(\sum_{kk=1}^{N_{jj}}P_{tx}(f_{jj},kk)\cdot L_p(i,f_{jj},kk)\cdot G\left(f_{jj},kk\right)/\left(H(f_j,f_{jj},kk)\right))\right)}{\left(L_p(i,f_j,k)\cdot G\left(f_j,k\right)\right)}. \quad (7.11)$$

✧ Step 3:

Some interference margin due to the degradation of each $P_{tx}^{'}(f_j,k)$ may be in the step 2. Therefore, in this step, the most severe interfere-victim reference point to adjust the maximum output power of TVBDs is chosen according to the following criteria:

if SM is not considered in the step 1,

$$i^{'}=\arg_i\left(\min\left(\begin{array}{l} I_{acceptable}(i,f_j)-P^{'}_{tx}(f_j,k)\cdot\left(L_p(i,f_j,k)\cdot G\left(f_j,k\right)\right) \\ -\sum_{jj=1,\,jj\neq j}^{O_j}(\sum_{kk=1}^{N_{jj}}P^{'}_{tx}(f_{jj},kk)\cdot L_p(i,f_{jj},kk)\cdot G\left(f_{jj},kk\right)/\left(H(f_j,f_{jj},kk)\right)) \end{array}\right)\right), \quad (7.12)$$

and if SM is considered in the step 1,

$$i^{'}=\arg_i\left(\min\left(\begin{array}{l} I_{acceptable}(i,f_j)-P^{'}_{tx}(f_j,k)\cdot\left(L_p(i,f_j,k)\cdot G\left(f_j,k\right)\cdot SM\right) \\ -\sum_{jj=1,\,jj\neq j}^{O_j}(\sum_{kk=1}^{N_{jj}}P^{'}_{tx}(f_{jj},kk)\cdot L_p(i,f_{jj},kk)\cdot G\left(f_{jj},kk\right)\cdot SM/H(f_j,f_{jj},kk)) \end{array}\right)\right), \quad (7.12')$$

✧ Step 4:

Calculation of output power adjustment value Δ to fulfil the interference margin for each TVBD in the following criteria:

if SM is not considered in the step 1,

$$I_{acceptable}(i', f_j) \geq P'_{tx}(f_j, k) \cdot \Delta_j \cdot \left(L_p(i', f_j, k) \cdot G\left(f_j, k\right) \right) + \sum_{jj=1, jj \neq j}^{O_j} \left(\sum_{kk=1}^{N_{jj}} P'_{tx}(f_{jj}, kk) \cdot L_p(i', f_{jj}, kk) \cdot G\left(f_{jj}, kk\right) / \left(H(f_j, f_{jj}, kk) \right) \right), \tag{7.13}$$

and if SM is considered in the step 1,

$$I_{acceptable}(i', f_j) \geq P'_{tx}(f_j, k) \cdot \Delta_j \cdot \left(L_p(i', f_j, k) \cdot G\left(f_j, k\right) \cdot SM \right) + \sum_{jj=1, jj \neq j}^{O_j} \left(\sum_{kk=1}^{N_{jj}} P'_{tx}(f_{jj}, kk) \cdot L_p(i', f_{jj}, kk) \cdot G\left(f_{jj}, kk\right) \cdot SM / H(f_j, f_{jj}, kk) \right), \tag{7.13'}$$

If all the value of Δ_j and Δ_{jj} are regard as the same value ($\Delta = (\Delta_j = \Delta_{jj})$), a selection criterion to choose the value of Δ could be obtained as follows:

if SM is not considered in the step 1,

$$\Delta \leq \frac{I_{acceptable}(i', f_j)}{\left(\begin{array}{l} P'_{tx}(f_j, k) \cdot \left(L_p(i', f_j, k) \cdot G\left(f_j, k\right) \right) \\ + \sum_{jj=1, jj \neq j}^{O_j} \left(\sum_{kk=1}^{N_{jj}} P'_{tx}(f_{jj}, kk) \cdot L_p(i', f_{jj}, kk) \cdot G\left(f_{jj}, kk\right) / \left(H(f_j, f_{jj}, kk) \right) \right) \end{array} \right)}, \tag{7.14}$$

and if SM is considered in the step 1,

$$\Delta \leq \frac{I_{acceptable}(i', f_j)}{\left(\begin{array}{l} P'_{tx}(f_j, k) \cdot \left(L_p(i', f_j, k) \cdot G\left(f_j, k\right) \cdot SM \right) \\ + \sum_{jj=1, jj \neq j}^{O_j} \left(\sum_{kk=1}^{N_{jj}} P'_{tx}(f_{jj}, kk) \cdot L_p(i', f_{jj}, kk) \cdot G\left(f_{jj}, kk\right) \cdot SM / H(f_j, f_{jj}, kk) \right) \end{array} \right)}. \tag{7.14'}$$

✧ Step 5:

The final results of local specific maximum output power of TVBDs are calculated as follows:

$$P''_{tx}(f_j, k) = P'_{tx}(f_j, k) \cdot \Delta. \tag{7.15}$$

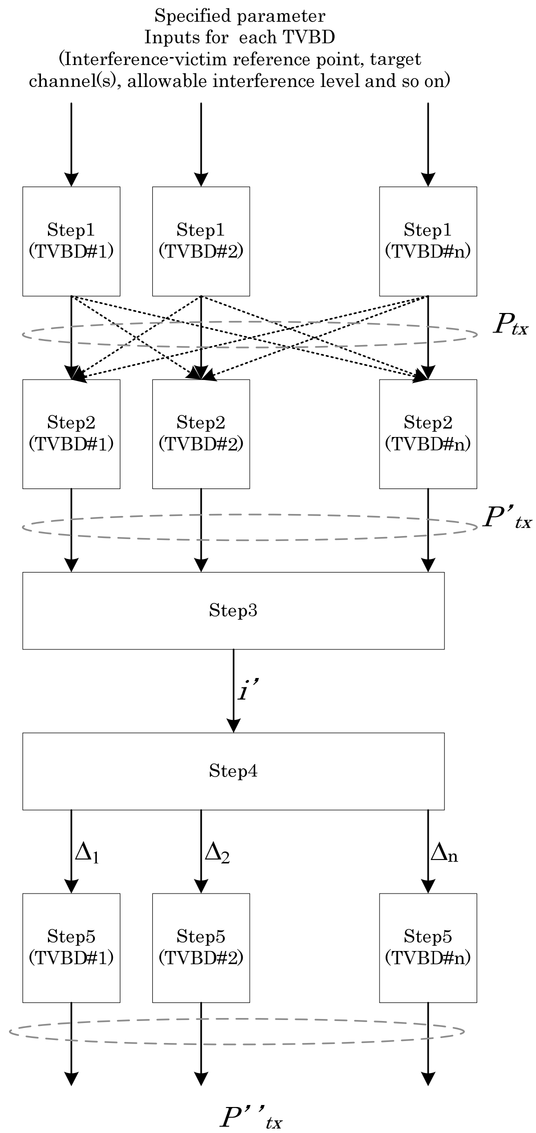

Figure 7.2: Procedure to calculate local specific maximum output power of TVBD(s).

The above steps are summarized in Figure 7.2. The approach based on this procedure can provide the nearly-optimized values of TVBD(s) for the ideal local specific maximum output power of TVBDs being calculated by the equation (7.3).

- **Method #2**

Margin based approach to specify the maximum output power of TVBDs is explained in this section. The equation to specify the maximum permitted EIRP of multiple TVBDs can be reformed based on equation (7.3) with *MI* (Multiple Interference margin)[11] and *SM* (Safety margin) values to specify the multiple TVBDs transmission effects as follows:

If the tartget TVBD uses the same channel as the usage channel(s) of interfere-victim receiver in the reference point,

$$P_{tx}(f_j,k)=\left(I_{acceptable}(i,f_j) \Big/ L_p(i,f_j,k)\cdot G\left(f_j,k\right)\cdot\left(MI\cdot SM\right)\right) . \tag{7.16}$$

If the tartget TVBD uses the different channel with the usage channel(s) of interfere-victim receiver in the reference point,

$$P_{tx}(f_{jj},kk)=\left(I_{acceptable}(i,f_j) \Big/ L_p(i,f_{jj},kk)\cdot G\left(f_{jj},kk\right)\cdot MI\cdot SM \,/\, H(f_j,f_{jj},kk)\right) . \qquad (7.16)'$$

The definitions of both MI and SM are referred to [1]. The approach based on MI and SM parameter setting seems to be easiest one to implement in database calculation, but the communication opportunity of TVBD(s) may decrease when the results do not show the ideal local specific maximum output power of TVBDs which could be calculated using the equation (7.3).

[11] Definition of *MI* in the section 4.3 of reference [1]: “Multiple interference margin of 3-6 [dB] (depending on the number of the interfaces) that takes account of aggregated interference from multiple (co-channel and adjacent channel) WSD(White Space Device)s operating in a given area at the same time (3 dB corresponds to 2 interferes, 5 dB – 3 interfaces, 6 dB – 4 interfaces).”

