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Wireless Coexistence Working Group

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Purpose	
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7. Coexistence mechanisms and algorithms

7.1 Introduction

A coexistence system contains two basic mechanisms to address coexistence of TVBD networks or devices in TVWS band: coexistence management and neighbor discovery. Coexistence management is the mechanism with which CMs of a coexistence system determine how potentially interfering TVBD networks or devices can effectively share a set of radio resources. This mechanism is specified in 7.2. Neighbor discovery is the mechanism with which CMs find out potentially interfering TVBD networks or devices. Additionally the CMs get from the neighbor discovery any information related to neighbors required for the CMs to communicate with each other. This mechanism is specified in 7.3.

An IEEE 802.19.1 compliant coexistence system has means to obtain measurement reports from registered TVBD networks or devices. A CM may use the measurement reports from TVBD networks or devices that are registered to it to support coexistence decision making and neighbor discovery. The TVBD network or device measurements are described in 7.4.

7.2 Coexistence management

Coexistence management is the mechanism with which a CM serves TVBD networks or devices so that they can operate efficiently in available channels of the TVWS band. The CM determines how to share radio resources among a set of TVBD networks and devices that are potentially interfering each other. For TVBD networks or devices this is visible as a set of coexistence services that are available for it.

Each CM shall provide two types of service for TVBD networks or devices: a) information service, b) management service. Additionally, as parts of the management service each CM shall provide two modes of the management service: a) TV channel mode, b) operating frequency mode.

For the TVBD networks or devices that are subscribed to the information service the CM provides information about other users of the available radio resources. For those TVBD networks or devices the CM doesn’t determine operating parameters but all the decisions are made by the TVBD network or device.

For the TVBD networks or devices that are subscribed to the management service the CM provides either one or more TV channels to operate within or an operating frequency to operate with. One or more TV channels are given to the TVBD networks or devices that are subscribed to the TV channel mode of the management service. An operating frequency is given to the TVBD networks or devices that are subscribed to the operating frequency mode of the management service.

7.2.1 Coexistence decision making

Each CM shall implement the following three guidelines in the coexistence decision making regardless of the decision making algorithm in use:

a) First, a non-overlapping TVBD operating channel is selected for each TVBD network or device to avoid co-channel interference

b) If that is not possible, group similar TVBD networks or devices together in frequency domain

c) If even that is not possible, start splitting the TVBD operating channels of the TVBD networks or devices for example in the time domain, the code domain or the frequency domain

Before a CM makes coexistence decisions it ensures that it has up to date information about available TV channels, neighboring TVBDs and radio environment related to the TVBD networks and devices to which the decisions apply. The CM shall use the relevant procedures specified in clause **Error! Reference source not found.** to obtain all the up to date information.

7.2.1.1 Decision making topologies

Three different decision making topologies are specified for IEEE 802.19.1 coexistence system:

— Autonumous

— Distributed

— Centralized

When the autonomous decision making is applied, a CM makes decisions on coexistence independently from other CMs.

When the distributed decision making is applied, a CM negotiates with other CMs that serve the neighboring TVBD networks or devices about decisions.

When the centralized decision making is applied, one CM controls decision making of one or more other CMs. The CM that controls the decision making is called a master CM. The CM that is controlled by a master CM is called a slave CM.

With all three decision making topologies a CM shall obtain information about neighboring TVBD networks or devices to make the decisions. .

7.2.1.1.1 Decision making topology management

CMs may change the decision making topology at any time. The rules and procedures that are applied in those changes are specified here.

7.2.1.2 Information service

When a TVBD network or device is subscribed to the information service, it receives neighbor and radio environment information from the CM. The TVBD network or device determines its operating parameters. The TVBD network or device shall indicate the operating parameters to the CM.

7.2.1.3 Management service

A CM shall issue reconfiguration commands to those TVBD networks or devices that are subscribed to the management service. A CM may also issue measurement requests for those TVBD networks or devices.

7.2.1.3.1 TV channel mode of the management service

When a TVBD network or device is subscribed to the TV channel mode of the management service, it receives from the CM one or multiple TV channels for use. The TVBD network or device shall determine its operating frequency from within the limits of the TV channels from the CM. Once the TVBD network or device has selected its operating parameters, it shall indicate those to the CM.

7.2.1.3.2 Operating frequency mode of the management service

When a TVBD network or device is subscribed to the operating frequency mode of the management service, it receives from the CM an operating frequency for use. The TVBD network or device shall operate as per the given operating frequency.

7.2.1.4 Coexistence decision making algorithms

7.2.1.4.1 Algorithm based on neighbor report and radio environment information

7.2.1.4.1.1 Introduction

Coexistence decision making algorithm is focused on providing necessary reconfiguration comments for a TVBD or TVBD network to operate. In short we will use the term network for TVBD or TVBD network. According to current system any change in the environment can trigger the decision making algorithm. Therefore it is important to select which TVBD/N to optimize. Flowchart of coexistence decision making algorithm is provided in Figure 1.

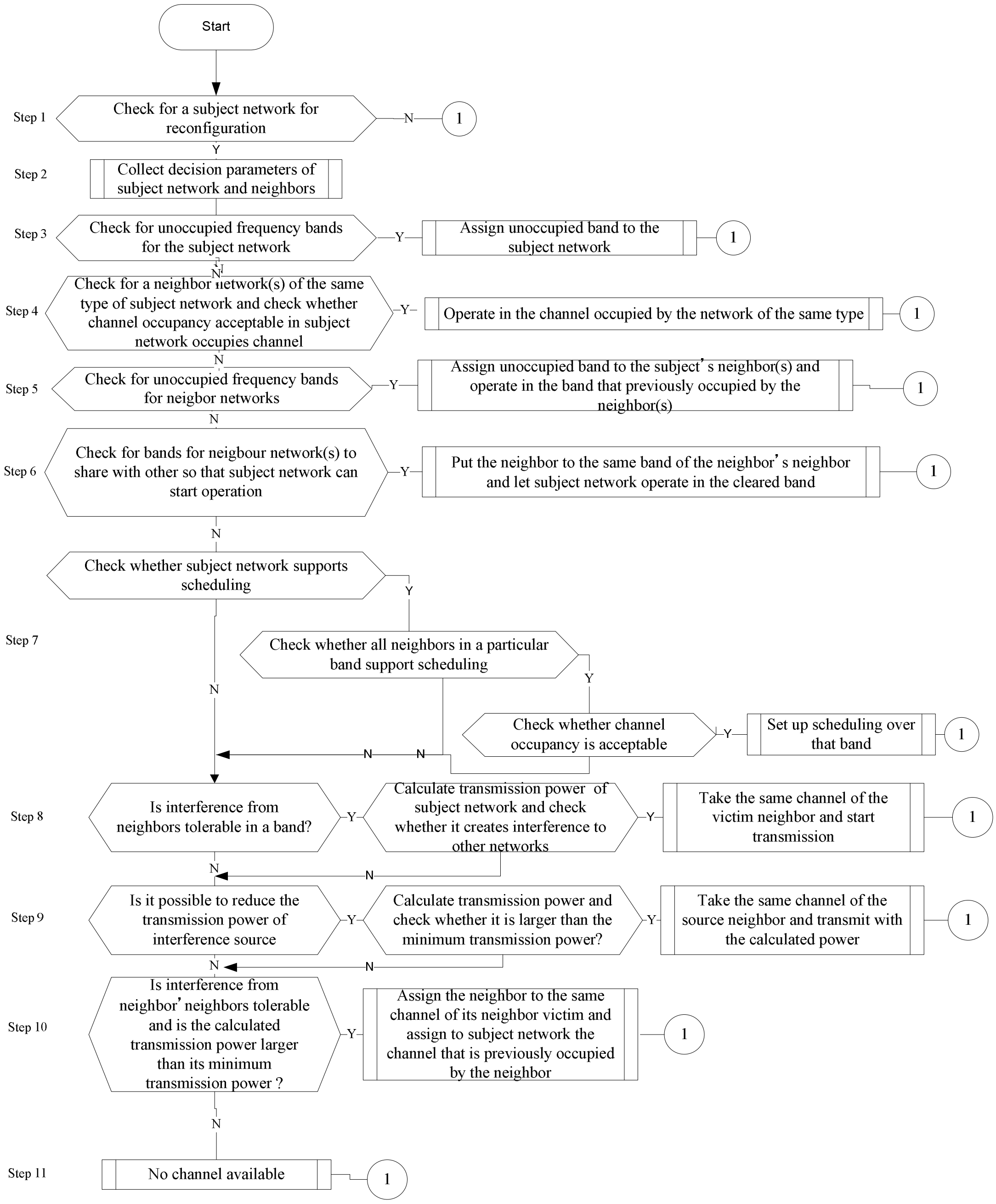

Figure 1— Coexistence decision making algorithm flowchart

7.2.1.4.1.2 Detailed description of the algorithm steps

Step 1: If subject network is not specified, the first step is to analyze the environment and to select the subject network among possible TVBDs or TVBD networks to reconfigure. TVBD or TVBD network with the minimum allocated resource percentage is chosen.

Step 2: Decision parameters for the subject network and its neighbors are created. Parameters include a list where for each available frequency band of a network, the status of the neighboring networks is included. The list below includes decision parameters.

Obtain for subject network and neighboring networks	
Network ID	
Network Technology	11af, 22
Repeat for each available frequency band of the network	
Start Frequency	
Stop Frequency	
Maximum transmit power over this frequency band	
Interference margin	defines as amount of interference that a device tolerates above the noise level from another device at a receiver input
Transmit power requirement	The minimum transmit power to achieve required transmission rate.
Status	Free, occupied known, occupied unknown, not measured
Occupancy	If currently operating in this band real occupancy at the moment, if not it is required occupancy to operate
Total Occupancy	Current total occupancy of the frequency band by neighbors
Total Interference level from neighbors	
Repeat for each of neighbor operating in this frequency band	
Network ID	
Network Technology	
Start frequency	
Stop frequency	
Coexistence type	
Occupancy	
Possible Interference level to subject network	
Possible Interference level from subject network	
Total Interference level from other neighbors	
Interference margin	
Neighbor transmit power requirement	
Status	
Neighbor Networks Support frequency band	
Schedule support	

Step 3: The third step of the algorithm is to finding unoccupied frequency bands for subject network:

— According to available frequency bands , find frequency bands of subject network whose status are marked as “Free ”

$$Ch = \{\arg_i Status_i = \text{"Free"} \mid i \in Int, 1 \le i \le \#of\ supported\ freqency\ bands\}$$

$$Ch = \{\arg_i Status_i = \text{"Free"} \mid i \in Int, 1 \le i \le \#of\ supported\ freqency\ bands\}$$

— Within all free frequency bands, find a frequency band with minimum “maximum power limitation” which are larger than the “transmit power requirement” of the subject network.

— $I = \{\arg_i \min_i (PT_i^{max} \ge PT^{req}) \mid i \in Ch, 1 \le i \le \#of\ supported\ freqency\ bands\}$

, , where PT_i^{max} is the“maximum power limitation” for frequency band i.

— If no frequency band is available ($I = \emptyset$,) go to step 4.

$$Ch = \{\arg_i Status_i = \text{"Free"} \mid i \in Int, 1 \le i \le \#of\ supported\ freqency\ bands\}$$

— If $I \neq \emptyset$, assign the first available frequency band to subject network,

Step 4: System searches for a frequency band which are occupied by the network of the same type of the subject network

— Find frequency bands in spectrum map whose statuses are marked as “Occupied known” and check “Network Technology” and find the networks of the same type to subject network . System should also check for power requirements.

— $Ch = \{\arg_i (Status_i = \text{"Occupied known"}\ \&NetTech = Type\ of\ subject\ network\ \&(PT_i^{max} \ge PT^{req})) \mid i \in Int, 1 \le i \le \#of\ \ supported\ frequency\ bands\}$

— Check “Total occupancy” of those frequency bands, and find frequency bands with the remained frequency band occupancy is larger than the required load of subject network.

$I = \{\arg_i \min_i((1 - O_i^{Total} - O_A^{Req})) \mid i \in Ch\}$, where O_i^{Total} is the total occupancy of frequency bandi, O_A^{Req} is the required frequency band load of network A.

— If no frequency band is available ($I = \emptyset$,) go to step 5.

— If $I \neq \emptyset$, assign the first available frequency band to subject network ,

Step 5: System searches for possible unoccupied frequency bands for neighbors of the subject network and checking if subject network can occupy current channel of the neighbor.

— According to available frequency bands , find frequency bands of subject network whose status are marked as “Occupied known and there power limitations are supported ”

$$Ch = \{\arg_i Status_i = \text{"Free"} \mid i \in Int, 1 \le i \le \#of\ supported\ freqency\ bands\}$$

$$Ch = \{\arg_i Status_i = \text{"Free"} \mid i \in Int, 1 \leq i \leq \#of\ supported\ freqency\ bands\}$$

- Among those bands check if the neighbor networks has free available channels in which their power limitations are met.
- If no frequency band can be cleared for subject network go to step 5.
- If not, find the available frequency band in which mimimum number of neighbors is moved. Assign those neighbors to new band and assign the subject network to their frequency band.

Step 6: System check for frequency bands which are occupied by the neighbors of neighbor networks of the same types of neighbor network and checking if neighbor network can move that band

- According to available frequency bands , find frequency bands of subject network whose status are marked as “Occupied known and there power limitations are supported ”

$$Ch = \{\arg_i Status_i = \text{"Free"} \mid i \in Int, 1 \leq i \leq \#of\ supported\ freqency\ bands\}$$

$$Ch = \{\arg_i Status_i = \text{"Free"} \mid i \in Int, 1 \leq i \leq \#of\ supported\ freqency\ bands\}$$

- Among those bands check if the neighbor networks has available channels in which their power limitations are met, which is occupied by the same type of neighbors.
- Check “Total occupancy” of those frequency bands, and find frequency bands with the remained frequency band occupancy is larger than the required load of neighbor network.
- If no frequency band can be cleared for subject network go to step 5.
- If not, find the available frequency band in which mimimum number of neighbours is moved. Assign those neighbors to new band and assign the subject network to their frequency band.

Step 7: System checks whether subject network can support scheduling.

- If no go to step 8

$$Ch = \{\arg_i Status_i = \text{"Free"} \mid i \in Int, 1 \leq i \leq \#of\ supported\ freqency\ bands\}$$

- If yes, check whether all neighbors in an available band which enables subject network to use its full power supports scheduling with the subject network.
- Check “Total occupancy” of those frequency bands, and find frequency bands with the remained frequency band occupancy is larger than the required load of subject network.
- If yes, assign the subject network to the band with the highest occupancy.
- If no band can be found with enough remaining occupancy, check if occupancy loads can be reduced in the remaining bands.
- If yes assign the subject network to first available band.

— If not go to step 8.

Step 8: System checks if interference from interference source neighbors is tolerable for subject network.