7.2.3 Mechanism and algorithm #2 for service model #2

7.2.3.1 Preface

Let us first form the aggregated mutual interference power among TVBDs which includes in-block/out-of-block emission. It could be calculated as follows:

$$I_{\text{secondary}}(l, f_j) = \sum_{k=1,(k\neq l)}^{M_j} P_{tx}(f_j,k)\cdot L_p(i, f_j,k)\cdot G\left(f_j,k\right) + \sum_{jj=1,\, jj\neq j}^{O_j} \sum_{kk=1,kk\neq l}^{N_{jj}} \left(P_{tx}(f_{jj},kk)\cdot L_p(i, f_{jj},kk)\cdot G\left(f_{jj},kk\right)/\left(H(f_j, f_{jj},kk)\right)\right), \tag{7.17}$$

and if SM is considered,

$$I_{\text{secondary}}(l, f_j) = \sum_{k=1,(k\neq l)}^{M_j} P_{tx}(f_j,k)\cdot L_p(i, f_j,k)\cdot G\left(f_j,k\right)\cdot SM + \sum_{jj=1,\, jj\neq j}^{O_j} \sum_{kk=1,kk\neq l}^{N_{jj}} \left(P_{tx}(f_{jj},kk)\cdot L_p(i, f_{jj},kk)\cdot G\left(f_{jj},kk\right)\cdot SM\ /\left(H(f_j, f_{jj},kk)\right)\right), \tag{7.17'}$$

where $I_{\text{secondary}}(l, f_j)$ shows the aggregated interference level to the TVBD# l from the other TVBDs for the frequency channel # j. The results[12] being calculated by this equation would be prepared for each TVWS channel for each TVBD. The next section explains the mechanism and its algorithm using this equation, to realize service model #2.

7.2.3.1 Method

The basic procedure to generate the interference level information of each TVWS channel for each TVBD is shown in the Figure 7.3. The example of database information table for the target TVBD is shown in the Table 2. This interference level information will be helpful for the channel selection for TVWSs. Because the master TVBD(s) of a TVWS network may be able to find adequate channel(s) from its operable frequency channel(s) without large system overhead due to spectrum sensing deployment, if the master TVBD knows its minimum network requirements such as required link quality, network coverage and so on.

Moreover, in a worst case where some of the TVBD(s) will be unable to find the operable frequency channel(s) to satisfy the minimum network requirements, the maximum output power re-allocation deployment as shown in Figure 7.4 may be useful. For example, the optimized maximum output power ($P_{\text{optimized},tx}(f_j,k)$) TVBD# k for the frequency channel # j can be formed as follows:

$$P_{\text{optimized},tx}(f_j,k) = \begin{cases} P_{tx}(f_j,k)\big/\Delta_{f_j,k} & \Delta_{f_j,k} > 1.0 \\ P_{tx}(f_j,k) & else \end{cases}, \tag{7.18}$$

$$\Delta_{f_j,k} = SINR_{est}(f_j,k,R)\ /\ SINR_{req}\left(f_j,k,R\right), \tag{7.19}$$

where $\Delta_{f_j,k}$, $SINR_{est}(f_j,k)$, $SINR_{req}\left(f_j,k\right)$ and $P_{tx}(f_j,k)$ show the SINR margin of the TVBD# k and the frequency channel # j, estimated minimum SINR (Signal to Interference plus Noise Ratio) of the

[12] The result(s) can update using the spectrum sensing result(s) which may be reported from each master TVBD of each TVWS network to IEEE P802.19.1 system.

TVWS network managed by TVBD# k for the frequency channel # j in the edge point of maximum required communication range (R) of the network, required maximum SINR of the TVWS network managed by TVBD# k for the frequency channel # j in the edge point of the maximum required communication range (R) of the network, and the initial maximum output power of TVBD# k for the frequency channel # j being calculated based on the method of the section 7.2.2.

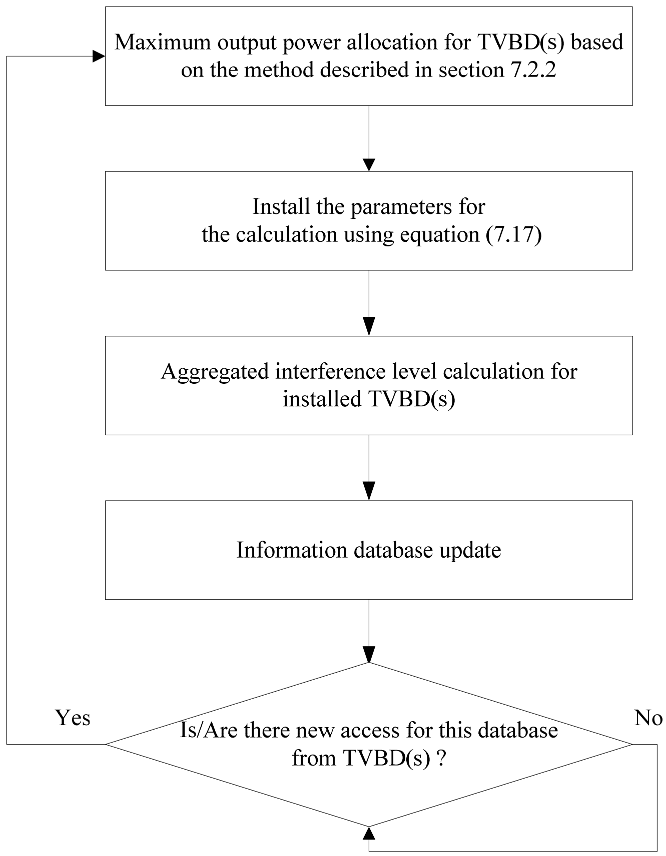

Figure 7.3: Database update basic procedure.

Table 2. Example of database information table for the target TVBD.

	Aggregated interference level	Maximally allowed output power	…
Available Frequency channel #1	X_1	Y_1	…
…	…	…	…
Available Frequency channel #m	X_m	Y_m	…

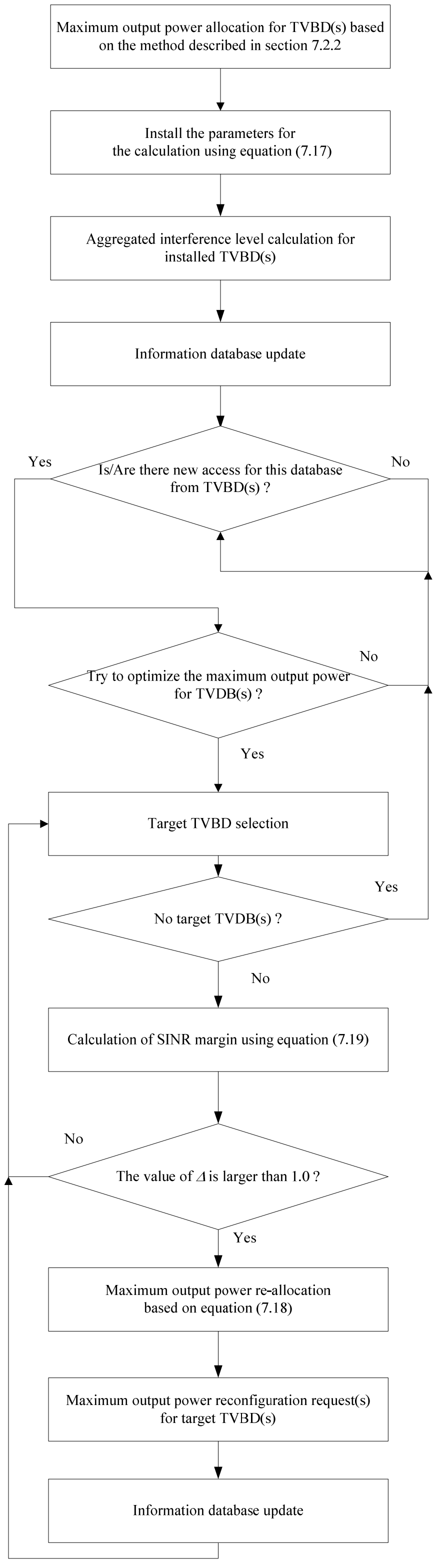

Figure 7.4: Database update procedure to optimize maximum output power of (master) TVBDs.

7.2.4 Requirements for IEEE P802.19.1 system architecture

Requirements for IEEE P802.19.1 entities

TBD.

Requirements for interfaces between IEEE P802.19.1 internal entities

TBD.

Requirements for interfaces between IEEE P802.19.1 internal entity and IEEE P802.19.1 external entity

TBD.

7.2.5 Requirements for IEEE P802.19.1 reference model

TBD.

7.2.6 Requirements for IEEE P802.19.1 protocol and procedures

TBD.

7.2.7 Network deployment examples

TBD.

7.3 Resource management

7.3.1 Service models

This section introduces proposed service models on resource management. These mechanism and algorithm to realize this service model are described in the section 7.3.2.