— Within all free frequency bands, find a frequency band with minimum “maximum power limitation” which are larger than the “transmit power requirement” of the subject network.

— $I = \{\arg_i \min_i (PT_i^{max} \geq PT^{req}) \mid i \in Ch, 1 \leq i \leq \#of\ available\ freqency\ bands\}$
, , where PT_i^{max} is the“maximum power limitation” for frequency band i.

— Check whether total interference from all networks is below the interference threshold of the subject network.

— Check additional interference from subject network is tolerable to neighbor networks.

— If yes, assign the channel to the network

— If no, go to step 9.

Step 9: System checks if interference from interference source neighbors can be reduced to a tolerable level for subject network.

— Within all free frequency bands, find a frequency band with minimum “maximum power limitation” which are larger than the “transmit power requirement” of the subject network.

— $I = \{\arg_i \min_i (PT_i^{max} \geq PT^{req}) \mid i \in Ch, 1 \leq i \leq \#of\ available\ freqency\ bands\}$
, where PT_i^{max} is the“maximum power limitation” for frequency band i.

— Check whether added interference from subject network is tolerable for neighbor networks,

— Check whether any of the neighbors can reduce its power in those bands, recalculate the interference power to the subject network and the new interference margin of the neighbor networks. If it is tolerable for both subject network and neighbor networks, assign the band to the subject network and set the new power values for neighbors. If not go to step 10.

Step 10: CM checks if a frequency band can be allocated to subject network by finding another band for the neighbor networks in which the interference is tolerable.

— Within all free frequency bands, find a frequency band with minimum “maximum power limitation” which are larger than the “transmit power requirement” of the subject network.
$I = \{\arg_i \min_i (PT_i^{max} \geq PT^{req}) \mid i \in Ch, 1 \leq i \leq \#of\ available\ freqency\ bands\}$
, where PT_i^{max} is the“maximum power limitation” for frequency band i.

— Check if enough networks in a band can be moved to another band until the interference level is tolerable for the subject network.

— If interference from subject network is tolerable to remaining networks in the band, assign neighbor networks to new channels and subject network to the available channel. If not go to step 11.

Step 11: If all steps fail indicate that no channel is available.

7.2.1.4.1.3 Output from decision making algorithm

OperatingFrequency	StartFeq, StopFreq
Transmit PowerLimit	
frequency bandIsShared	To show whether the frequency band is shared with other networks or not
Transmission schedule	
ScheduleStartTime	Negotiation between CMs if necessary
ScheduleDuration	
NumberOfScheduleRepetitions	
Schedule Repetition period	
TransmissionStartTime for a network	Controlled by one CM
TransmissionDuration for a network	

Transmission start time and transmission duration is specified by a CM. One transmission duration is scheduled for one network.

Schedule start time and schedule duration is decided by CM negotiation. One schedule duration is scheduled for one CM.

Schedule repetition period is decided by CM negotiation. One schedule repetition period is shared by several CMs.

7.2.1.4.2 Algorithm based on operating channel selection

Coexistence problems between TVBD networks or devices might occur due to the disparity between the number of allocable TV channels and the number of required TV channels for TVBD networks or devices over a given area.

The following three channel allocation methods for operating channel selection are considered as depicted in Figure 2:

— Individual TV channel allocation

— Shared TV channel allocation by TVBD networks of the same/similar type

— Shared TV channel allocation by TVBD networks of the dissimilar type

In the individual TV channel allocation, TV channels are dynamically assigned to each TVBD network which use different TV channels. So it is possible that non-overlapped TV channels are allocated to TVBD networks. This guarantee co-channel-interference-free TV channel use and coexistence problem can be eliminated through a proper TV channel allocation.

In shared TV channel allocation, two or more TVBD networks share the same TV channel. There could be a number of TV channels that are being shared.

If a TV channel is shared by the TVBD networks of the same/similar type, self-coexistence mechanisms shall be applied to mitigate co-channel interference. For example, two or more 802.22 systems can share the same TV channel using their self-coexistence mechanism, call on-demand frame contention (ODFC).

If a TV channel is shared by TVBD networks of the dissimilar type, inter-system coexistence mechanisms shall be applied to mitigate co-channel interference.

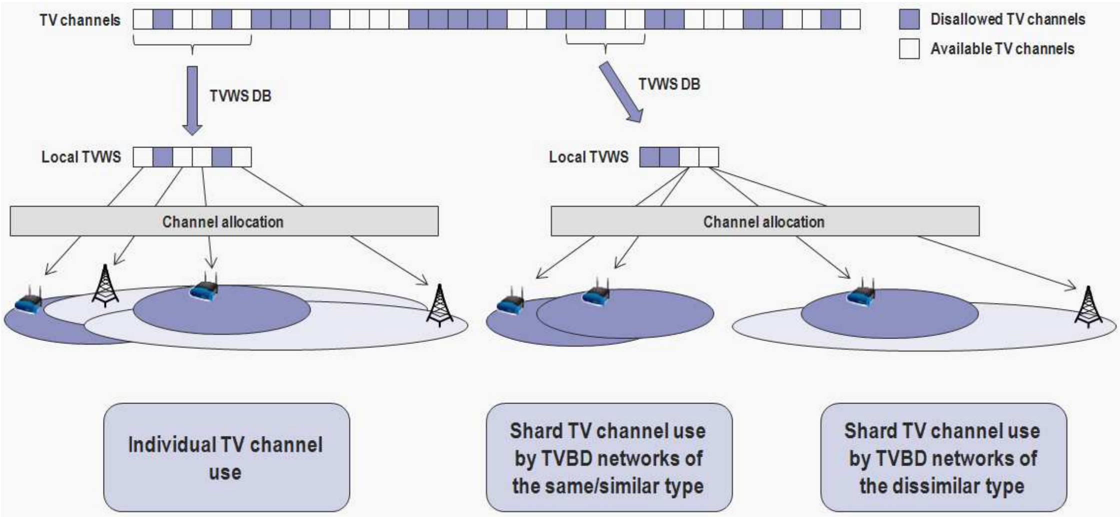

Figure 2— Three channel allocation methods

Operating channel selection is done by a CM with interacting between CE/CDIS. Operating channel selection mechanism mainly consists of two parts: Channel classification and channel allocation. The detailed procedure of the decision making of operating channel selection by a CM is as follows:

Step 1: Perform channel classification to prepare channel allocation to the registered CEs. Update channel classification and registration information of the corresponding registered TVBD networks or devices

— Channel classification is triggered if flag 'Initiate_Channel_Classification' is set to be 1. This flag is set to be 1 if the CM has been initialized after power on or TVWS channels from TVWS DB have been updated.

— As depicted in Figure 3, the CM firstly performs registered CE discovery in order to find out context information of registered CEs belong to the CM.

— After getting context information from the registered CEs, the CM accesses TVWS DB to get the list of allowed channels, and find out the available channel and the restricted channel that can be used by TVBD networks or devices. To do that, the CM might send an identifier of each TVBD as required by regulation.

— In case, TVWS DB is not available within a certain time limit, the CM requests each registered CE to send disconnection request to the CM.

— After getting allowed lists from TVWS DB, the CM performs neighbor CM discovery to get context information of neighbor CMs from the CDIS, and get channel classification information from its neighbor CMs.

— Once neighbor CM discovery is accomplished, the CM performs channel identification as depicted in Figure 4. Through this, the CM identifies the available channel, the restricted channel, the operating channel already taken by the registered CE of the neighbor CM among allowed channels from TVWS DB.

— The CM finally sets flag 'Initiate_Channel_Allocation' to be 1, in order to trigger channel allocation.

Step 2: Perform channel allocation based on channel classification and other aspects such as TVWS DB update, registered CE discovery update, neighbor CM discovery update, neighbor CM channel classification update and registered CE's channel move request.

- Channel allocation is triggered if flag 'Initiate_Channel_Allocation' is set to be 1. This flag is set to be 1 if the following occurs:
  - If the CM has done channel classification
  - If the neighbor CM discovery has been updated
  - If the neighbor CM channel classification has been updated
  - If the registered CE discovery has been updated
  - If the registered CE requests channel move and there are no available channels or restricted channels to allocate
- As shown in Figure 5, the CM firstly checks if Timer $T_{Refresh\_TVWS\_DB}$ is expired. If it is expired, the CM performs TVWS channel update. If not, the CM continues channel allocation process and checks current channel classification.
- Based on current channel classification, the CM decides if individual channel assignment is possible for all registered CEs considering its neighbor CM. If possible, i.e., in individual channel assignment mode, the CM allocates an exclusive operating channel to each registered CE and sends reconfiguration request to registered CEs. If a registered CE does not accept the CM's reconfiguration request, the CM discards that registered CEs. The CM updates channel classification again to reflect channel allocation, and finally the CM sends updated channel classification information to its neighbor CMs.
- If individual channel assignment mode is not possible, the CM enters co-channel sharing mode and shall apply a proper operating channel selection algorithm and/or a co-channel sharing mechanism to each registered CE. Negotiation might be needed if a negotiation with its neighbor CM is needed. Flowchart of operating channel selection for the CM is shown in Figure 6.

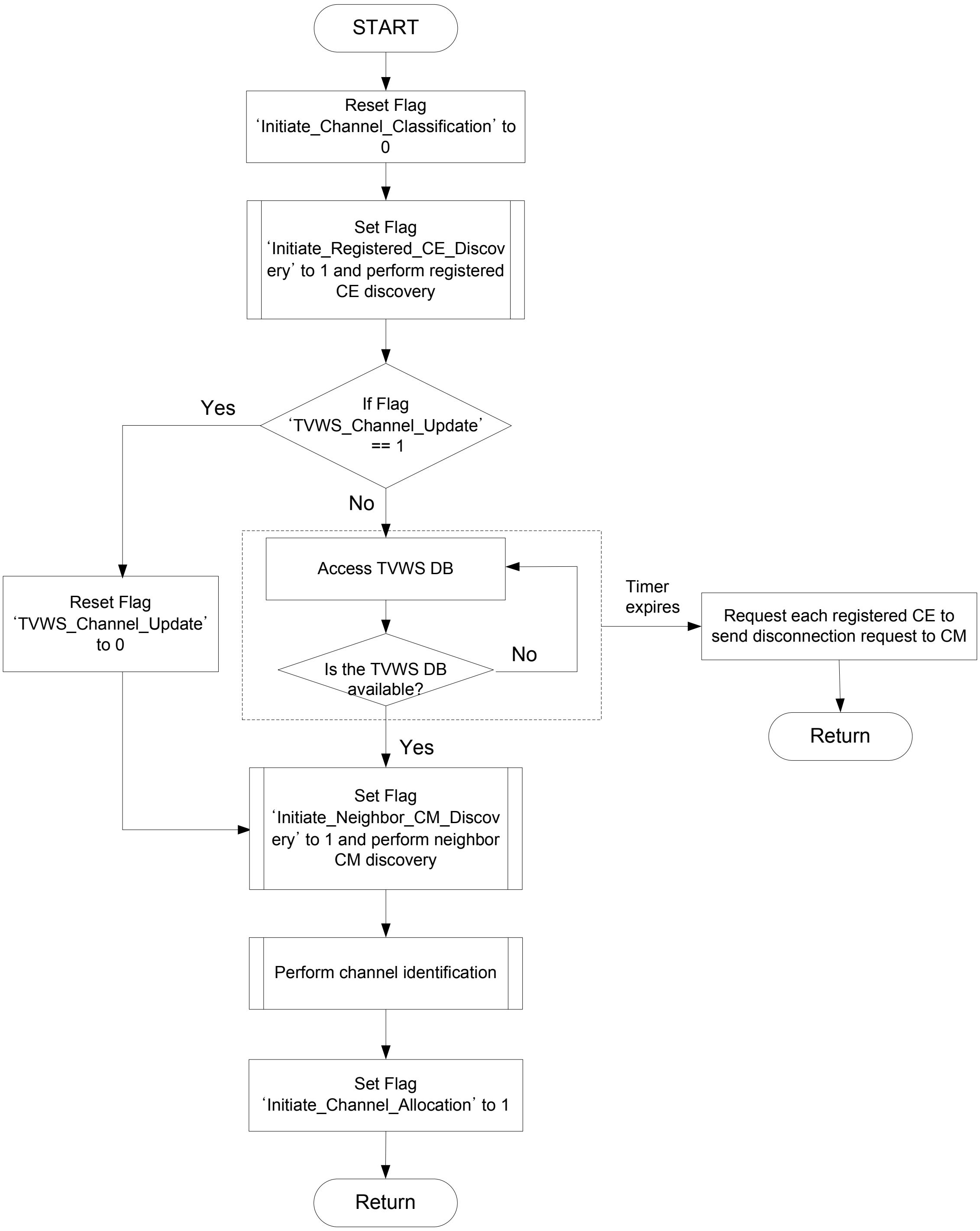

Figure 3— Flowchart of channel classification

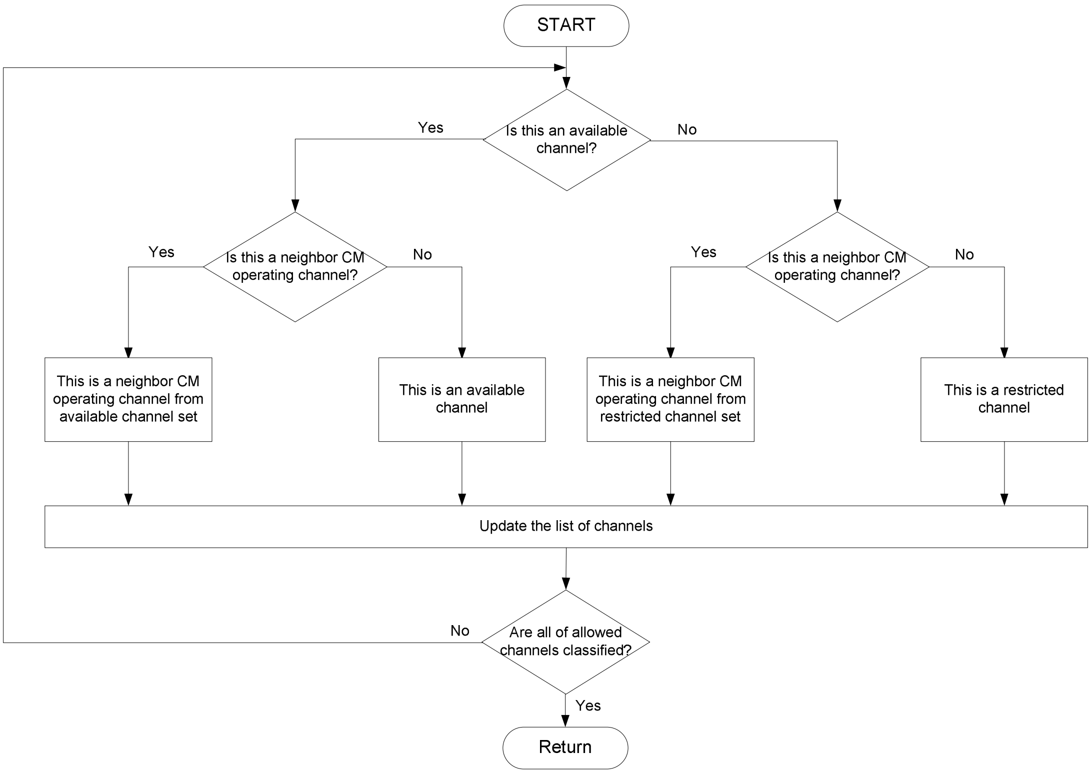

Figure 4— Flowchart of channel identification

TVWS channel update is periodically checked during the CM operation. If TVWS DB is updated, the CM notifies channel shutdown to all registered CEs, and goes back to channel classification step 1. In case, TVWS DB is not available within a certain time limit, the CM notifies shutdown of all operating channels to all registered CEs, and requests each registered CE to send disconnection request to the CM.