Service model #1: Dynamic frequency channel allocation

This service provides dynamic frequency channel allocation for multiple neighbour TVWS networks. Two kinds of examples are shown in Figure 7.5, Figure 7.6, Figure 7.7 and Figure 7.8, respectively.

Let us first explain one of the examples of target scenario and its solution as shown in Figure 7.5 and Figure 7.6. In this case, TVWS network#1 operates in TVWS channel F1 and RAT(Radio Access Technology) #1 (R1). TVWS network#2 operates in TVWS channel F1 and RAT#2 (R2). In this case, each TVWS network may cause harmful interference each other. This situation will occur in actual TVWS network operation, if multiple master TVBDs individually select own network configuration. If IEEE802.19.1 system offers the operation channel change request for master TVBD of TVWS network and the master TVBD of TVWS network #2 accepts the request to change the operation frequency channel to F2, they will be able to operate without harmful interference each other.

Next let us explain another example of target scenario and its solution as shown in Figure 7.7 and Figure 7.8 In this case, TVWS network#1/network#3 operates in F1 and R1/R3. TVWS network#2 want to operate using R2, but in this case, the network #2 cannot find any operable frequency channel. This situation will occur in actual TVWS network operation, if multiple master TVBDs individually select own network configuration. In this case, if IEEE802.19.1 system offers the operation channel change request for master TVBD of TVWS network and the master TVBD accepts the request, the master TVBD of TVWS network#2 will be able to operate in channel F2.

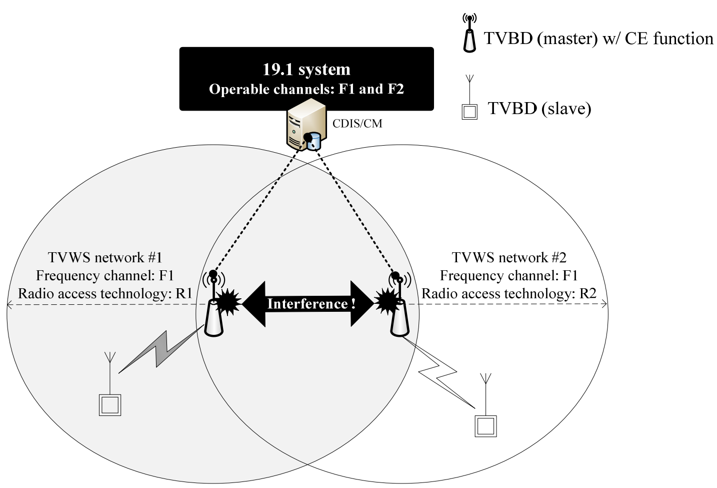

Figure 7.5: Example of the target coexistence scenario in this service model.

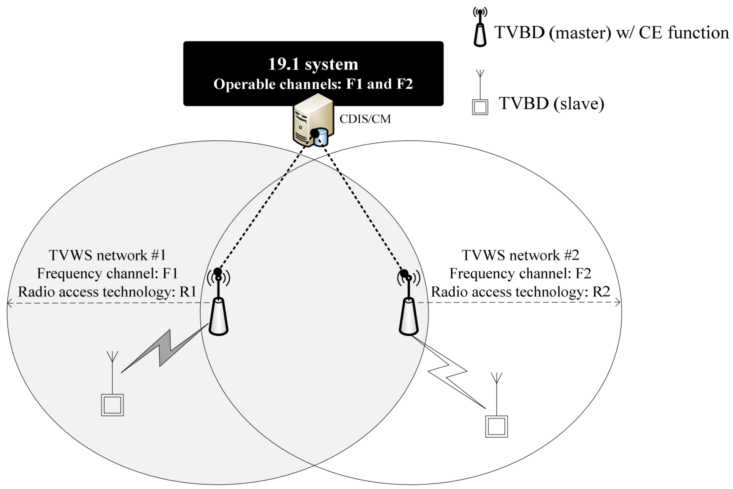

Figure 7.6: Example of the solution for this target coexistence scenario.

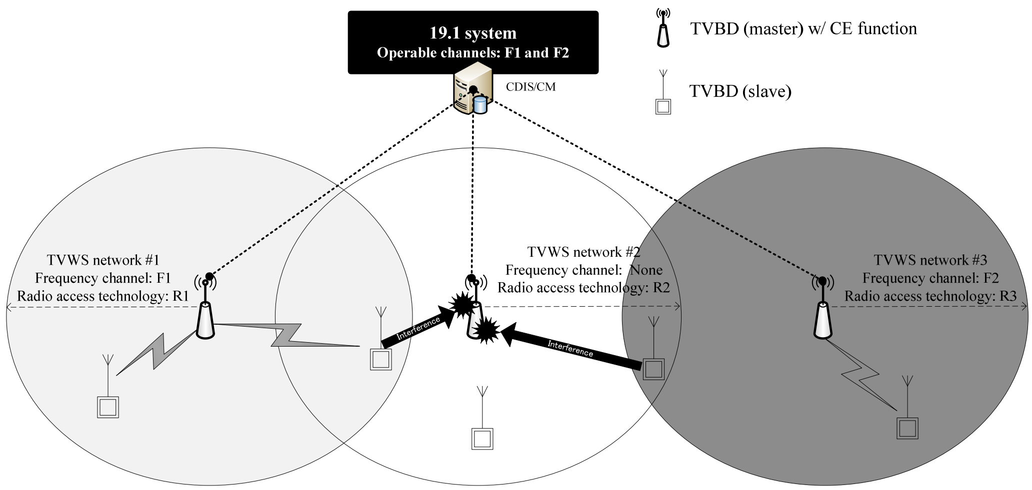

Figure 7.7: Example of the target coexistence scenario in this service model.

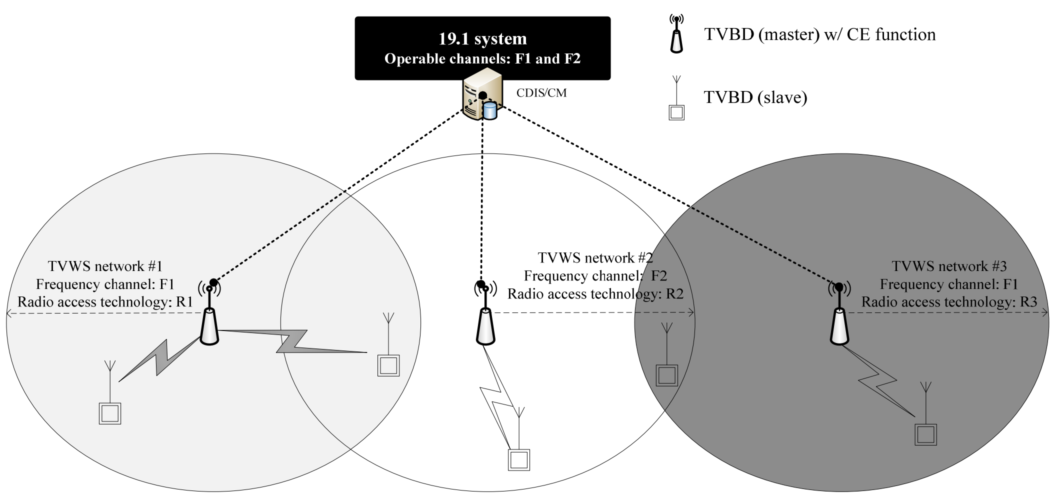

Figure 7.8: Example of the solution for this target coexistence scenario.

Service model #2: RAT selection support

This service provides RAT selection support for multiple neighbour TVWS networks. The example is shown in Figure 7.9 and Figure 7.10, respectively. In this case, TVWS network#1 operates in F1 and R1, although this network can operate using the different RAT (R2). TVWS network#2 operates in F1 and R2. In this case, each TVWS network may cause harmful interference each other. This situation will occur in actual TVWS network operation, if multiple master TVBDs individually select own network configuration. In this case, if IEEE802.19.1 system offers the operation RAT change request, and if the master TVBD of TVWS network #1 accepts the request to change the operation RAT to R2, they will be able to operate without harmful interference each other[13], if the information exchange between the networks is possible using each RAT.

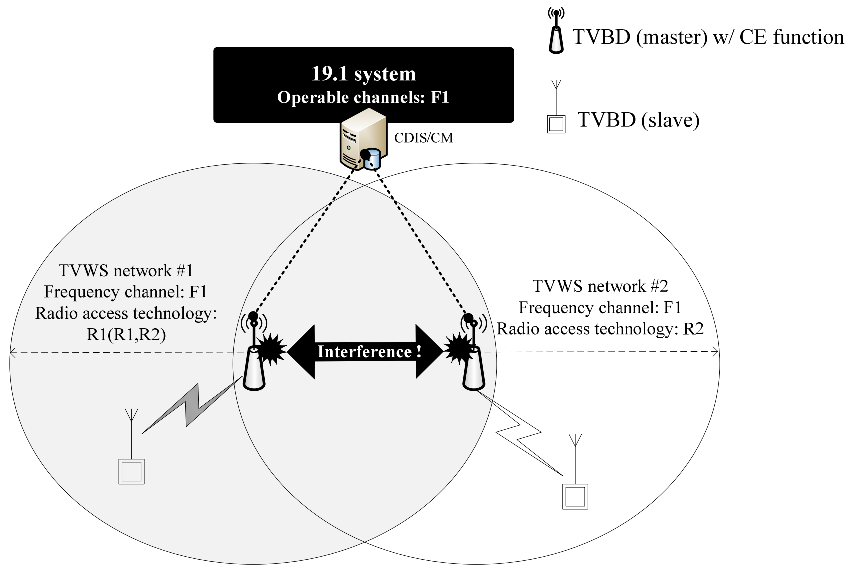

Figure 7.9: Example of the target coexistence scenario in this service model.

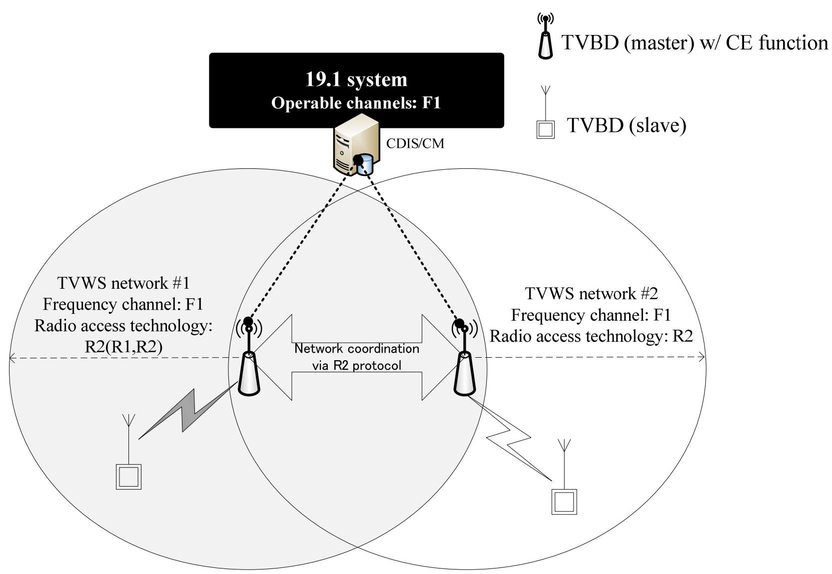

Figure 7.10: Example of the solution for this target coexistence scenario.

[13] This decision will need the RAT protocol capability check whether the coexistence protocol works well in the situation.

Service model #3: Wireless network coverage extension support

This service provides wireless network coverage extension support for multiple neighbour TVWS networks. The example is shown in Figure 7.11 and Figure 7.12, respectively. In this case, TVWS network#1 operates in F1 and R2. TVWS network#2 operates in TVWS channel F2 and R1, although this network can operate using the different RAT (R2). In this case, each TVWS network cannot communicate each other via wireless link. In this case, if a master TVBD requests the wireless network connection with its neighbour network, and if IEEE P802.19.1 system can support to connect each network via wireless communication, they will be able to communicate each other via wireless link. This service model may be useful in a case where the fixed internet access speed is so slow, but the application needs low latency connection.

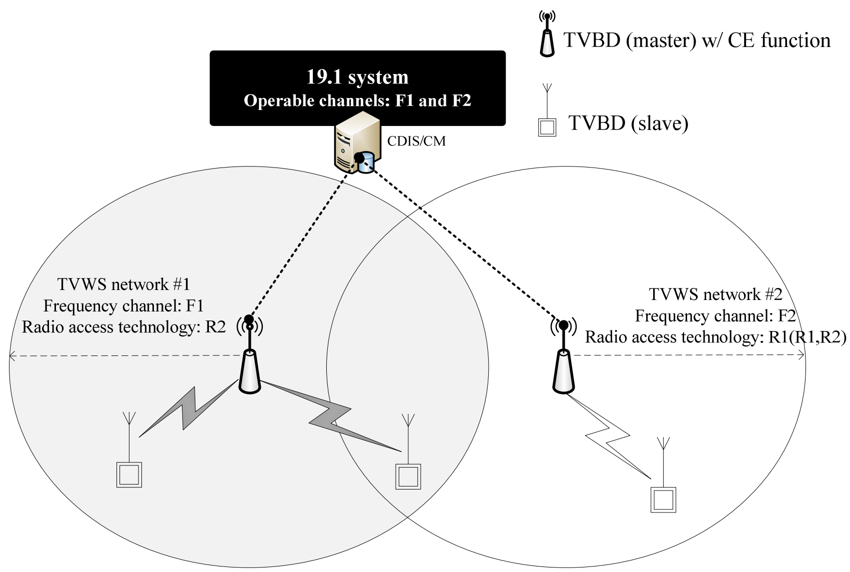

Figure 7.11: Example of the target coexistence scenario in this service model.

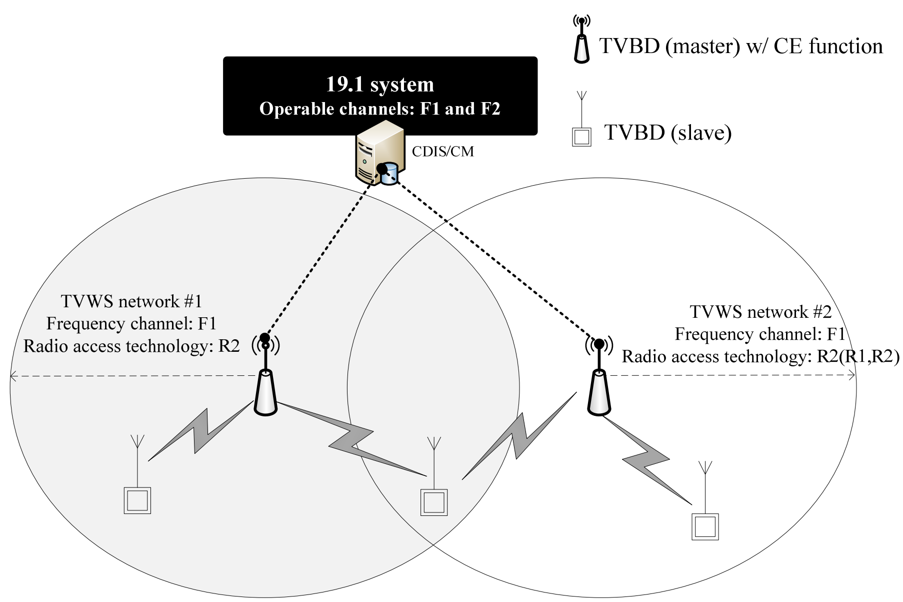

Figure 7.12: Example of the solution for this target coexistence scenario.

Service model #4: Multi-channel operation support

This service provides multi-channel operation support for multiple neighbour TVWS networks. The example is shown in Figure 7.13 and Figure 7.14, respectively. In this case, TVWS network#1 operates in F1 and R1. TVWS network#2 operates in TVWS channel F2 and R2. In this case, if the TVWS network wants to expand the operation bandwidth, the master/slave TVBD may need a large overhead to find operable clean frequency channel.

In this case, if a master TVBD requests multi-channel selection support for IEEE P802.19.1, IEEE P802.19.1 system may be able to inform the additional operation channel(s), whose aggregated interference level is small, for the client master TVBD(s).

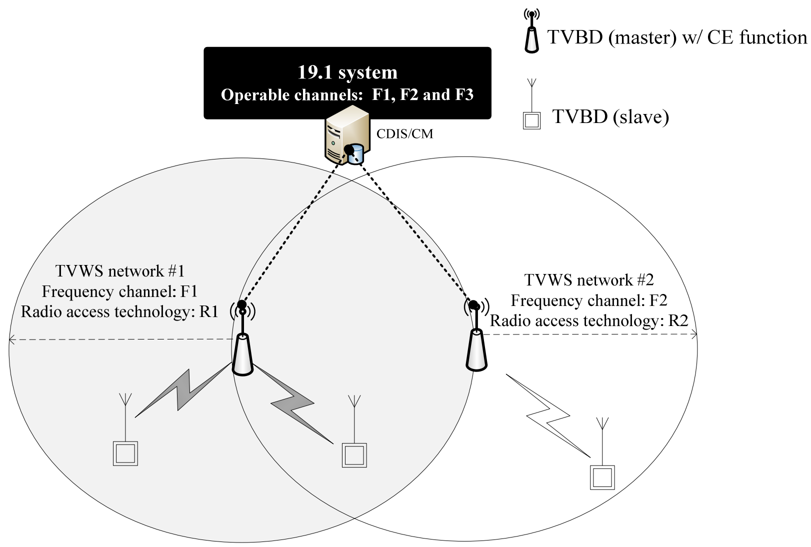

Figure 7.13: Example of the target coexistence scenario in this service model.