Registered CE discovery update is triggered if registered CE list of the CM has been changed. Through this, the CM perform registered CE discovery and channel allocation one by one.

Neighbor CM discovery update is triggered if neighbor CM list has been changed. The CM performs neighbor CM discovery and channel allocation by turns.

CM performs a registered CE channel move if the registered CE of the CM requests channel move due to failure of required quality of service (QoS) with allocated operating channel from the CM. As depicted in Figure 5 the CM allocates a new operating channel to the CE requesting channel move if there are available channels or restricted channels. After that the CM updates channel classification, and announces it to its neighbor CMs. If there are no available channels or restricted channels to allocate, the CM set flag 'Initiate_Channel_Allocation' to be 1 and performs channel allocation.

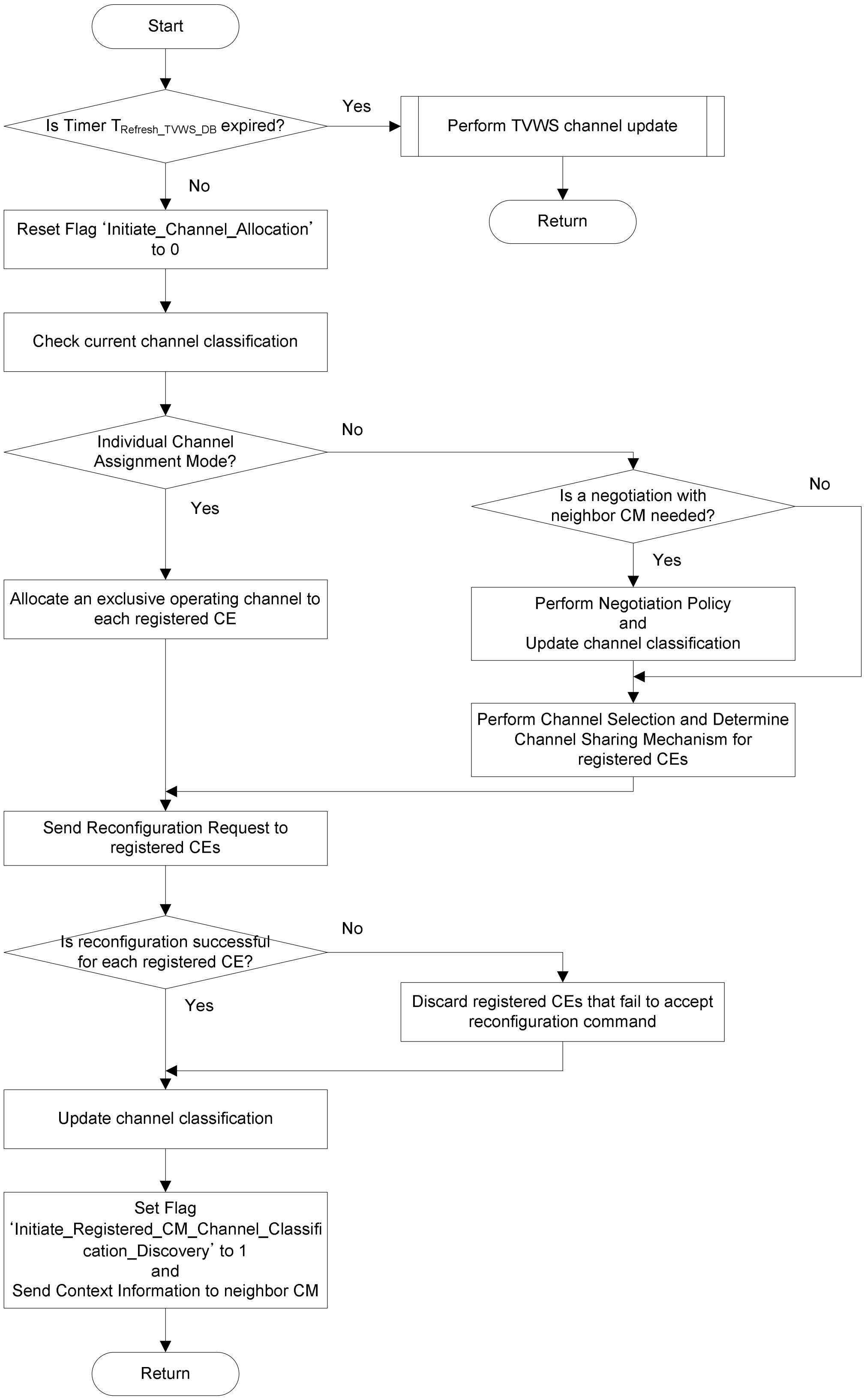

Figure 5— Flowchart of channel allocation

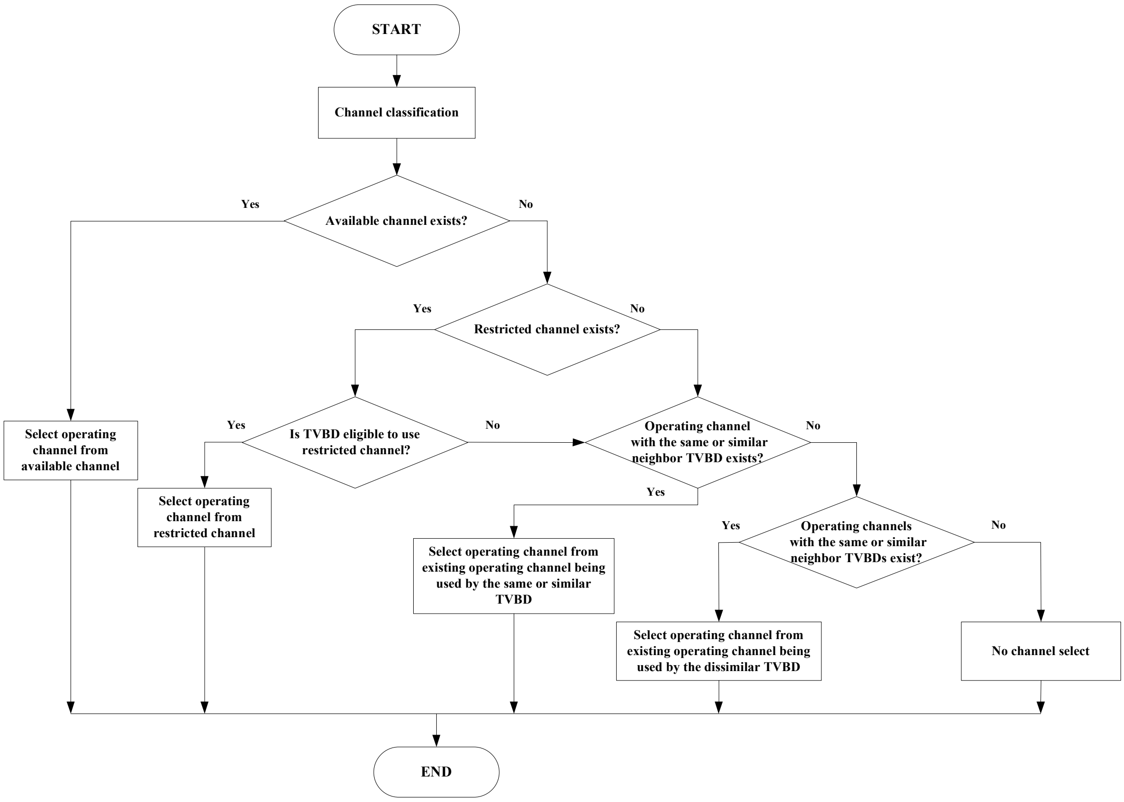

Figure 6— Flowchart of operating channel selection

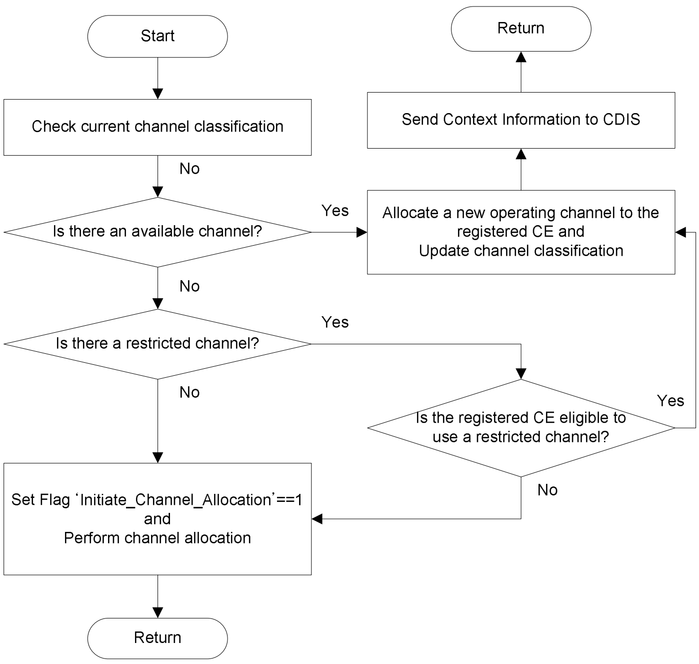

Figure 7— Flowchart of channel move

7.2.1.4.3 Algorithm based on negotiation among CMs

This algorithm enables the coexistence system to share the frequency bands of the coexistence managers effectively in a case where two or more TVBDs are inter-CM neighbor relation. The inter-CM neighbors are registered to the different CM and interfered with each other over the same operating channel due to their geo-location, transmission range, interference range, and etc. The key processing components, which are conducted in CM, are decision making of operating channel list, round-robin mode parameters and competition mode parameters.

Based on the decision making of operating channel list, when all neighbor CMs allow the independent use, the inter-CM neighbor network uses independent operating channels, i.e., non-overlapped operating channels with neighbor networks or devices, called etiquette mode. On the other hand, when some neighbor CMs disallow the independent use, the inter-CM neighbor network shares operating channels with neighbor networks or devices, called contention mode. Since time-division multiplexing (TDM) is the promising technique for sharing operating channels we consider two kinds of mechanism such as round-robin mode and competition mode. Round-robin mode sequentially assigns time slot to all inter-CM neighbor networks. Competition mode assigns time slot to particular inter-CM neighbor networks through competition among inter-CM neighbor networks. Detailed explanations of etiquette, round-robin and competition modes are given in the following subsections.

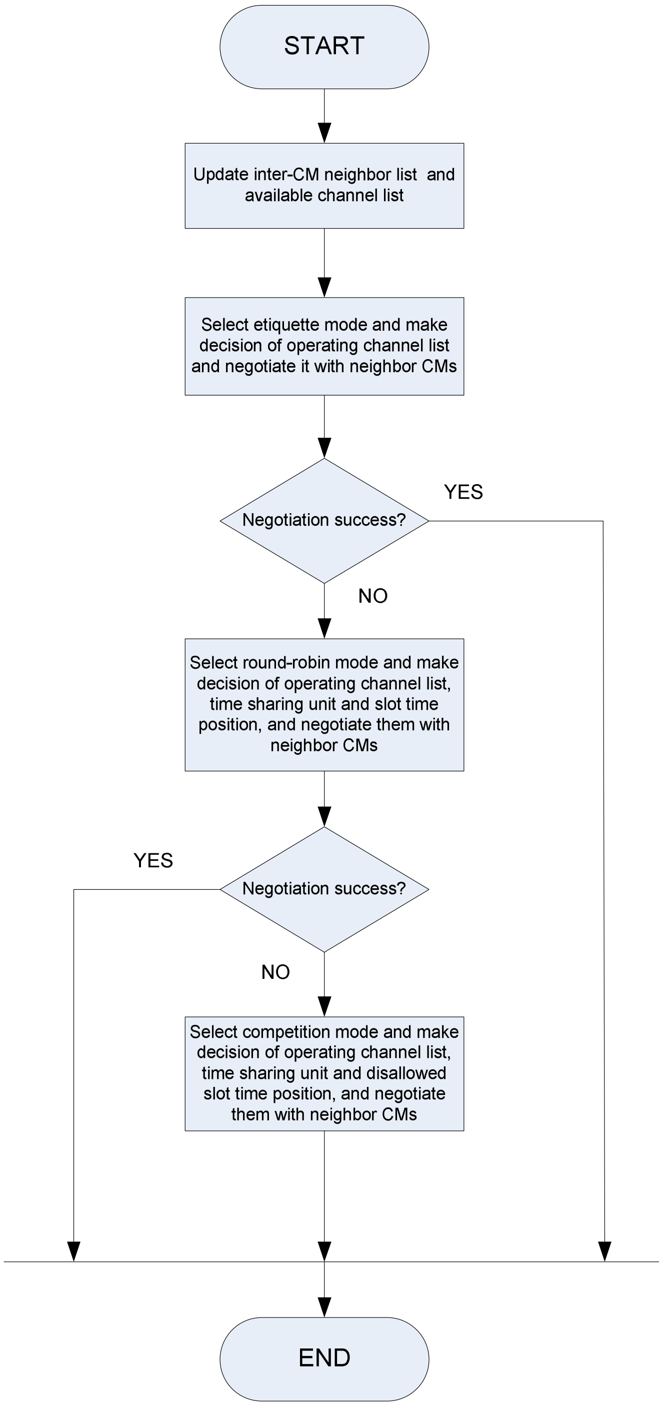

Figure 8— CM operation in inter-CM negotiation

7.2.1.4.3.1 Etiquette mode

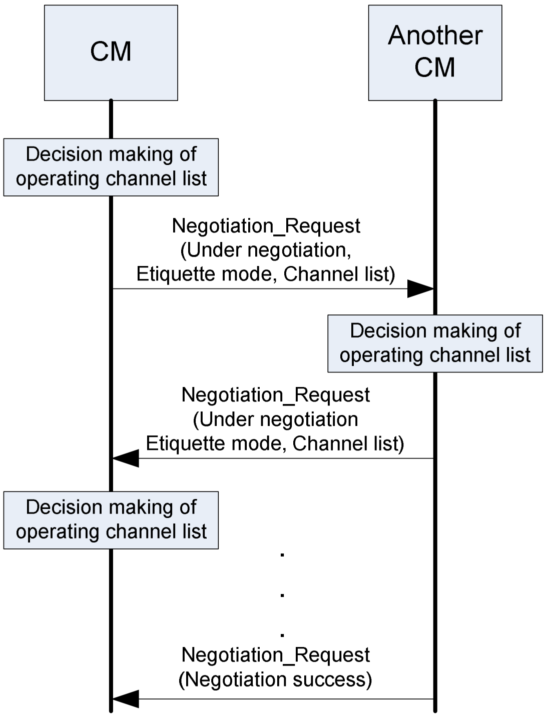

Figure 9— Message sequence for the etiquette mode

As mentioned above, when all inter CMs allow the independent use, the inter-CM neighbor network uses independent operating channels, i.e., non-overlapped operating channels with neighbor networks or devices. As shown in Figure 9, after decision making of operating channel list a CM requests its desired operating channel list to another CM. Also, another CM gives the response for CM's request after making decision of operating channel list. Each CM continues negotiation about the desired operating channel list for CM's request until another CM responses negotiation success message. Since independent operating channels use is possible when all inter CMs allow the independent use, negotiation is performed to all inter CMs. The procedure of decision making of operating channel list consists of 7 steps where step 2-5 are used for checking usable channel list of the registered TVBDs, and step 6 is used for tuning operating channel list through message exchange between neighbor CMs. The detail procedure of decision making of operating channel list is given as follows:

Step 1: Update channel classification and registration information of the corresponding registered TVBDs

— If the number of message exchanges exceeds the pre-defined number, go to step 7

— If another CM requests changing operating channel list and there is no updated TVBD information, go to step 6

Step 2: Check channel classification of the corresponding registered TVBD to find available channels

— If there is no available channels in channel classification, go to step 7

Step 3: Check the list of supported channel number of the registered TVBD

- If there is no available channels in the supported channels, go to step 7

Step 4: Check the network type of the registered TVBD to find that the registered TVBD is fixed type or portable/personal type

- If there is no available channels to satisfy regulation of the corresponding network type, go to step 7

Step 5: Check required resource of the registered TVBD to find required bandwidth

- If there is no enough available channels to satisfy required bandwidth, go to step 7

Step 6: Select the operating channel list satisfying step 2-5

- If another CM requests changing operating channel list and its parameter is acceptable, select the parameters
- If another CM's request is not acceptable, select an alternative operating channel list satisfying step 2-5
- If there is no proper available channels, go to step 7

Step 7: Set to negotiation failure

7.2.1.4.3.2 Round-robin mode

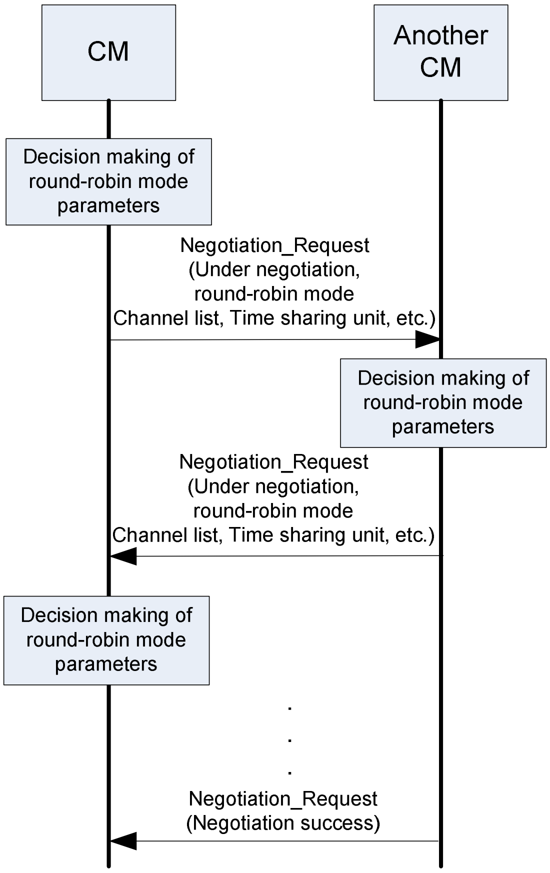

Figure 10 — Message sequence for the round-robin mode

As mentioned above, an inter-CM neighbor in round-robin mode shares operating channels and time slot is be assigned sequentially to all inter-CM neighbor networks. Since time slot is assigned to all inter-CM neighbors, the primary advantage of this mode is fairness. As shown in Figure 10, after decision making of round-robin mode parameters a CM requests its desired operating channel list and time sharing unit information, etc. to another CM. Also, another CM gives the response for CM's request after making decision of round-robin mode parameters. A CM continues negotiation with all inter CMs until receiving negotiation success message. The procedure of decision making of round-robin mode parameters consists of 7 steps where step 2 is used for checking whether the registered TVBDs support time scheduling and step 3-4 are used for tuning co-channel sharing related parameters through message exchange between neighbor CMs. The detail procedure of decision making of contention mode is given as follows:

Step 1: Update channel classification and registration information of the corresponding registered TVBDs

- If the number of message exchanges exceeds the pre-defined number, go to step 7
- If another CM requests changing round-robin mode parameters, then go to the following corresponding step;
  - For changing operating channel list, go to step 3
  - For changing time sharing unit, go to step 4

Step 2: Check whether the corresponding registered TVBDs support time scheduling

- If not supportable, then go to step 7

Step 3: Select the operating channel list through channel classification, TVBD information such as required resource, supported channel number and network type

- If another CM requests changing operating channel list and its parameter is acceptable, select the parameters
- If another CM’s request is not acceptable, select an alternative operating channel list based on channel classification and TVBD information
- If parameter change requested by another CM is remained, then go to the following corresponding steps;
  - For changing time sharing unit, go to step 4

Step 4: Select time sharing unit such as reference time, window time and slot time through the registered TVBD information

- If another CM requests changing time sharing unit and its time unit is acceptable, select the parameters
- If time unit of another CM is not acceptable, select an alternative time sharing unit based on the registered TVBD information
  - Select reference time to make time synchronization with other inter-CM neighbors
  - Select window time satisfying required system QoS performance (latency, duty cycle, etc.) based on the registered TVBD information
  - Select slot time satisfying required duty cycle of the registered TVBD based on the registered TVBD information

Step 5: Select number of required slots based on time sharing unit, the inter-CM neighbor list and registered TVBD information

Step 6: Selects slot time position based on time sharing unit, number of required slots and the registered TVBD information

Step 7: Set to negotiation failure

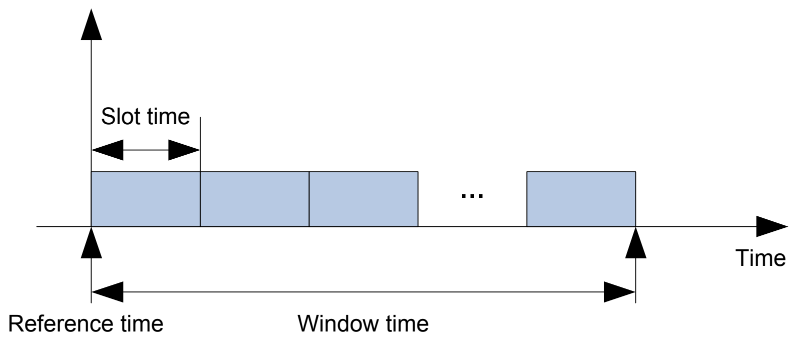

Figure 11 — Time sharing unit information for contention mode

7.2.1.4.3.3 Competition mode

As mentioned above, in competition mode, time slot is assigned to particular inter-CM neighbor network by competition among inter-CM neighbor networks. As shown in Figure 12, after decision making of competition mode parameters a CM requests its desired operating channel list and time sharing unit information, etc. to another CM. Also, another CM gives the response for CM's request after making decision of competition mode parameters. A CM continues negotiation with all inter CMs until receiving negotiation success message. Finally, after decision making of announcement parameters, a host CM notifies negotiation results such as winner CM list and list of slot time position to all neighbor CMs.

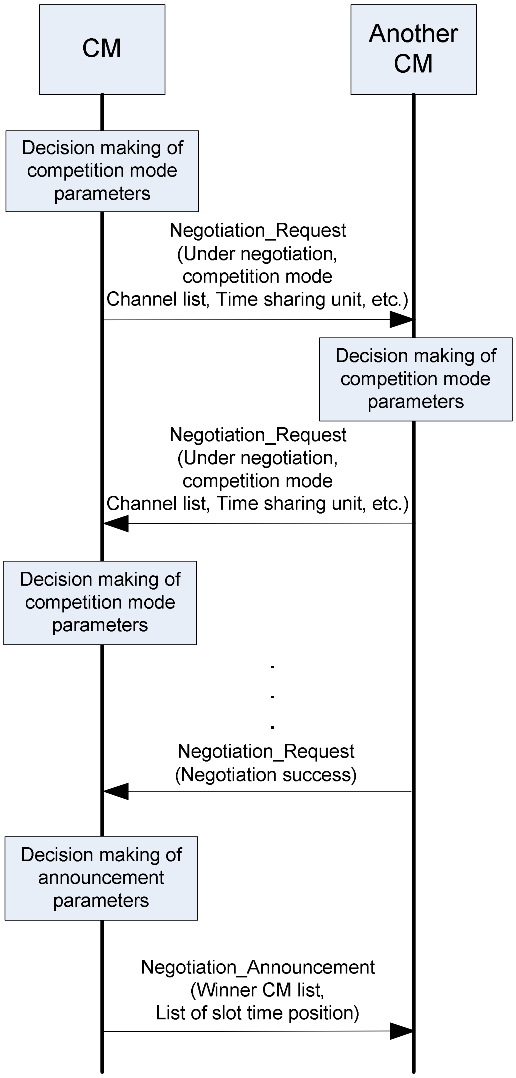

Figure 12— Message sequence of the competition mode

The procedure of decision making of competition mode parameters consists of 7 steps where step 2 is used for checking whether the registered TVBDs support time scheduling and step 3-4 are used for tuning co-channel sharing related parameters through message exchange between neighbor CMs. The detail procedure of decision making of competition mode parameters is given as follows:

Step 1: Updates channel classification and registration information of the corresponding registered TVBDs

- If the number of message exchanges exceeds the pre-defined number, go to step 7
- If another CM requests changing competition mode parameters, then go to the following corresponding step;
  - For changing operating channel list, go to step 3
  - For changing time sharing unit, go to step 4

Step 2: Check whether the corresponding registered TVBDs support time scheduling

- If not supportable, then go to step 7

Step 3: Selects the operating channel list through channel classification, TVBD information such as required resource, supported channel number and network type

- If another CM requests changing operating channel list and its parameter is acceptable, select the parameters
- If another CM's request is not acceptable, select an alternative operating channel list based on channel classification and TVBD information
- If parameter change requested by another CM is remained, then go to the following corresponding steps;
  - For changing time sharing unit, go to step 4

Step 4: Selects time sharing unit such as reference time, window time and slot time through the registered TVBD information

- If another CM requests changing time sharing unit and its time unit is acceptable, select the parameters
- If time unit of another CM is not acceptable, select an alternative time sharing unit based on the registered TVBD information
  - Select reference time to make time synchronization with other inter-CM neighbors
  - Select window time satisfying required system QoS performance (latency, duty cycle, etc.) based on the registered TVBD information
  - Select slot time satisfying required duty cycle of the registered TVBD based on the registered TVBD information

Step 5: Check disallowed slot time position based on time sharing unit, the inter-CM neighbor list and registered TVBD information

Step 6: Generate list of contention numbers through random number generator

Step 7: Set to negotiation failure

Also, the detail procedures of decision making of announcement parameters by a host CM are given as follows:

Step 1: Check the disallowed slot time position and list of contention numbers from all inter-CM neighbors

Step 2: Check time sharing unit information decided by negotiation between neighbor CMs

Step 3: Selects the winner CM list and list of slot time position

- Select the winner CM list in increasing order of contention number
- Select list of slot time position through winner CM list and time sharing unit information

7.2.1.4.3.4 Input and output parameters of inter-CM negotiation

Input and output parameters for decision making related to negotiation between neighbor CMs are as follows:

Input parameters for decision making of operating channel list	
Channel classification information	
List of supported channel number	
Network type	
Required resource	to check required bandwidth
Output parameters for decision making of operating channel list	
Operating channel list	

Input parameters for decision making of round-robin mode parameters	
Channel classification information	
List of supported channel number	
Network type	
Network technology	
Required resource	to check required bandwidth
Neighbor list	
Tx schedule supported	
Output parameters for decision making of round-robin mode parameters	
Operating channel list	
Time sharing unit information	reference time, window time, slot time
Number of required slots	
Slot time position	

Input parameters for decision making of competition mode parameters	
Channel classification information	

List of supported channel number	
Network type	
Network technology	
Required resource	to check required bandwidth
Neighbor list	
Tx schedule supported	
Output parameters for decision making of competition mode parameters	
Operating channel list	
Time sharing unit information	reference time, window time, slot time
Disallowed slot time position	
List of contention numbers	

Input parameters for decision making of announcement parameters	
Time sharing unit information	reference time, window time, slot time
Disallowed slot time position	
List of contention numbers	
Output parameters for decision making of announcement parameters	
Winner CM list	
List of slot time position	

7.2.1.4.4 Algorithm based on co-channel sharing via TVBD network geometry classification

7.2.1.4.4.1 Introduction

It is very important for a coexistence system to support a common channel selection mechanism and algorithm, because it will make easier for multiple CMs to communicate and synchronize each other. Subsequently, the method shall enable the system to optimize the efficiency of the frequency utilization as much as possible. This is because the number of operable channels seems not to be abundance in most of TVBD network deployment scenarios, so the mechanism shall adapt the methods to increase the efficiency of the frequency utilization as much as possible.

There are two cases in channel selection procedure. One is the different channel assignment in a case where the number of operable channels is abundant for neighbor TVBD networks or devices, and the other is the co-channel sharing in a case where the system cannot assign different channel among neighbors. This section highlights only the part of the co-channel sharing mechanism to increase the efficiency of the frequency utilization, in a case where the system cannot assign different channel among neighbors.

The next subsection introduces one of the algorithm implementation examples, but this standard shall support the following channel selection management basis in finding the possible method to share the target channel with neighbors:

— Co-channel sharing management via wireless network coexistence technologies (coexistence beacon mechanism in IEEE802.22) based on network geometry classification among similar/dissimilar TVBD networks, and

— Co-channel sharing management via backhaul connection among similar/dissimilar TVBD networks or devices.