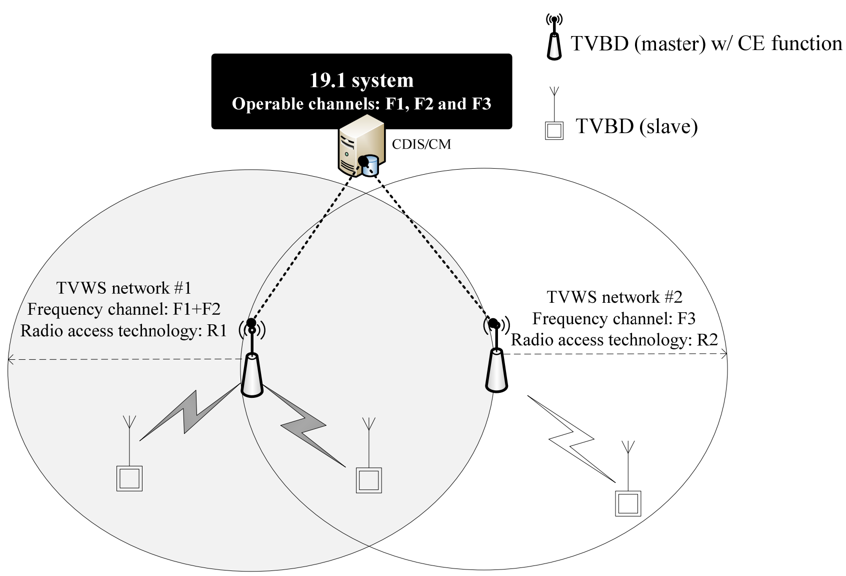

Figure 7.14: Example of the solution for this target coexistence scenario.

Service model #5: Resource sharing support

This service provides resources sharing operation support for multiple neighbour TVWS networks. The example is shown in Figure 7.15 and Figure 7.16, respectively. In this case, TVWS network#1 operates in F1 and R1. TVWS network#2 want to operate using R2, but this case cannot find any operable frequency channel because of the harmful interference from the TVWS network#1. In this case, if IEEE802.19.1 system supports the both time synchronized operation and the time/frequency resource sharing to each master TVBD, each network will be able to coexist in F1 even if each network will operate in different RATs[14]. This service model can be also adopted for the other network configuration as shown in Figure 7.5, Figure 7.9 and Figure 7.11.

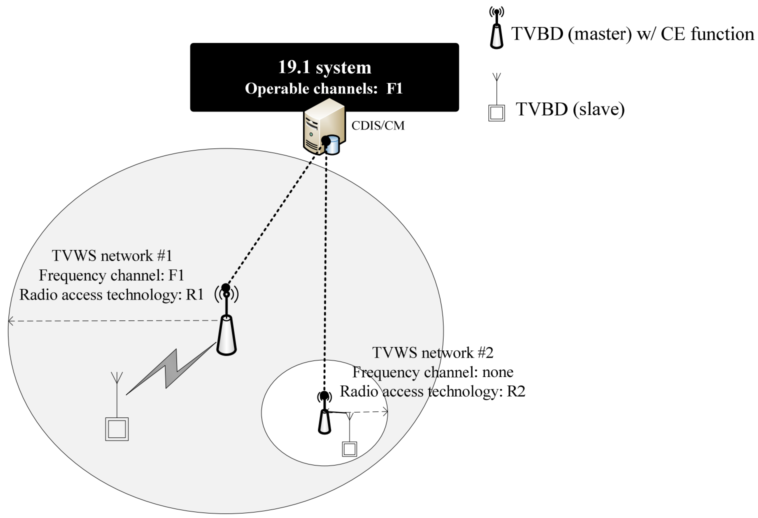

Figure 7.15: Example of the target coexistence scenario in this service model.

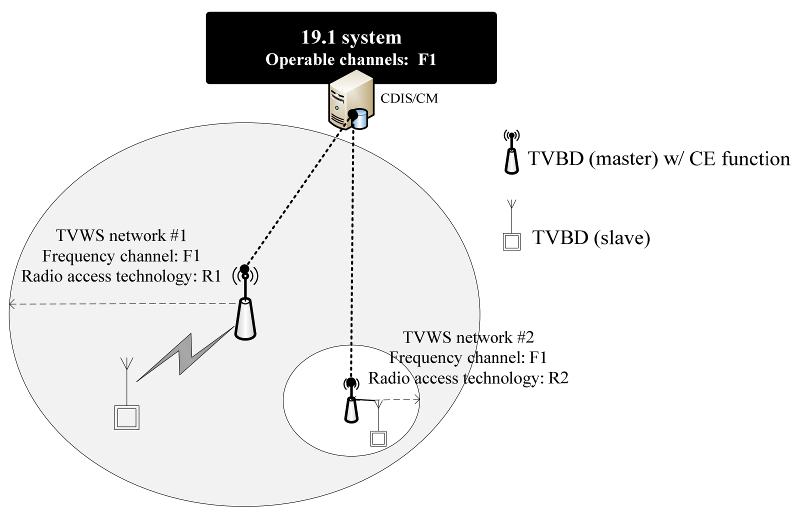

Figure 7.16: Example of the solution for this target coexistence scenario.

[14] This decision will need the RAT protocol capability check whether the coexistence protocol works well in the situation.

7.3.2 Mechanism and algorithm

7.3.2.1 Preface

This section provides the procedure of TVWS network resource management service. The procedure is composed of six steps as shown in Figure 7.17. Each step is as follows:

- Step 1:

  Required information to conduct TVWS network coexistence service for TVDBs is collected in this step. Required information from the master TVBD(s) are listed as follows:
  - Operable TVWS frequency channel list
  - Network configuration parameters
    - Positioning information of master TVBD (and its slave TVBDs), antenna height, positioning information, operable RAT(s) ID(s), current RAT operation ID, support network coexistence function ID of each operable RAT, usage frequency channel, duty cycle, number of slave node, spectrum sensing result for each channel, expected network coverage, estimated emission level from its own network and so on

- Step 2:

  Network configuration estimation using the information from each TVWS network is conducted in this step. The estimation method is described in next section. The processing for service model #3 and #4 skips in the step 6 directly from the step 2. On the other hand, the service model#1, #2 and #5 operation proceed next step.

- Step 3:

  Problem estimation, which occurs among neighbor TVWS networks, is conducted in this step. The problem categorization is explained in next section.

- Step 4:

  Solution analysis based on the problem estimation is conducted in this step. The method is explained in next section.

- Step 5:

  Network reconfiguration parameter selection for network coexistence or resource sharing management with synchronization operation support is conducted in this step. The representative network reconfiguration parameter candidates are given as follows:
  - Recommendated TVWS frequency channel(s)
  - Recommended RAT

- Step 6:

  Network reconfiguration is requested for each network to be reconfigured in this step. The request types are categorized in next section.

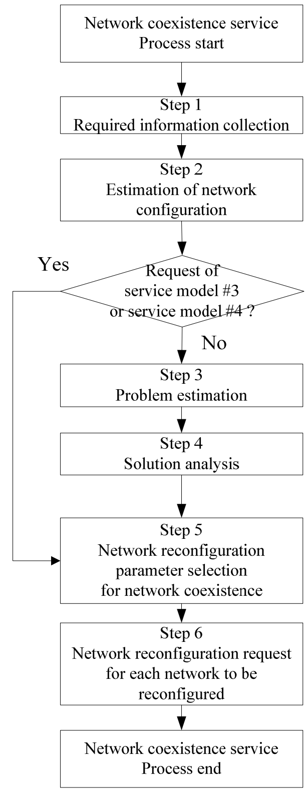

Figure 7.17: Generic procedure of resource sharing service.

7.3.2.2 Method

First, let us clarify what the trigger to start this processing is. Two kind of start triggers could be considerd as follows:

- Activated case from the master TVBD (w/ CE) of each TVWS network which detected the harmful interference from the other network(s) for a target channel
  - In this case, the master TVBD(s) only has (have) to request to IEEE P802.19.1 system if any problem is detected in their network operation, without its own network problem analysis by itself. Once IEEE P802.19.1 system received the request from the master TVBD(s), the system will first conduct the problem estimation. If the system can find the problem to be solved and its solution using the network reconfiguration parameters for the target master TVBD(s), the network reconfiguration parameter(s) is (are) decided and informed the parameters of the target master TVBD(s).
- Activated case due to autonomous detection of IEEE P802.19.1 system for network coexistence problem, if there is update on TVWS network registered in the system
  - In this case, IEEE P802.19.1 system autonomouly estimates the coexistene problem using the network configuration parameters of each registerd TVWS network. If the system finds the problem to be solved and its solution using the network reconfiguration parameters for the target master TVBD(s), the network reconfiguration parameter(s) for the target master TVBD(s)is (are) decided and informed as the recommended network configuration of each network.