7.2.1.5 Network geometry classification

Network geometry is classified in the following four types.

1) Class#1

This class #1 is specified in a case where two different TVBD network coverage areas are overlapped each other as shown in **Error! Reference source not found.**, and each master TVBD may be able to communicate each other if the same RAT (Radio Access Technology) and the same operation channel are utilized without causing harmful interference each other. 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).

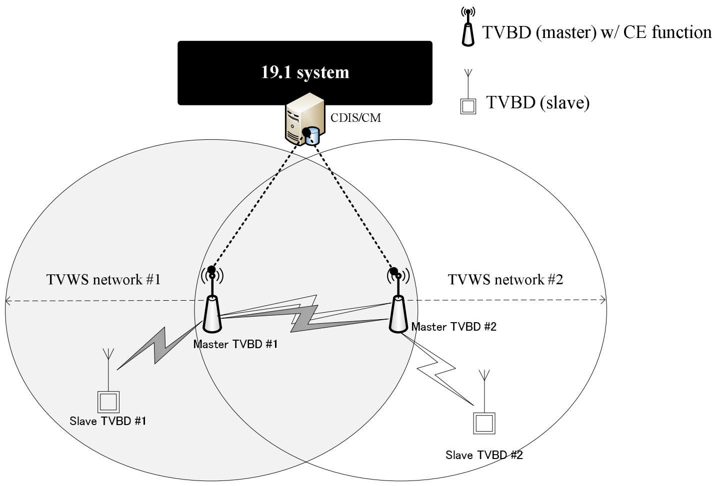

Figure 13 — Class#1 network geometry

2) Class#2

This class #2 is specified in a case where two different TVBD 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 **Error! Reference source not found.**. 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. 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 exchanges 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).

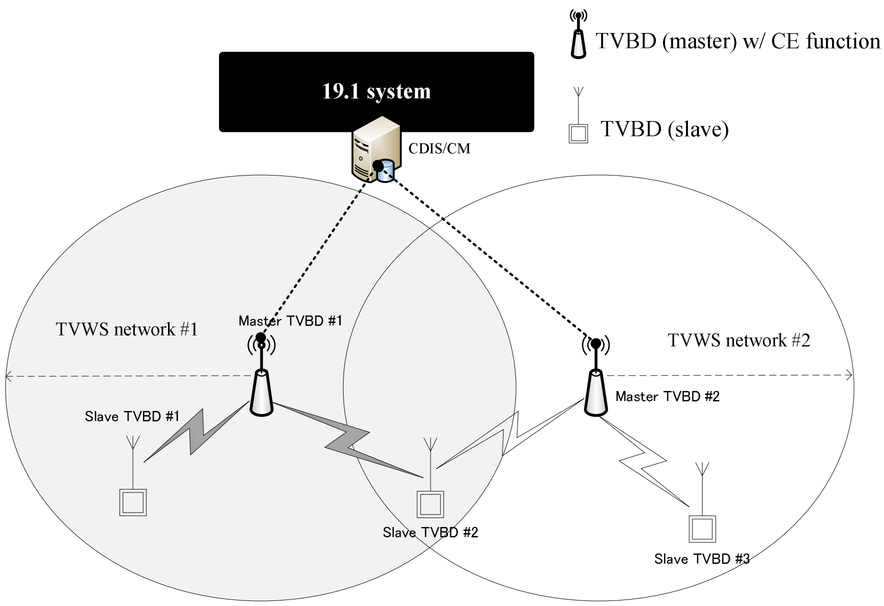

Figure 14 — Class#2 network geometry

3) Class#3

This class #3 is specified in a case where two different TVBD network coverage areas are not overlapped each other as shown in **Error! Reference source not found.**, 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 ($I_{\mathrm{secondary}}$) 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_{TVBD}) from the other network, the situation is classified in Class#3b. Subsequently, if the resource sharing and the synchronized operation are possible via backhaul connection 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 backhaul connection in Class#2b because of its capability and latency problem and so on, the situation is classified in Class#3b(2).

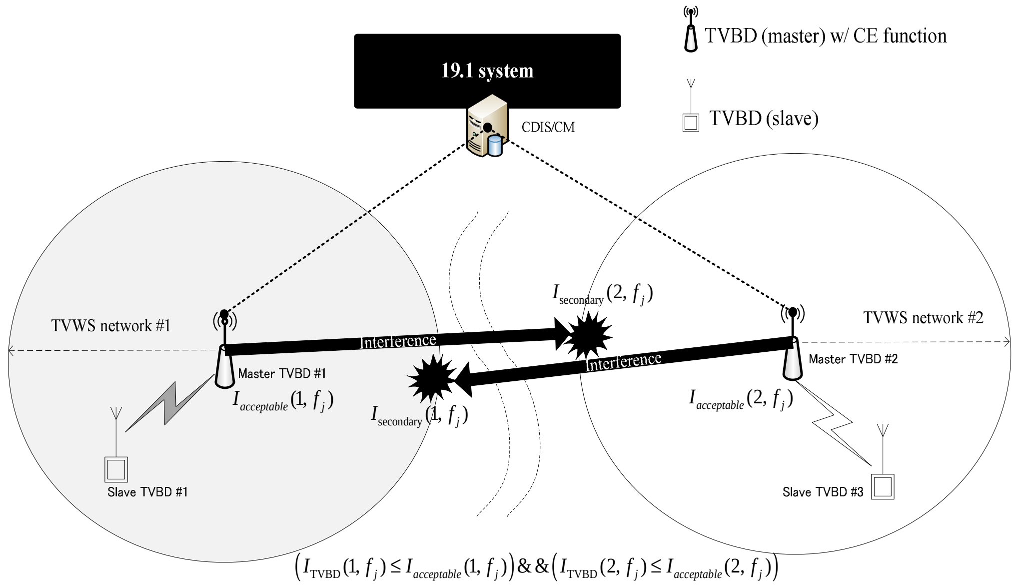

Figure 15 — Class#3 network geometry

4) Class#4

This class #4 specified in a case where two different TVBD network coverage areas are overlaid each other as shown in **Error! Reference source not found.**. 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. 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. 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.

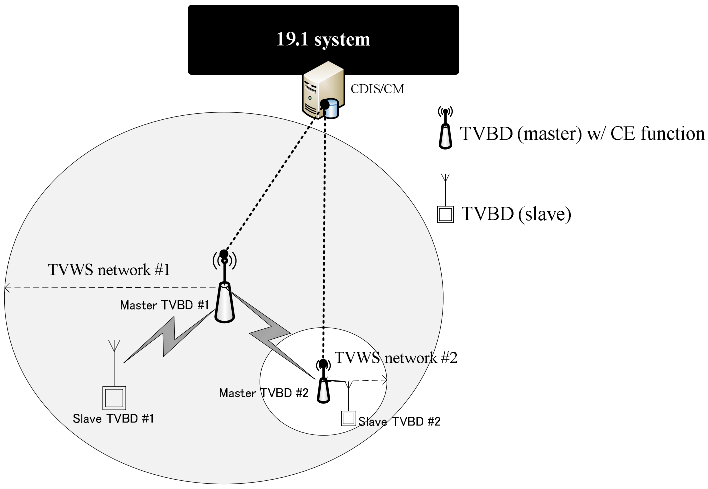

Figure 16 — Class#4 network geometry

7.2.1.5.1.1 Algorithm description

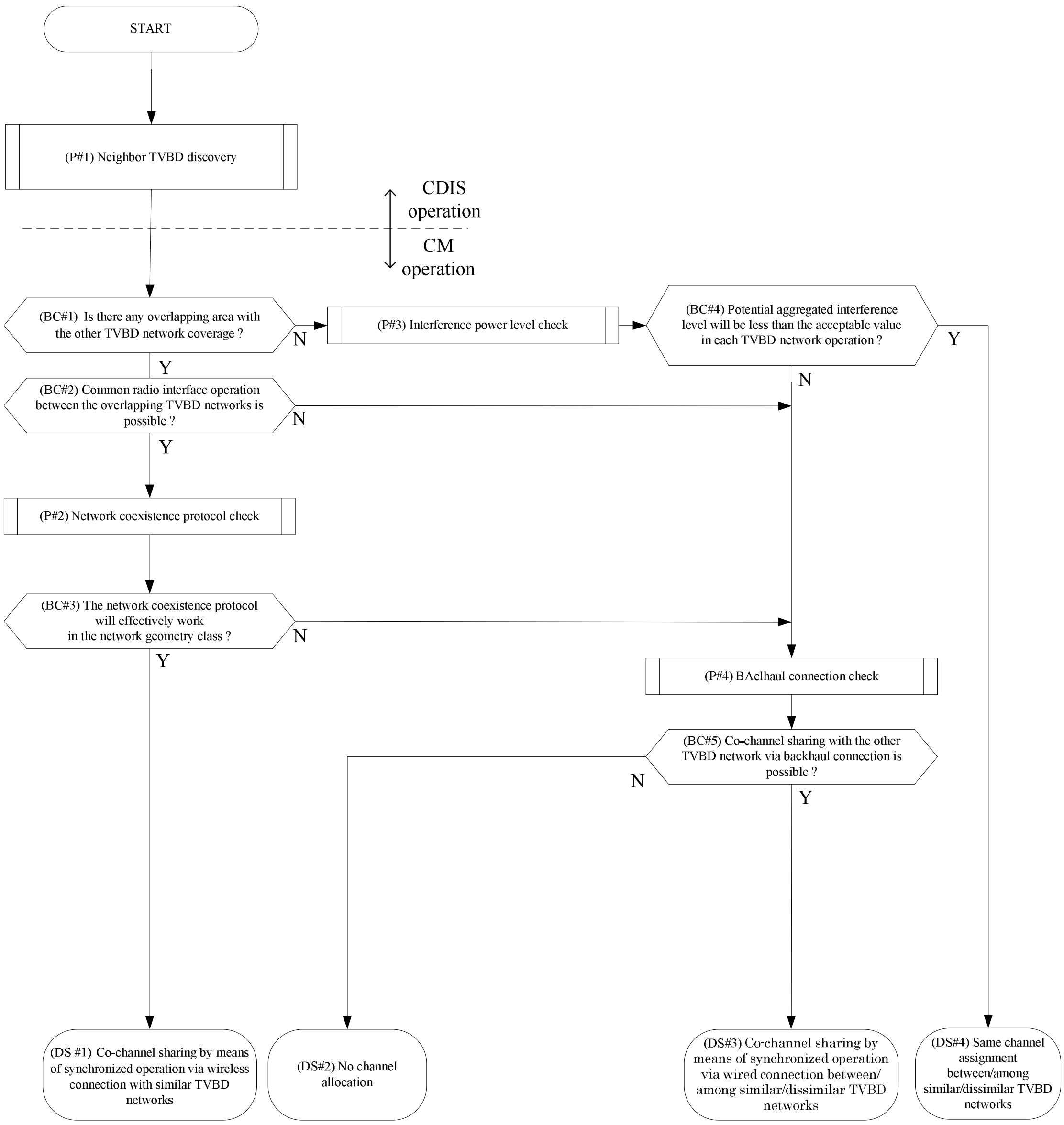

Figure 17 — Co-channel sharing procedure

The **Error! Reference source not found.** shows the channel selection procedure. This procedure is composed of four final decision statuses (DS#1-DS#4) of this channel selection procedure, four processes (P#1-P#4) for the decision making of channel selection, and five branch conditions (BC#1-BC5).

The four final decision statuses are as follows:

(DS#1)

— Co-channel sharing by means of synchronized operation via wireless connection with similar TVBD network

(DS#2)

- No channel allocation for the target TVBD

(DS#3)

- Co-channel sharing by means of synchronized operation via backhaul connection between/among similar/dissimilar TVBD networks

(DS#4)

- Same channel assignment between/among similar/dissimilar TVBD networks

The four processes are as follows:

(P#1)

- Neighbor TVBD discovery
  - This process shall be conducted using the procedures and the message exchange in chapter 6, and the CM can obtain the neighbor TVBD network geometry class information from CDIS. This information is specifically utilized in the network coexistence protocol check process (P#2).

(P#2)

- Network coexistence protocol check process
  - This process shall check whether or not the network coexistence protocol as indicated with NetworkTechnology and addNetworkTechnology can effectively work in the network geometry class.
  - The result of this process is utilized in the final decision making process whether or not co-channel sharing by means of synchronized operation via wireless connection with similar TVBD network is possible.

(P#3)

- Interference power level check process
  - This process shall be conducted using the TVBD tolerable interference power level information of TolerableInterferenceLevel of Discovery_Information, and the result of this process is utilized in the decision making on co-channel sharing with the other TVBD network.

(P #4)

- Backhaul connection check process
  - This process shall be conducted using the guaranteed QoS information of GuranteedQoSOfBackhaulConnection and is necessary for the decision making on co-channel sharing with neighbor TVBD network.
  - There will be several viewpoints in checking backhaul connection, but the following check point shall be at least necessary.
    - Ascertain whether the required minimum bit rates and the required communication latency can be satisfied in conducting co-channel sharing via backhaul connection with the similar/dissimilar TVBD network

The five branch conditions are as follows:

(BC#1)

- This branch condition shall be conducted based on the result of the network geometry classification process. If the network geometry class is class#1/class#2/class#3, go to BC#2. If not, go to P#3.

(BC#2)

- This branch condition shall be conducted based on the capability of the operable radio interface of the target TVBD networks. If the same radio interface can utilize in all the target TVBD networks, go to P#2. If not, go to P#4.

(BC#3)

- This branch condition shall be conducted based on the network coexistence protocol check. If the co-channel sharing via wireless link is possible, go to DS#1. If not, go to P#4.

(BC#4)

- This branch condition shall be conducted based on the result of mutual interference power level check process. If the co-channel sharing does not cause the harmful interference for the other TVBD network operation, go to DS#4. If not, go to P#4.

(BC#5)

- This branch condition shall be conducted based on the result of backhaul connection check process. If the co-channel sharing is possible, go to DS#3. If not, go to DS#2.

7.2.1.5.2 Algorithm based on load balancing

7.2.1.5.2.1 Introduction

It is very important for a coexistence system to effectively utilize the distributed processing power of the coexistence system operation, and to maximize the number of the registered TVBD networks or devices in accordance with the conditions of the coexistence system operation. Specifically in a case where a CM is co-located in a TVBD device, the channel selection processing for the connected CE and the connected TVBD network/device will be large burden from a viewpoint of its power consumption. Or, in a case where the number of TVBD network or device dynamically changes in an ad hoc outdoor event e.g. a music concert, effective utilization of distributed CM processing power will be great help for an ad hoc coexistence system installation.

Although next subsection introduces one of the algorithm implementation examples on channel selection process, this standard supports the three channel selection policies, which are centric coordination, distributed/autonomous coordination and cooperative coordination, and its dynamic reconfiguration on the channel selection policies in accordance with the capable processing load in each CM operation.