Next, let us explain the proposed procedures to find the better network configuration as shown in Figure 7.18. The feature of this procedure is an example of the methods based on a policy which is to optimize the efficiency of the TVWS frequency reuse. Each Sub-step is conducted as follows:

Sub-step#0 [Estimation of maximum communication radius of master TVBD(s)]

The maximum communication radius can be estimated using the network configuration parameters of master TVBD(s) based on the method [1][4][5][6][7]. The estimation result(s) may be adjusted using the sensing result(s) from its slave TVBD(s), and include error margin for the positioning information and path loss estimation and so on.

Sub-step#1 [Is (Are) there any overlapping area(s) in each network coverage area?]

- This anallysis will be conducted using the estimated network coverage area in Sub-step#0. If this answer is yes, go to Sub-step#8. In this case, the network configuration will be Class#1/#2/#4[15]. If no, go to Sub-step#2. In this case, the network configuration will be Class#3[16].

Sub-step#2 [Interference power level is accepted in each network?]

- If this answer is yes, go to Sub-step#3. In this case, the network configuration will be Class#3a[17]. If no, go to Sub-step#4. In this case, the network configuration will be Class#3b[18].

Sub-step#3 [Operation channel change request to the selected common frequency channel(s) usage]

- In this step, the recomemnded usage frequency channel(s) list is imformed to the target TVBD(s) if necessary to change the network configuration parameter(s). This case should be one of the good examples of service model#1.

Sub-step#4 [Another channel selection is possible for the networks?]

[15] Please refer to (*3) "Classification of network configuration" in page 29.
[16] Please find the footnote 14.
[17] Please find the footnote 14.
[18] Please find the footnote 14.

- ✧ If this answer is yes, go to Sub-step#5. If no, go to Sub-step#6.

Sub-step#5 [Operation channel change request to the selected different frequency channel(s) usage]

- ✧ In this step, the recomemndation of usage frequency channel(s) list is imformed to the target TVBD(s) if necessary to change the network configuration parameter(s). This case should be one of the good examples of service model#1.

Sub-step#6 [Resource sharing and the synchronized operation are possible for each network?]

- ✧ This step analyzes whether the resource sharing and the synchronized operation are possible via each backbone network. If yes, go to Sub-step#7. If no because of its capability and latency problem and so on, any solution will be unable to be found in this system.

Sub-step#7 [Resource sharing and its synchronized operation support]

- ✧ This step will provide the resource sharing and its synchronized operation for the target networks via interface(s) between the master TVBD(s) and the system. This case should be a good example of service model#5.

Sub-step#8 [Common RAT operation is possible in the target overlapping networks?]

- ✧ If yes, go to Sub-step#9. If no, go to Sub-step#10.

Sub-step#9 [The start trigger of this processing is activated from TVWS network(s) which detected interference problem?]

- ✧ If yes, go to Sub-step#11. This means that there was a detection of unavoidable communication error in the target network. If no, go to Sub-step#10.

Sub-step#10 [Coexistence protocol of each RAT will be effectively worked?]

- ✧ If yes, go to Sub-step#3. If no, go to Sub-step#4. This decision needs the operable RAT protocol capability check whether the coexistence protocol works well in the situation.

Sub-step#11 [Current operation RAT is the same RAT each other?]

- ✧ If yes, go to Sub-step#10. If no, go to Sub-step#12.

Sub-step#12 [Coexistence protocol in operable RAT(s) will be effectively utilized?]

- ✧ If yes, go to Sub-step#13. If no, go to Sub-step#4.

Sub-step#13 [Reconfiguration request to change a selected RAT operation for the TVBD(s) of the target network]

- ✧ In this step, the recomemndation of usage RAT list is imformed to the target TVBD(s) if necessary to change the network configuration parameter(s). This case should be an example of service model#2[19].

[19] In this model, if the synchronized operation support is necessary in the selected RAT due to the lack of clock offset compensation method between the networks, this step shall additionally support the synchronized operation for each network.

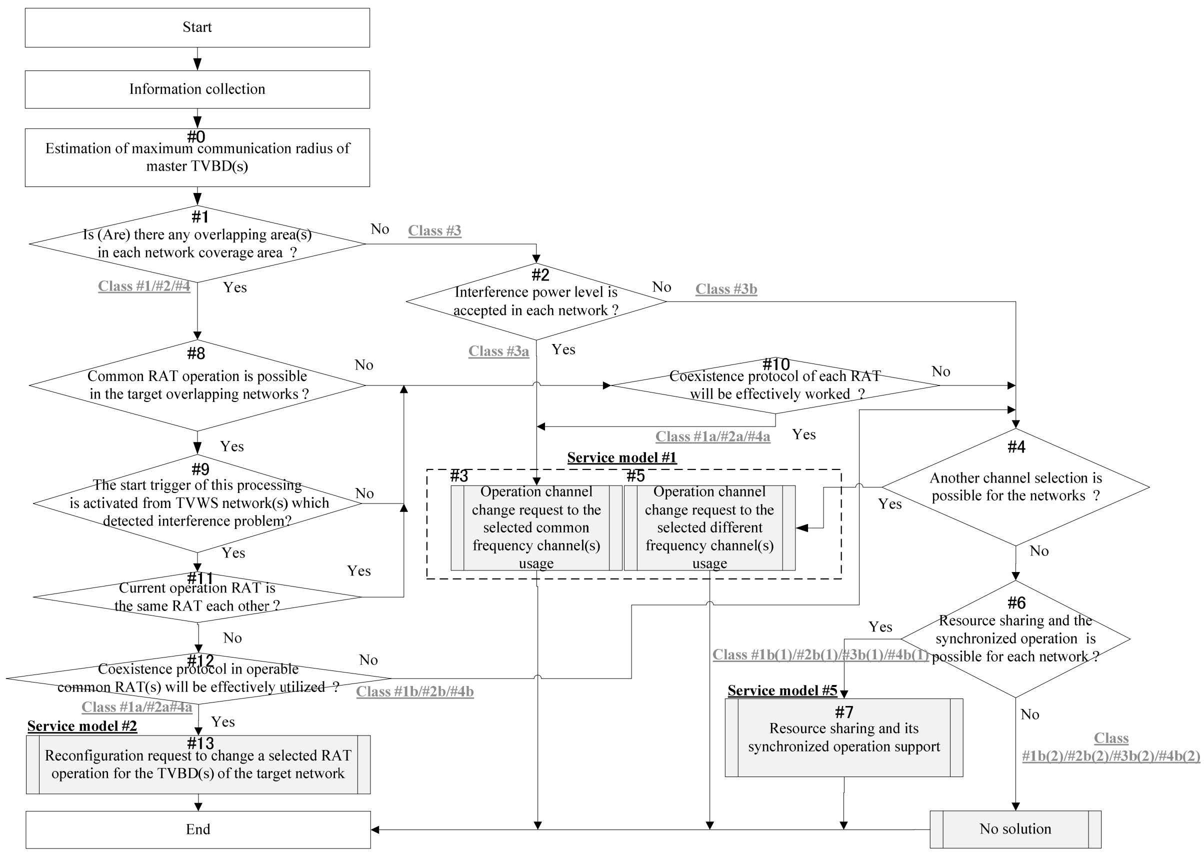

Figure 7.18: Flowchart #1 for the step 3, 4 and 5.

Finally, let us propose an alternative procedure to find the better network configuration for each activated case as shown in Figure 7.19. The feature of this procedure is an example of the methods based on a policy which is to avoid the occurrance of the TVWS network coexistence as much as possible without relying on the coexistence network protocol stack of each RAT in the target TVWS networks. Each Sub-step is conducted as follows:

Sub-step#0 [Estimation of maximum communication radius of master TVBD(s)]

The maximum communication radius can be estimated using the network configuration parameters of master TVBD(s) based on the method [1][4][5][6][7]. The estimation result(s) may be adjusted using the sensing result(s) from its slave TVBD(s), and include error margin for the positioning information and path loss estimation and so on.

Sub-step#1 [Is (Are) there any overlapping area(s) in each network coverage area?]

- ✧ This anallysis will be conducted using the estimated network coverage area in Sub-step#0. If this answer is yes, go to Sub-step#8. In this case, the network configuration will be Class#1/#2/#4 . If no, go to Sub-step#2. In this case, the network configuration will be Class#3 .

Sub-step#2 [Interference power level is accepted in each network?]

- ✧ If this answer is yes, go to Sub-step#3. In this case, the classified network configuration will be Class#3a . If no, go to Sub-step#4. In this case, the classified network configuration will be Class#3b .

Sub-step#3 [Operation channel change request to the selected common frequency channel(s) usage]

- ✧ In this step, the recomemnded usage frequency channel(s) list is imformed to the target TVBD(s) if necessary to change the network configuration parameter(s). This case should be one of the good examples of service model#1.

Sub-step#4 [Another channel selection is possible for the networks?]

- ✧ If this answer is yes, go to Sub-step#5. If no, go to Sub-step#6.

Sub-step#5 [Operation channel change request to the selected different frequency channel(s) usage]

- ✧ In this step, the recomemndation of usage frequency channel(s) list is imformed to the target TVBD(s) if necessary to change the network configuration parameter(s). This case should be one of the good examples of service model#1.

Sub-step#6 [Resource sharing and the synchronized operation are possible for each network?]

- ✧ This step analyzes whether the resource sharing and the synchronized operation are possible via each backbone network. If yes, go to Sub-step#7. If no because of its capability and latency problem and so on, any solution will be unable to be found in this system.

Sub-step#7 [Resource sharing and its synchronized operation support]

- ✧ This step will provide the resource sharing and its synchronized operation for the target networks via interface(s) between the master TVBD(s) and the system. This case should be a good example of service model#5.

Sub-step#8 [The start trigger of this processing is activated from TVWS network(s) which detected interference problem?]

- ✧ If yes, go to Sub-step#4. This means that there was a detection of unavoidable communication error in the target network. If no, go to the end.

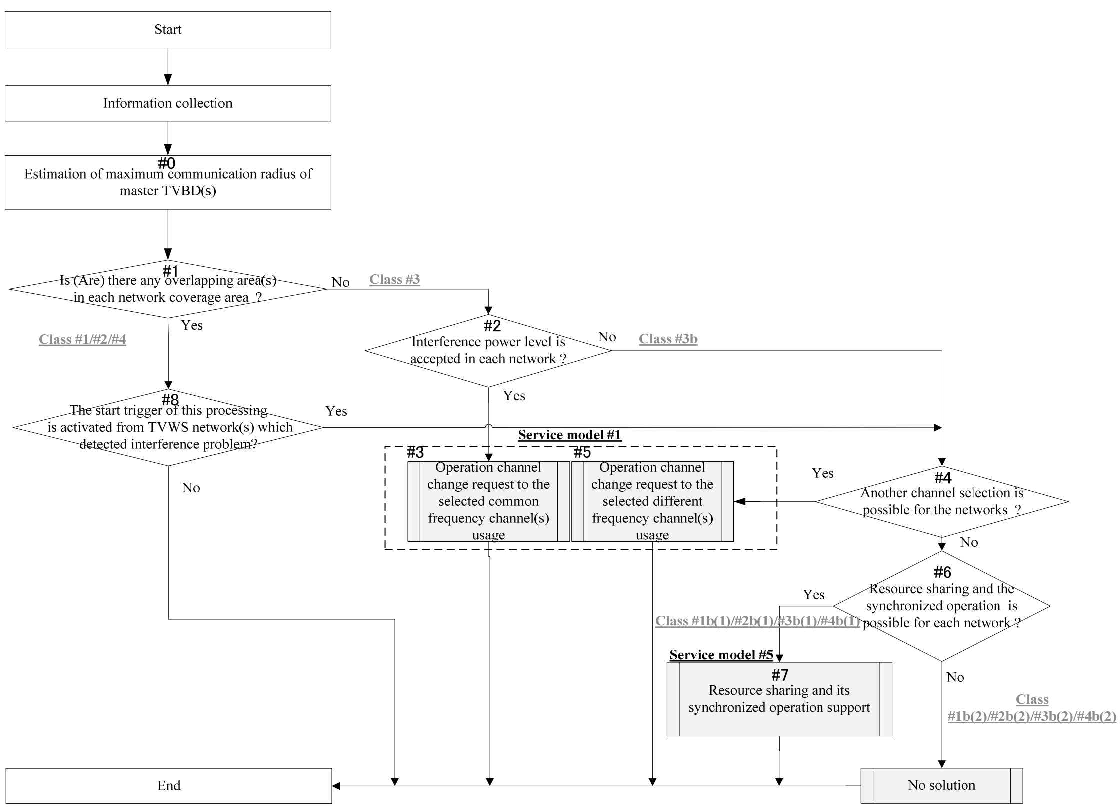

Figure 7.19: Flowchart #2 for the step 3, 4 and 5.

(*3) **Classification of network configuration**

Network configuration is classified in the following four types.

- Class#1

This class #1 is specified in a case where two different TVWS network coverage areas are overlapped each other as shown in Figure 7.20, and each master TVBD may be able to communicate each other if the same RAT and the same operation channel are utilized without causing harmful interference each other[20].

If the operable RAT supports effective coexistence protocol to protect each network from the harmful mutual interference, the situation is classified in Class#1a. On the other hand, if the operable RAT does not support effective coexistence protocol to protect harmful mutual interference, the situation is classified in Class#1b.

Subsequently, if the resource sharing and the synchronized operation is possible via each backbone network in Class#1b, the situation is classified in Class#1b(1). On the other hand, if the resource sharing and the synchronized operation is impossible via each backbone network in Class#1b because of its capability and latency problem and so on, the situation is classified in Class#1b(2)

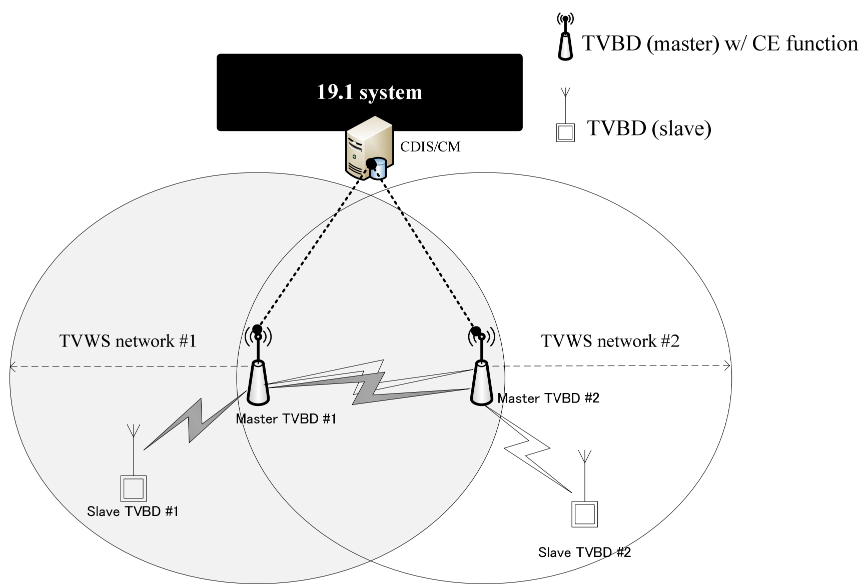

Figure 7.20: Class#1 network configuration.

[20] This decision will need the RAT protocol capability check whether the coexistence protocol works well in the situation. For example, coexistence beacon mechanism of IEEE 802.22 will effectively work in this situation. On the other hand, if the network scheduling information exchange function between the master TVBDs with enough clock offset compensation method between the networks is supported in IEEE 802.11 based TVBD(s), it will also work in this situation. If not, any packet transmission from its slave TVBD in non-overlapping area, which received the permission from the master TVBD before that, cannot stop in the network, although the master TVBD can receive the NAV (Network Allocation Vector) information from the other network(s).

- Class#2

This class #2 is specified in a case where two different TVWS network coverage areas are overlapped each other, but each master TVBD cannot communicate each other even if the same RAT and the same operation channel are used as shown in Figure 7.21. In this case, some of slave TVBD(s) and the other master TVBD(s) can communicate each other if the same RAT and the same operation channel are used[21].

If the operable RAT supports effective coexistence protocol to protect each network from the harmful mutual interference, the situation is classified in Class#2a. On the other hand, if the operable RAT does not support effective coexistence protocol to protect harmful mutual interference, the situation is classified in Class#2b.

Subsequently, if the resource sharing and the synchronized operation is possible via each backbone network in Class#2b, the situation is classified in Class#2b(1). On the other hand, if the resource sharing and the synchronized operation is impossible via each backbone network in Class#2b because of its capability and latency problem and so on, the situation is classified in Class#2b(2)

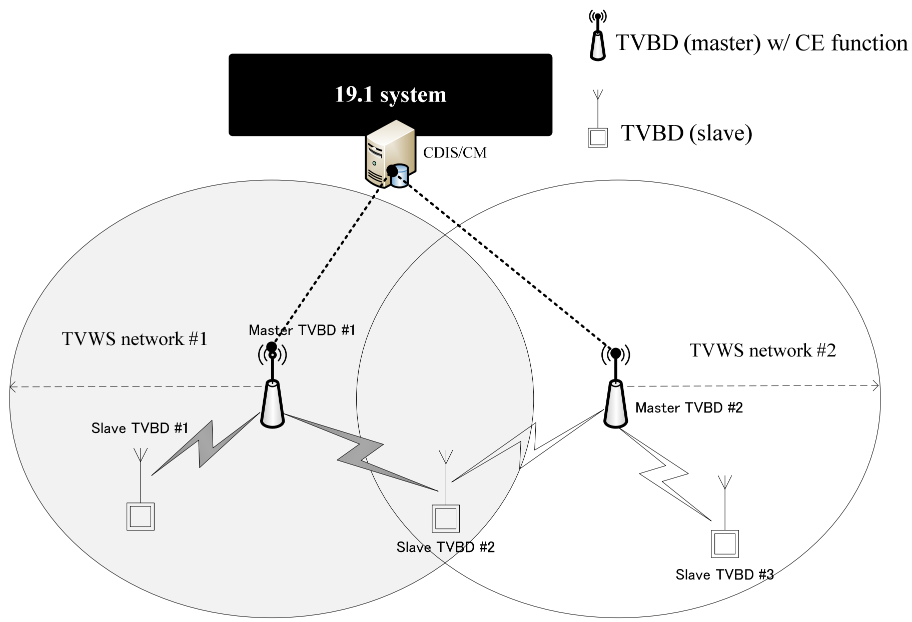

Figure 7.21: Class#2 network configuration.