7.2.1.5.2.2 Algorithm description

Algorithm of the dynamic switching of the channel selection policies, which changes the channel selection policy in accordance with the conditions of the coexistence system operation, is shown in Figure 18.

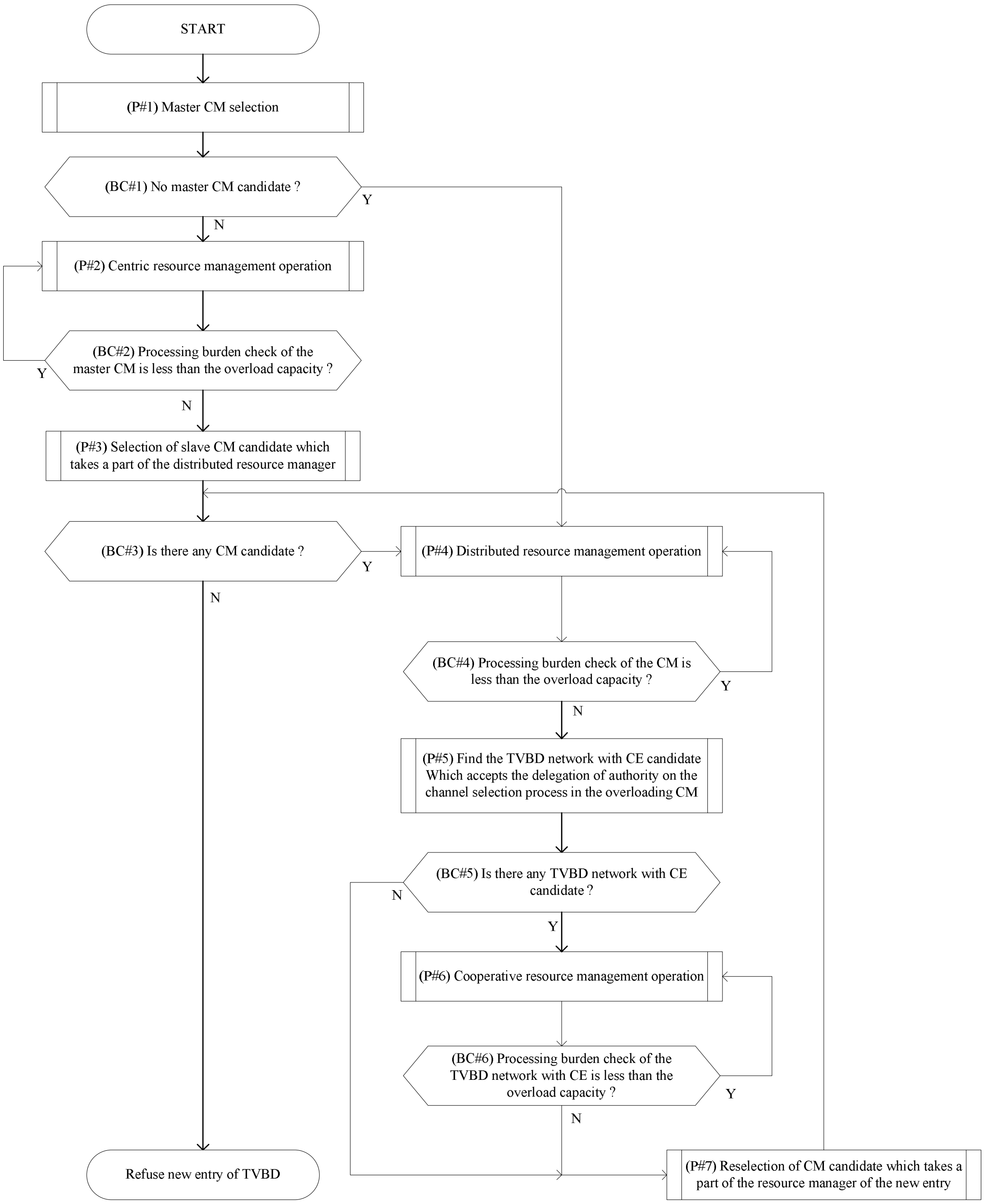

Figure 18 — Channel policy switching procedures

This procedure is composed of seven processes (P#1-P#7), and six branch conditions (BC#1-BC6) as follows.

The seven processes are shown as follows:

(P#1)

— Master CM selection

(P#2)

— Centric channel selection operation via the master CM

(P#3)

— Selection of a slave CM candidate, which takes a part of the distributed resource manager, using the maximum number of controllable TVBD device or network as defined with MaximumNumberOfControlableTVBD

(P#4)

— Distributed channel selection operation by multiple CMs

(P#5)

— Find the TVBD network with CE candidate which accepts the delegation of authority on the channel selection process in the overloading CM, due to the acceptance of change request from management service to information service

(P#6)

— Cooperative channel selection operation, due to the acceptance of change request from management service to information service

(P#7)

— Reselection of a CM candidate which takes a part of the resource manager of the new entry of TVBD, using the maximum number of controllable TVBD device or network as defined with MaximumNumberOfControlableTVBD

The xix branch conditions are shown as follows:

(BC#1)

— This branch condition shall be conducted based on the result of the master CM selection process. If the master CM candidate is found, go to P#4. If not, go to P#2.

(BC#2)

— This branch condition shall be conducted based on the result of the processing burden check of the master CM. If the burden seems to be lower than the overload capacity of the master CM, back to P#2. If not, go to P#3.

(BC#3)

— This branch condition shall be conducted based on the result of the selection of slave CM candidate which takes a part of the distributed resource manager. If the slave CM candidate is founded, go to P#4. If not, refuse new entry of TVBD.

(BC#4)

— This branch condition shall be conducted based on the result of the processing burden check of the target CM. If the burden seems to be lower than the overload capacity of the target CM, back to P#4. If not, go to P#5.

(BC#5)

— This branch condition shall be conducted based on the result of the selection of CE candidate which accepts the delegation of authority on the channel process in the overloading CM, due to the acceptance of the change request from management service to information service. If the CM candidate is founded, go to P#6. If not, go to P#7.

(BC#6)

— This branch condition shall be conducted based on the result of the processing burden check of the target CE. If the burden seems to be lower than the overload capacity of the target CE, back to P#6. If not, go to P#7.

7.2.1.5.3 Algorithm based on output power level control

7.2.1.5.3.1 Introduction

It is very important for a coexistence system to address the aggregated interference problem in the target protection service contour due to the multiple simultaneous transmissions of neighbors. For example, the target protection service will be an incumbent service and a prioritized TVBD network or device (i.e. early comer of each corresponding channel) and so on. Specifically in a case where multiple similar/dissimilar TVBD networks or devices are using same channel in a neighborhood area, a harmful interference may occur in a protection service contour. To solve this problem, coexistence system shall support at least one of the methods as follows:

- Flexible margin based calculation method
  - The output power level of the registered TVBD networks or devices is calculated using the flexible multiple interference margin (*MI*) value in accordance with the number of active TVBD networks or devices in neighborhood area.
- Calculation method of maximized output power level of TVBD networks or devices
  - The output power level of the registered TVBD networks or devices is calculated based on the total aggregated in-block emission level and out-block level of the active TVBD networks or devices in neighborhood area.

First, a few definitions are provided for the terms and concepts used with the algorithm. Those are followed by the algorithm implementation examples.

7.2.1.5.3.1.1 Maximally allowed interference level ($I_{acceptable}$)

Maximally allowed interference level to the protection service receiver could be calculated as follows:

$$I_{acceptable} = P_{rx\_required}\left(f_{BS}\right) \Big/ 10^{\frac{PR(f_{CR}-f_{BS})}{10}} \quad , \tag{1}$$

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

7.2.1.5.3.1.2 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 protection service as shown in **Error! Reference source not found.**, would be.

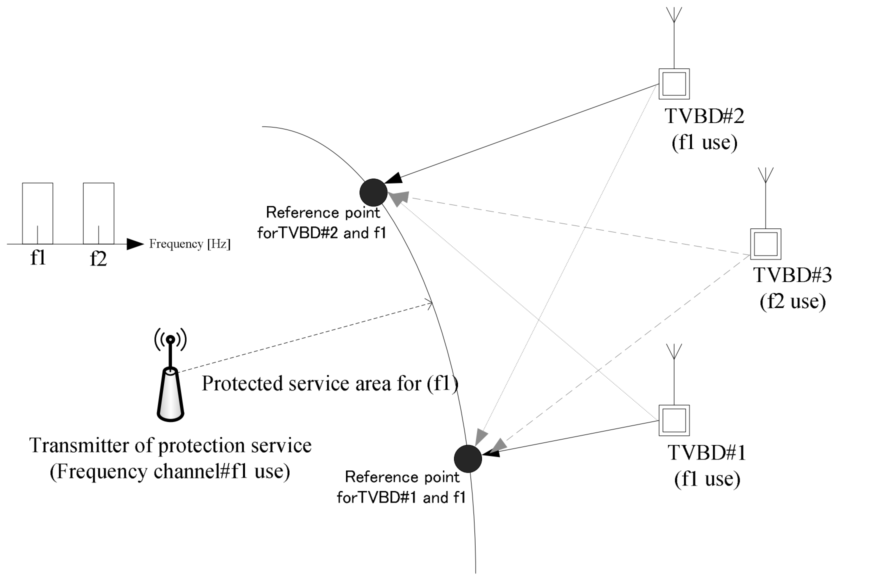

Figure 19 — Selection criterion of the interference-victim reference points for the maximum power allocation for multiple TVBDs

7.2.1.5.3.1.3 Reference point on a potential interfering node

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 protection service contour, 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 as shown in **Error! Reference source not found.**. 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 protection service contour.

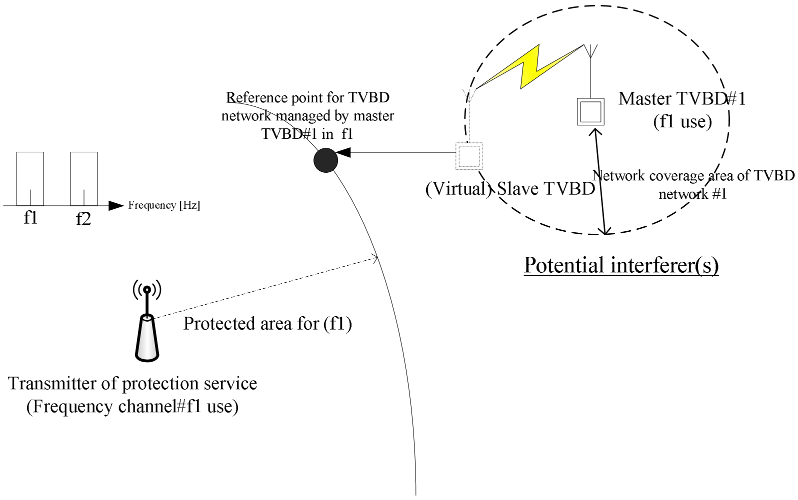

Figure 20 — Example of a reference point on a potential interfering node selection criterion of the interference-victim reference points for the maximum power allocation for multiple TVBDs

7.2.1.5.3.2 Algorithm description

7.2.1.5.3.2.1 Flexible margin based calculation

Flexible margin based calculation way of output power level is explained in this section. The calculation way can be formed as follows:

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

$$P_{tx}\left(f_j,k\right)=I_{acceptable}\left(i,f_j\right)+L_p\left(i,f_j,k\right)-G\left(f_j,k\right)-MI-SM \qquad (1)$$

If the target TVBD uses a different channel with the usage channel(s) of interference-victim receiver in the reference point,

$$P_{tx}\left(f_{jj},kk\right)=I_{acceptable}\left(i,f_j\right)+L_p\left(i,f_{jj},kk\right)-G\left(f_{jj},kk\right)-MI-SM+H\left(f_j,f_{jj},kk\right) \qquad (1')$$

Definition of each parameter is shown in Table 1. *MI* is assumed to be an adjustable value according to number of active TVBD networks or devices.

Table 1— Parameters for output power level control algorithm

Input/Output/EstimatedValues in CM	Parameter	Notes
Input from the other TVBD network or device/TVWS DB to a CM	$I_{acceptable}(i,f_j)$ (dBm)	Maximally allowed interference level to the protection service receiver in interfere-victim reference point # i for the frequency channel # j

Output from a CM to a CDIS/CE/TVBD network or device	$P_{tx}(f_j, k)$ (dBm)	Maximum permitted EIRP of TVBD # k for frequency channel # j. This maximum value may be different from the other TVBD(s) according to its location.
EstimatedValues based on in CM	$L_p(i, f_j, k)$ (dB)	Path loss between TVBD # k and interfere-victim reference point # i for frequency channel # j
EstimatedValues in CM	$P_{tx}(f_{j\,or\,jj}, k\,\text{or}\,kk)$ (dBm)	Maximum permitted EIRP of TVBD #(k or kk) for frequency channel #(j or jj)
EstimatedValues in CM	$L_p(i, f_{j\,or\,jj}, k\,\text{or}\,kk)$ (dB)	Path loss between TVBD #(k or kk) and the interfere-victim reference point # i for frequency channel #(j or jj)
EstimatedValues in CM	$G\left(f_{j\,or\,jj}, k \text{ or } kk\right)$ (dB)	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
EstimatedValues in CM	$H(f_j, f_{jj}, kk)$ (dB)	Total rejection level 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.
EstimatedValues in CM	M_j	Number of TVBD(s) which may use the target frequency channel #(j) simultaneously
EstimatedValues in CM	N_{jj}	Number of TVBD(s) which may use the target frequency channel #(jj) simultaneously
EstimatedValues in CM	O_j	Number of neighbor channel(s) for the target frequency channel # j being considered in calculating aggregated mutual

		interference power level

7.2.1.5.3.2.2 Calculation method of maximized output power level of TVBD

An optimized solution to specify the output power of TVBD networks or devices is explained in this section. If one considers the mutual in-block/out-of-block interference effects among TVBDs, one of the calculation ways could be as follows:

(Step 0)

The parameters for each TVBD which are shown in Table 1are input.