[21] This decision will need the RAT protocol capability check whether the coexistence protocol works well in the situation. For example, coexistence beacon mechanism of IEEE 802.22 between the master TVBD and the slave TVBD(s) may not effectively work in this situation, if the two networks are not synchronized each other. On the other hand, if the network scheduling information exchange function between the master TVBD and the slave TVBD(s) managed by the other master TVBD with enough clock offset compensation method between the networks is supported in IEEE 802.11 based TVBD(s), it will also work in this situation. If not, any packet transmission from the TVBD(s) in non-overlapping area cannot stop in the network, although the slave TVBD(s) in the overlapping area can receive the NAV (Network Allocation Vector) information from the other network(s).

- <u>Class#3</u>

This class #3 is specified in a case where two different TVWS network coverage areas are not overlapped each other as shown in Figure 7.22, and each master/slave node cannot communicate each other even if the same RAT and the same operation channel is used.

If the acceptable interference level ($I_{acceptable}$) for each network is defined using its own network requirement such as the required SINR at the edge point of the expected network coverage and the value $I_{acceptable}$ shall be larger than the value of the aggregated interference power ($I_{\text{secondary}}$) from the other network, the situation is classified in Class#3a. On the other hand, if the value $I_{acceptable}$ shall be smaller than the value of the aggregated interference power ($I_{\text{secondary}}$) from the other network, the situation is classified in Class#3b.

Subsequently, if the resource sharing and the synchronized operation is possible via each backbone network in Class#3b, the situation is classified in Class#3b(1). On the other hand, if the resource sharing and the synchronized operation is impossible via each backbone network in Class#2b because of its capability and latency problem and so on, the situation is classified in Class#3b(2).

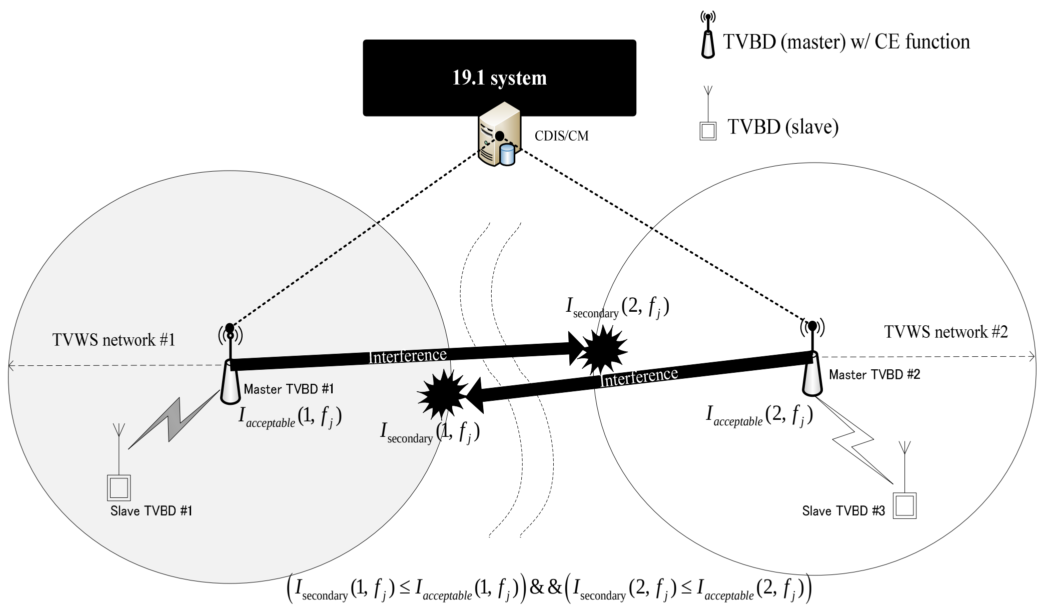

Figure 7.22: Class#3 network configuration.

- Class#4

This class #4 specified in a case where two different TVWS network coverage areas are overlaid each other as shown in Figure 7.23. The term “overlaid” means here that a smaller network coverage area of TVWS network #2 is totally covered in a wider network area of TVWS network #1[22,23].

If the operable RAT supports effective coexistence protocol to protect each network from the harmful mutual interference, the situation is classified in Class#4a. On the other hand, if the operable RAT does not support effective coexistence protocol to protect harmful mutual interference, the situation is classified in Class#4b.

Subsequently, if the resource sharing and the synchronized operation is possible via each backbone network in Class#4b, the situation is classified in Class#4b(1). On the other hand, if the resource sharing and the synchronized operation is impossible via each backbone network in Class#4b because of its capability and latency problem and so on, the situation is classified in Class#4b(2).

Good example of Class#4b with different RAT operation is shown in the Figure 7.24. This case assumes that one of the TVWS network operating based on CSMA such as IEEE 802.11af and the network exists in the TVWS network operating based on OFDMA such as IEEE802.22. In this case, the CSMA resource may be able to be allocated in the OFDMA operation resource.

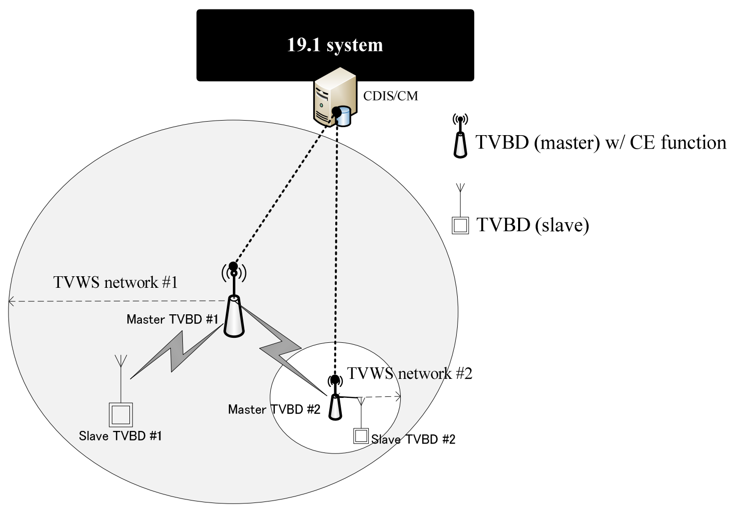

Figure 7.23: Class#4 network configuration

[22] This decision will need the RAT protocol capability check whether the coexistence protocol works well in the situation. For example, the coexistence protocol of IEEE 802.22 can effectively work in this situation. Subsequently, the master/slave TVBD(s) in the overlapping area can receive the NAV (Network Allocation Vector) information from the other network(s), so it can also work in this situation. However, if the interference power from network #1 to network #2 is in harmful level for the network #2 operation, it may be unable to operate network#2.

[23] The obligation interference management for the primary protection could be shrunk in the master TVBD#1 in this case. On the other hand, it shall be in master TVBD of each TVWS network in the other classes.

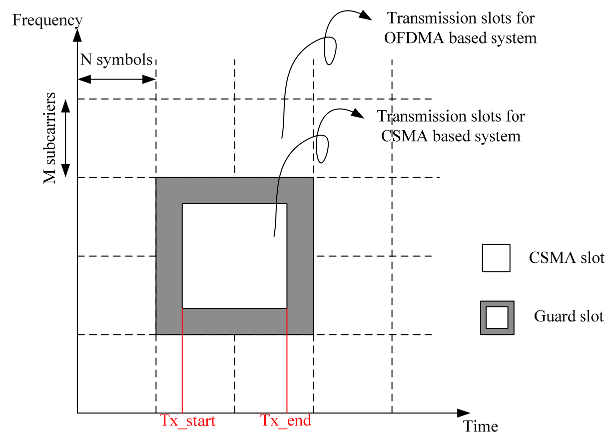

Figure 7.24: Example of resource sharing operation.

7.3.4 Requirements for IEEE P802.19.1 system architecture

Requirements for IEEE P802.19.1 entities

TBD.

Requirements for interfaces between IEEE P802.19.1 internal entities

TBD.

Requirements for interfaces between IEEE P802.19.1 internal entity and IEEE P802.19.1 external entity

TBD.

7.3.5 Requirements for IEEE P802.19.1 reference model

TBD.

7.3.6 Requirements for IEEE P802.19.1 protocol and procedures

TBD.

7.3.7 Network deployment examples

TBD.

8 Appendix

TBD.