(Step 1)

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

(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:

$$P_{tx}^{'}\left(f_j,k\right)=10\log_{10}\left[10^{\frac{I_{acceptable}\left(i,f_j\right)}{10}}-\sum_{jj=1,\,jj\neq j}^{O_j}\sum_{kk=1}^{N_{jj}}10^{\frac{P_{tx}\left(f_{jj},kk\right)+L_p\left(i,f_{jj},kk\right)-G\left(f_{jj},kk\right)+H\left(f_j,f_{jj},kk\right)}{10}}\right] \quad (2)$$
$$+L_p\left(i,f_j,k\right)-G\left(f_j,k\right).$$

(Step 3)

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

if SM is not considered in the step 1,

$$i^{'}=\arg_i\left(\min\left(\begin{array}{l}10^{\frac{I_{acceptable}\left(i,f_j\right)}{10}}-10^{\frac{P_{tx}^{'}\left(f_j,k\right)-L_p\left(i,f_j,k\right)+G\left(f_j,k\right)}{10}}\\-\sum_{jj=1,\,jj\neq j}^{O_j}\sum_{kk=1}^{N_{jj}}10^{\frac{P_{tx}^{'}\left(f_{jj},kk\right)-L_p\left(i,f_{jj},kk\right)+G\left(f_{jj},kk\right)-H\left(f_j,f_{jj},kk\right)}{10}}\end{array}\right)\right), \quad (3)$$

and if SM is considered in the step 1,

$$i^{'}=\arg_i\left(\min\left(\begin{array}{l}10^{\frac{I_{acceptable}\left(i,f_j\right)}{10}}-10^{\frac{P_{tx}^{'}\left(f_j,k\right)-L_p\left(i,f_j,k\right)+G\left(f_j,k\right)+SM}{10}}\\-\sum_{jj=1,\,jj\neq j}^{O_j}\sum_{kk=1}^{N_{jj}}10^{\frac{P_{tx}^{'}\left(f_{jj},kk\right)-L_p\left(i,f_{jj},kk\right)+G\left(f_{jj},kk\right)-H\left(f_j,f_{jj},kk\right)+SM}{10}}\end{array}\right)\right), \quad (3')$$

(Step 4)

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

if SM is not considered in the step 1,

$$I_{acceptable}\left(i^{'}, f_j\right) \geq 10\log_{10}\left[\begin{array}{l} 10^{\frac{P^{'}_{tx}\left(f_j,k\right)+\Delta_j-L_p\left(i^{'},f_j,k\right)+G\left(f_j,k\right)}{10}} \\ +\sum_{jj=1,\,jj\neq j}^{O_j}\sum_{kk=1}^{N_{jj}}10^{\frac{P^{'}_{tx}\left(f_{jj},kk\right)+\Delta_{jj}-L_p\left(i^{'},f_{jj},kk\right)+G\left(f_{jj},kk\right)-H\left(f_j,f_{jj},kk\right)}{10}}\end{array}\right], \quad (4)$$

and if SM is considered in the step 1,

$$I_{acceptable}\left(i^{'}, f_j\right) \geq 10\log_{10}\left[\begin{array}{l} 10^{\frac{P^{'}_{tx}\left(f_j,k\right)+\Delta_j-L_p\left(i^{'},f_j,k\right)+G\left(f_j,k\right)+SM}{10}} \\ +\sum_{jj=1,\,jj\neq j}^{O_j}\sum_{kk=1}^{N_{jj}}10^{\frac{P^{'}_{tx}\left(f_{jj},kk\right)+\Delta_{jj}-L_p\left(i^{'},f_{jj},kk\right)+G\left(f_{jj},kk\right)-H\left(f_j,f_{jj},kk\right)+SM}{10}}\end{array}\right], \quad (4')$$

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,

$$\Delta \leq I_{acceptable}\left(i^{'}, f_j\right) - 10\log_{10}\left[\begin{array}{l} 10^{\frac{P^{'}_{tx}\left(f_j,k\right)-L_p\left(i^{'},f_j,k\right)+G\left(f_j,k\right)}{10}} \\ +\sum_{jj=1,\,jj\neq j}^{O_j}\sum_{kk=1}^{N_{jj}}10^{\frac{P^{'}_{tx}\left(f_{jj},kk\right)-L_p\left(i^{'},f_{jj},kk\right)+G\left(f_{jj},kk\right)-H\left(f_j,f_{jj},kk\right)}{10}}\end{array}\right], \quad (5)$$

and if SM is considered in the step 1,

$$\Delta \leq I_{acceptable}\left(i^{'}, f_j\right) - 10\log_{10}\left[\begin{array}{l} 10^{\frac{P^{'}_{tx}\left(f_j,k\right)-L_p\left(i^{'},f_j,k\right)+G\left(f_j,k\right)+SM}{10}} \\ +\sum_{jj=1,\,jj\neq j}^{O_j}\sum_{kk=1}^{N_{jj}}10^{\frac{P^{'}_{tx}\left(f_{jj},kk\right)-L_p\left(i^{'},f_{jj},kk\right)+G\left(f_{jj},kk\right)-H\left(f_j,f_{jj},kk\right)+SM}{10}}\end{array}\right] \quad (5')$$

.

(Step 5)

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

$$P^{''}_{tx}\left(f_j, k\right) = P^{'}_{tx}\left(f_j, k\right) + \Delta. \qquad (6)$$

The steps are summarized in Figure 21.

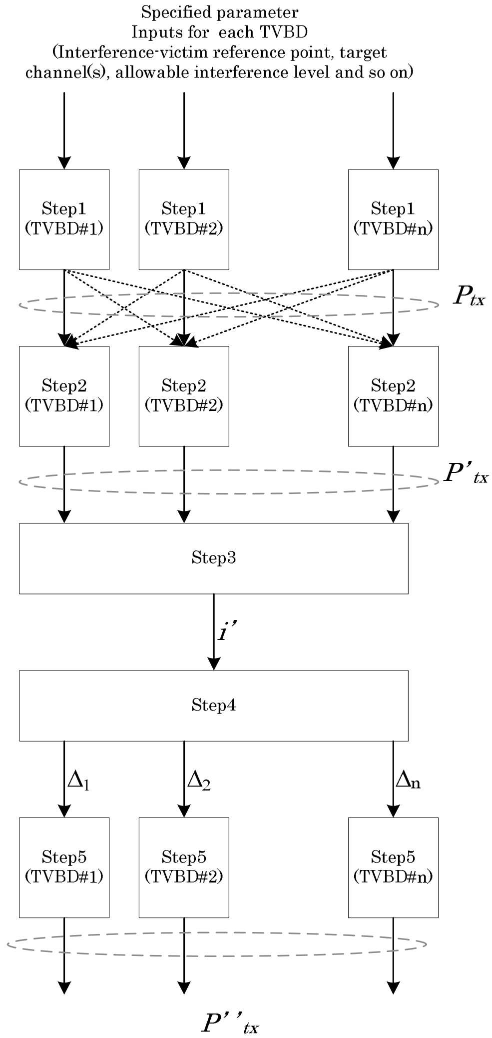

Figure 21 — Procedures to calculate local specific output power of TVBDs

7.2.1.6 Other algorithms of coexistence management

In addition to the coexistence decision making algorithm or algorithms a CM may have other algorithms related to the coexistence management. Examples of such algorithms are described in this clause.

7.2.1.6.1 Channel classification and channel set transition

This algorithm focuses on maintaining channel availability information for TVBD networks or devices operation over TV white space. The CM shall maintain the status of the TV channels which is available for TVBD networks or devices operation at their location according to the policies and rules established by regulation. The CM shall obtain information on the TV channel status with respect to the presence of incumbents and TVBD networks and devices at their location and it shall use this information as input parameters for coexistence decision making such as channel selection, channel management, and etc.

To maintain the status of the channels available for operation, the CM shall be able to collect and fuse information from the following sources:

- TV bands database
- CDIS
- Neighbor CMs
- Measurement report from CE (originated with TVBD networks or devices)

The channel availability information shall be defined during the initialization of CM and it shall be periodically updated during the operation of CM.

In order to start operation of TVBD networks or devices, CM shall select and assign a proper operating channel for TVBD to solve coexistence problems among TVBD networks or devices. A proper operating channel shall be selected from one of allowed channels at locations of TVBD networks or devices.

Status of given allowed channels will be dynamically changed based on incumbent activities, activities of other TVBD networks or devices, relocation of TVBDs, etc. To facilitate coexistence between TVBD networks or devices, the CM shall know status of TV channels at locations TVBD networks or devices such as:

- Which channel is available for TVBD networks or devices
- Which channel is disallowed by regulation, or by the request of incumbents
- Which channel should be protected due to current incumbent activity
- Which channel should be restricted with limitations in order to use by TVBD networks or devices
- Which channel is already being used by other TVBD networks or devices
- Etc.

The channel availability information shall be maintained based on TV channel classification. All TV channels are classified in the following 8 sets:

- Disallowed channels
- Allowed channels
- Available channels
- Protected channels
- Restricted channels
- Unclassified channels
- Operating channels
- Coexistent channels.

The disallowed set is a set of channels disallowed for any TVBD networks or devices by regulation, or by the request of incumbents. It should be provided by TV bands database and will be updated if necessary. For example, in the U.S. TV channel 3, 4, and 37 are disallowed by regulation. Also a TV channel registered at TV bands database by a licensed wireless microphone is disallowed for any TVBD networks or devices.

The allowed set is a set of channels allowed for TVBD networks or devices. It should be provided by TV bands database and will be updated if necessary. All TVBD networks or devices should first obtain a list of the allowed channels before their operating over TV channels.

The available set is a set of free channels available for TVBD networks or devices.

The restricted set is a set of channels restricted to use with limitations due to regulation. It can be used by TVBD networks or devices under limited conditions predefined by regulation. For example, in the U.S. a portable/personal TVBD can use "the first adjacent channel of the incumbent activating channel" with limited transmit power (≤ 40mW EIRP) by FCC regulation.

The protected set is a set of channels to be protected due to incumbent activity. It cannot be used by any TVBD networks or devices.

The unclassified set is a set of channels has not been classified as one of listed above three sets.

The operating set is a set of operating channels being used by each TVBD network or device. If each TVBD network or device has different operating channel, spectrum etiquette, i.e., FDM (frequency division multiplexing), among TVBD networks or devices is achievable.

The coexistent set is a set of channels being shared by two or more TVBD networks or devices as an operating channel. TVBD networks or devices might need a coexistence mechanism to resolve co-channel interference among them.

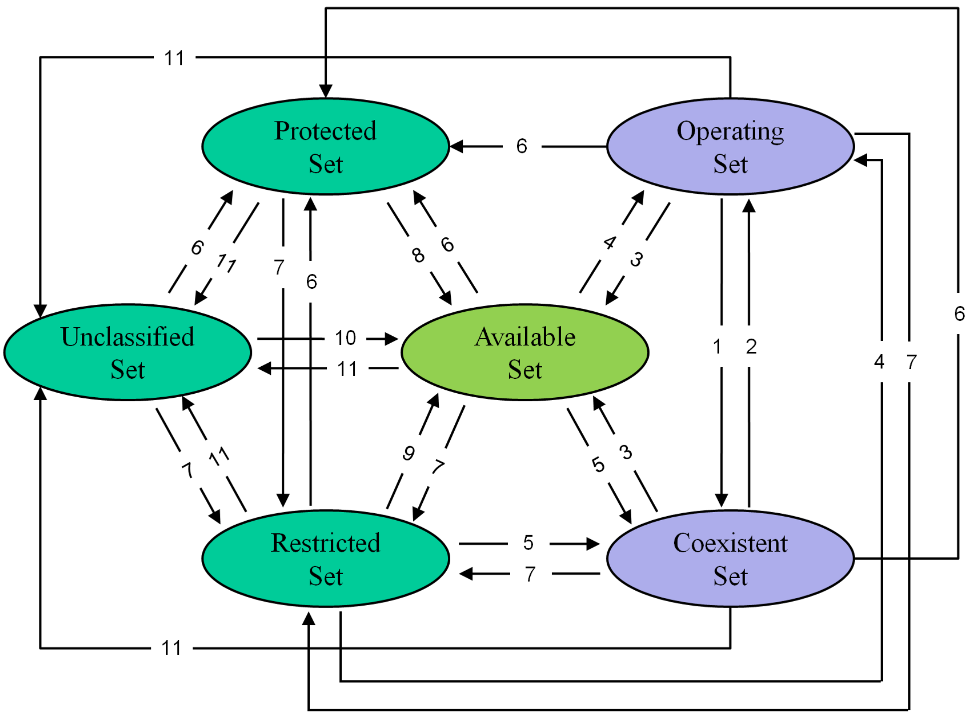

Figure 22 — Channel set transition diagram

The transition diagram for each channel set consists of 6 states and 11 events as depicted in Figure 22. The disallowed and allowed channels are omitted in this transition diagram because those channels are classified by TV bands database and the sum of available, restricted, protected, unclassified, operating, and coexistent channels is equal to the allowed channels. Possible events for each state transition are defined as follows:

— Event 1: If the channel already being used by one TVBD network (or device) is assigned to other TVBD networks (or devices) so that two or more TVBD networks (or devices) use the same channel as an operating channel

- Event 2: If the channel is released by other TVBD networks (or devices) so that the channel is being used by only one TVBD network (or device)
- Event 3: If the channel is released and not be used by any TVBD networks (or devices) due to the completion of its usage
- Event 4: If the channel is assigned to one TVBD network (or device) and not shared by any TVBD networks (or devices)
- Event 5: If the channel is assigned to two or more TVBD networks (or devices) at the same time
- Event 6: If an incumbent activity has been informed on the channel
- Event 7: If the channel temporarily satisfies the condition that requires its usage with limitations due to regulation, e.g., in the U.S. if an incumbent activity has been informed on the channel (N), the first adjacent channel (N±1) can be used by only a portable/personal TVBD with limited transmit power, say 100mW EIRP
- Event 8: If the channel is released by an incumbent due to the completion of its usage
- Event 9: If the channel is exempted from its temporary restriction and free to use without limitation, e.g., in the U.S. if the channel is released by the incumbent on the channel (N) due to the completion of its usage, the first adjacent channel (N±1) can be used by any TVBD networks (or devices)
- Event 10: If the channel is not occupied by an incumbent or any TVBD networks (or devices)
- Event 11: If the channel is not classified or updated within the predefined time expiration

Table 2— Channel set transition matrix

State / Event	Operating	Coexistent	Available	Protected	Restricted	Unclassified
Event 1	Coexistent					
Event 2		Operating				
Event 3	Available	Available				
Event 4			Operating		Operating	
Event 5			Coexistent		Coexistent	
Event 6	Protected	Protected	Protected		Protected	Protected
Event 7	Restricted	Restricted	Restricted	Restricted		Restricted
Event 8				Available		
Event 9					Available	
Event 10						Available
Event 11	Unclassified	Unclassified	Unclassified	Unclassified	Unclassified	

Based on channel classification and channel set transition diagram, the channel set transition matrix is defined as depicted in Table 2. Each row specifies the state transition due to each event. Each column specifies state transition due to the events in each row for a particular current state. A blank cell within the transition matrix implies that either the specific event cannot or should not occur within that state. And if the event does occur, the CM shall ignore it. For example, the protected channel cannot directly transit to operating channel. Therefore, there is no operating channel in the first column (i.e., operating column).

7.2.1.6.2 Un-configuration algorithm

A TVBD performs measurement on disabling mis-located TVBD or its configuration invalid channels and its CE reports measurement results to the CM. When the channel number is indicated in a measurement request message sent from a CM, the detection of disabling mis-located TVBD or its configuration invalid TVBD shall be done on that requested channels. If the measuring TVBD detects any signal from other TVBDs on the requested channels, it assumes that there is channel usage by a disabling mis-located TVBD or its configuration invalid TVBD. When the CM resides in a CMS and has one or more registered CEs residing in a fixed or a mode II TVBD under control, the CM may access to the TVWS DB to obtain available channel lists at the position of registered CEs and choose the channel to request measurement based on the available channel list. When the CM resides in a fixed or a mode II device with one or more registered CEs in a mode I TVBD, it may use the available channel list at the position of a fixed or a mode II device unless the location information of CE is known. When the CM does not give the explicit channel number to the CE of a measuring TVBD, the CE can make use of the available channel list obtained from a CM or a TVBD that can directly access to the TVWS DB. The CE would make a decision on which channel to measure during the requested measurement period base on the available channel list. In the case of CE residing in a fixed or mode II TVBD, it may obtain available channel list from the TVBD it is residing in because all the fixed and mode II TVBD must have an access to TVWS DB. It also can access to the CM to request available channel list at its position. If the CE resides in a mode I TVBD, it can obtain available channel list from a fixed or a mode II device it is associated to. If the CE resides in a sensing only TVBD, it can obtain available channel list by conducting channel sensing through TV bands. In this case, the CE or the TVBD does not have to aware of all the available channel lists all the time; it would be enough for them to have a couple of back-up channels. The CE may request a measuring TVBD to perform measurement on unavailable channels which are allocated to primary users based on the available channel list it obtained. If the measuring TVBD detects any signal from other TVBDs on those unavailable channels for itself, it assumes that there is channel usage by a disabling mis-located TVBD or its configuration invalid TVBD.

7.3 Neighbor discovery

Neighbor discovery is a mechanism with which a CM finds out for the TVBD networks or devices registered to it the potentially interfering TVBDs and any information related to them required for the CM to communicate with other CMs. A CM may perform neighbor discovery for TVBD networks or devices that are registered to it. That is called intra-CM neighbor discovery. A CM shall use the neighbor discovery service that CDISs provide to find at least those neighbor TVBD networks or devices that are registered to other CMs. That is called inter-CM neighbor discovery. A CM may also use a CDIS for both intra-CM and inter-CM neighbor discovery.

From the neighbor discovery the CM has all the potentially interfering TVBDs and the following related information for all the TVBD networks or devices that are registered to it:

1) Interferer identifier

2) Interferer’s CM

3) Interferer’s technology

4) Interference direction

5) Interference levels

7.3.1 Neighbor discovery service

Neighbor discovery service is a coexistence service that CDISs provide to CMs to find out potentially interfering TVBDs regardless of which CM serve those TVBDs. A CDIS shall provide to the CM up to date list of all the potentially interfering TVBDs that are registered to a coexistence system. A CM shall determine whether it wants the CDIS to perform only the inter-CM neighbor discovery or both the inter-CM neighbor discovery and the intra-CM neighbor discovery.

7.3.2 Neighbor discovery algorithms

7.3.2.1 Algorithm based on statistical analysis of the expected interference

7.3.2.1.1 Input parameters from a CE to the interferer discovery

Following information needs to be considered as input for interferer discovery calculations:

- Geo-location of the Mode II or Fixed device
- Environment type
  - Indoor/outdoor, urban/suburban/rural, (office, home, mall, floor number …)
- HAAT (hT and hR)
- Supported frequencies
- Reference bandwidth (BW)
- Receiver characteristics (two alternatives)
  - Minimum SINR for the network to operate (SINRmin) and noise figure (NF)
  - Minimum receiver sensitivity
- Transmitter characteristics
  - Maximum transmission power Ptxmax with antenna properties (see point 7)
  - EIRP
- Antenna directivity D(θ, ϕ)
  - θ is an azimuth angle and ϕ is an elevation angle (implicitly included in later equation) and antenna loss La (Combination of directivity and antenna loss is antenna gain)

7.3.2.1.2 Formulas for path loss evaluation

Propagation model has an essential role when estimating path loss between a transmitter and a receiver under study. Figure 23 illustrates a model to estimate interference between TVBDs of two networks, A and B. The master of network A and network Bare Fixed or Mode II devices who initial the network A and network B, respectively. Locations of these master TVBDs are known and those are the locations of Fixed or Mode II devices that are using the services of a coexistence system. If a mode II devices act under control of a master device (fixed or mode II) and no other devices depend on the operations and existence of such mode II devices, their location information is not necessary and the same process performs as that to Mode I devices.

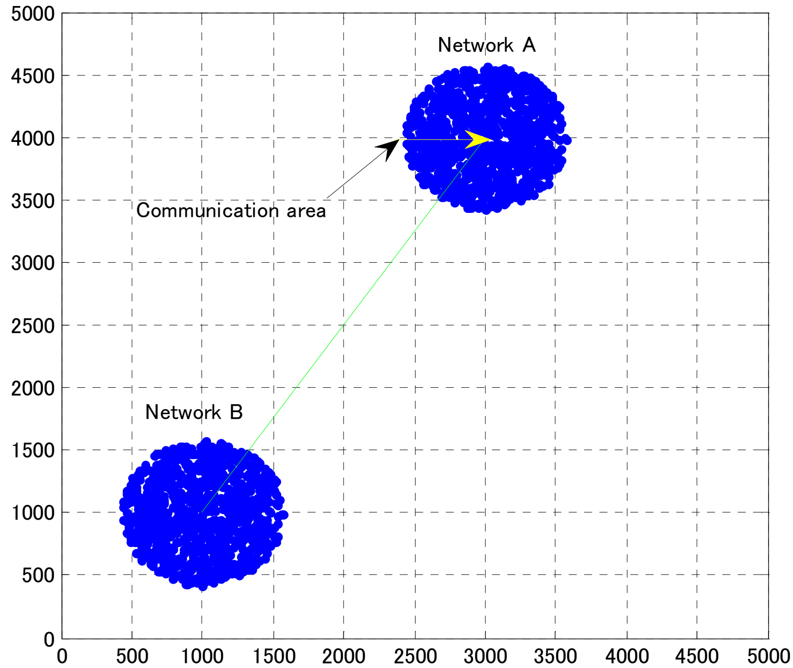

Figure 23 ・An illustration of interference calculation between two TVBDs representing two networks

Locations of Mode I TVBDs are not known but estimated by coexistence system. In the estimation, we assume that Mode I devices are uniformly distributed within the communication area of their master device (fixed or mode II) in network A and network B as shown in Figure 23. The cumulative distribution function (CDF) of potential interference from Network A to Network B is calculated by coexistence system, and vice versa. The interference level which 90% of devices receive interference equal or less than (refer to 90% interference level in the following context) is then taken as the possible interference value between two networks.

Following aspects needs to be taken into account when evaluating whether TVBDs are interferers or not:

- Propagation model (L(r, x))
  - L is attenuation over a certain link between a transmitter and a receiver. The r is the distance between the transmitter and the receiver and x represents all the other parameters that are needed to define the attenuation.
  - The following formula can be used to evaluate the attenuation between a transmitter and a receiver
    - $L(\ldots) = 10\log(4\pi r/\lambda)\alpha - 20\log(hT*hR)$,
    - in which λ is a wavelength and α is an environment related attenuation exponential (free space = 2, otherwise higher). Operating environment and maximum transmission power should be used to define the value of the attenuation exponential.
- Distribution model

- Both transmit and receive slave devices (Mode I or Slave Mode II) are assumed uniformly distributed around its master device (Fixed or Mode II) within the communication area.
- The location of devices can be randomly generated in polar coordinates, with radius r and angle φ following the distribution as.
  - pdf(φ)=1/2π
  - pdf(r)=(2/R^2)r
  - in which R is a radius of communication area.
- Communication area of a network
  - Communication area is the coverage area that the master devices (Mode II or Fixed devices), provides to their networks.
- Interference area of a network
  - Interference area is the area within which the signal level from any device of the network within the communication area of the network is equal to or larger than N+Im
    - Im is interference margin that defines how much interference a device tolerates above the noise level from another device at a receiver input before the other device is deemed as an interferer.
    - If the specification defines a commonly used Im value for all the networks and users, one can determine the interference area for each network separately without knowledge about the other network and its devices parameters. If each network/device can determine their own interference margin, one needs to determine interference areas for network pairs rather than for individual networks.
- What is the 90% potential interference level from a device in the network A to a device in the network B and vice versa?
  - This may be estimated by considering two randomly located slave devices of two networks, and finds out the interference level that 90% of devices receive interference equal or less than.
  - Prx = Ptxmax + Gt (θ_B) + Gr (θ_A) – L(r, x),
  - where Prx is receive power of a device in either network A or network B, Ptxmax is the maximum transmit power of a device from either network B or network A, respectively.. The L(r, x) represents the path loss between the two devices of two networks, where the distance between two devices of two networks r is calculated based on the randomly generated locations within communication area of two networks.
  - To calculate CDF of potential interference from a device in network A to a device in network B, or vice versa, at least 100 realizations of transmitter and receiver location shall be generated.
  - Figure 24 illustrates an example CDF of potential interference from a device in Network A to a device in network B, where 90% interference level is -93.4977dB. This value is taken as a potential interference between two networks.

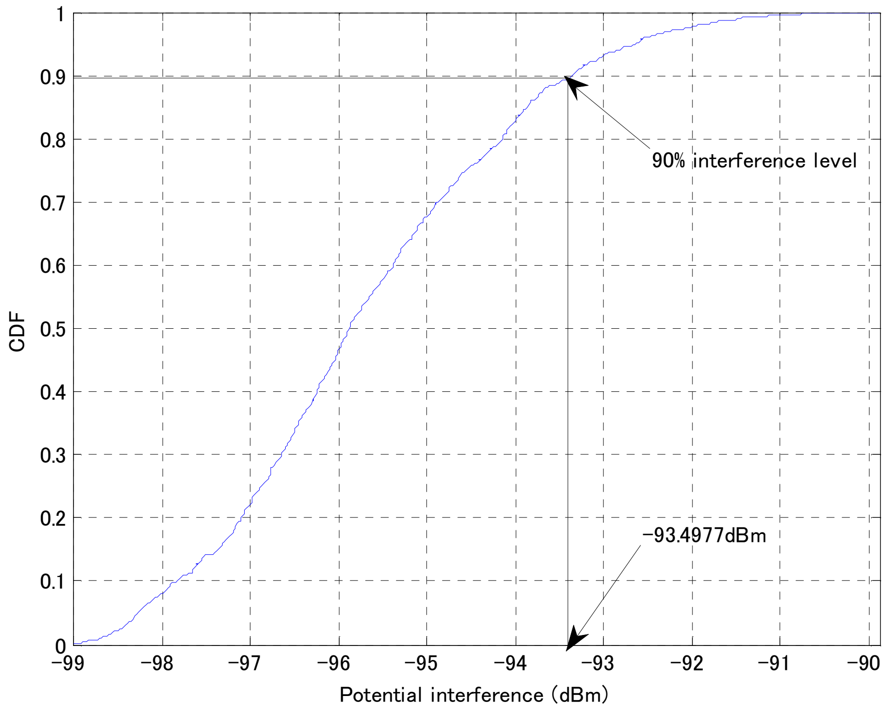

Figure 24 ・An illustration of CDF of potential interference between two TVBDs in two networks

With these parameters the CDIS estimates whether a TVBD and potential Mode I devices it may serve can interfere with TVBDs in another network operated by another TVBD connected to a coexistence system. Additionally, the CDIS estimates the interference type (mutual, source, victim) in case there is potential interference between the TVBDs.

Here we haven't considered the frequency that is used in the calculations. We shouldn't leave this entirely up to the implementations since if the range of the supported frequencies is large compared to the center frequency, the outcome of the analysis may vary a lot. We wonder if the specification should give clear rules in which frequencies of the commonly supported frequencies the analysis should be done.

7.3.2.1.3 Interferer discovery procedure

A CDIS performs interferer discovery calculations for each TVBD that has been registered to it. Calculations are done in TVBD pairs and if the TVBDs under consideration serve Mode I TVBDs or Slave Mode II device, the CDIS needs to evaluate 90% interference level of those devices and use those estimates as the interference level between any two Mode I or slave Mode II devices in two networks. Only those TVBDs that have overlap in operating frequency capabilities are taken into account in the evaluation. Their current operating frequency is not considered in the calculations but the TVBDs are considered interferers only if they have potential to operate in a same frequency and interfere.

The procedure is roughly as follows for each TVBD pair:

— Determine the locations of master device (Mode II or Fixed device), and generate more than 100 realizations of Mode I devices around each of masters.

- Calculate receiver power for each realization based on the propagation model.
- Evaluate the 90% potential interference between two networks for both directions
  - Prx_ax to represent 90% interference experienced by a device in the network A from a device in the network B
  - Prx_bx to represent 90% interference experienced by a device in the network B from a device in the network A
- Decision of interference status between the two networks and devices in them
  - Prx_ax and Prx_bx > Im+N (N=No+NF): Both are interferers to each other (mutual)
  - Prx_ax and Prx_bx < Im+N (N=No+NF): No interference
  - Prx_ax > Im+N and Prx_bx < Im+N (N=No+NF): Network A device is an interference victim
  - Prx_ax < Im+N and Prx_bx > Im+N (N=No+NF): Network A device is an interference source
  - If the communication areas overlap, following short cuts in the decision making can be done
    - If the both networks are serving Mode I devices with unknown location, the networks' devices are deemed interferers.
    - If only one of the networks is service Mode I devices with unknown location, the communication area of that network has to contain a location of a Mode II or Fixed device of the other network and the communication area of the Mode II of Fixed device of the other network has to overlap with the communication area of the first network

Prx above would be actually 10*lg (10^(Prx,calculated/10)+10^(N/10)) when measured in e.g. RSSI.

7.3.2.1.4 The outcome of the discovery

The outcome of the interferer discovery is as follows:

- Interference direction
  - Mutual, Source, Victim
- Prx_ax and Prx_bx

7.3.3 Other algorithms related to neighbor discovery

7.4 Measurements by TVBD networks or devices

An IEEE 802.19.1 compliant coexistence system has means to obtain measurement results from registered TVBD networks or devices. Each CM shall be able to request the registered TVBD networks or devices to perform measurements and provide measurement reports. A CM may use the measurement reports from TVBD networks or devices that are registered to it to support coexistence decision making and neighbor discovery.

Registered TVBD networks or devices may also provide measurement reports spontaneously. The following sub-clauses define the measurement types specified for TVBD networks or devices that are registered to a coexistence system.

7.4.1 SINR measurement

TBD

7.4.2 BER measurement

TBD

7.4.3 Sensing level measurement

TBD

7.4.4 Primary detection measurement

TBD

7.4.5 TVBD detection measurement

TBD

7.4.6 Channel load measurement

TBD