IEEE 802.19.1a
Wireless Coexistence

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| CID13 resolution: Text proposal on the frequency utilization pattern based coexistence management |
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Abstract

This contribution provides comment resolution on CID13. This text proposal includes new algorithm of coexistence management based on 802.19.1 standard and approved text, which introduces new parameter *frequency utilization pattern*.



=================== Text starts here ==========================

1. Entity operation
	1. CDIS operation
		* 1. **Obtaining coexistence set information**

*Revise the table of* ***listOfOperatingFrequencies*** *as follows*

|  |  |  |
| --- | --- | --- |
| *Parameter* | *Data type* | *Value* |
| ***freqRankIndex*** | ***INTEGER*** | Shall be set to indicate priority index of *frequencyRange* in this table if available. |
| ***frequencyRange*** | ***FrequencyRange*** | Shall be set to indicate operating frequency range. ~~Operating frequency range~~ |
| ***txPower*** | ***REAL*** | Shall be set to indicate the transmission power of the GCO in ***frequencyRange***. |
| ***resolutionBandwidth*** | ***REAL*** | Shall be set to indicate the resolution bandwidth of available frequency where GCO is operating, if applicable.  |
| ***typeOfOperatingFrequency*** | ***TypeOfFrequency*** | Shall be set to indicate the frequency type if the regulatory specifies. |
| ***occupancy*** | ***REAL*** | Optionally present. If present, this parameter shall be set to indicate occupancy of the GCO frequency range. |
| ***energyDetectionInfo*** | ***EnergyDetectionInfo*** | Optionally present. If present, this parameter shall be set to indicate energy detection information. |
| ***modulationParameters*** | ***ModulationParameters*** | Shall be set to indicate modulation parameters. |
| ***sicDemodulationProcedure*** | ***SICDemodulationProcedure*** | Optionally present. If present, this parameter shall be set to indicate SIC demodulation procedures to be configured as shown in 7.2.2.13. |
| ***coChGCOLimit*** | ***CoChGCOLimit*** | Limit on the maximum number of co-channel GCOs that shall operate simultaneously within a given region and frequency |
| ***freqUtilizationPattern*** | ***FreqUtilizationPattern*** | May be set to indicate the frequency utilization pattern. |

The following table specifies the elements of ***FreqUtilizationPattern***.

|  |  |  |
| --- | --- | --- |
| *Parameter* | *Data type* | *Value* |
| ***frequencyRange*** | ***FrequencyRange*** | Shall be set to indicate operating frequency range to be estimated. |
| ***parameterType*** | ***ParameterType*** | Shall be set to indicate the parameter type of frequency utilization pattern |
| ***timeThresholdForSuccessfulUsage*** | ***REAL*** | Shall be set to indicate the threshold of time duration for successful usage |
| ***windowStartTime*** | ***GeneralizedTime***  | Shall be set to indicate the start time of window |
| ***windowStopTime*** | ***GeneralizedTime*** | Shall be set to indicate the stop time of window |
| ***coverageArea*** | ***CoverageArea*** | Shall be set to indicate the coverage area associated with frequency utilization pattern |
| ***parameterValue*** | ***INTEGER*** | Shall be set to indicate the value of frequency utilization pattern  |

* 1. CM operation
		1. Profile 3
			1. **~~WSO~~GCO registration**

*Revise the table of* ***listOfOperatingFrequencies*** *as follows*

|  |  |  |
| --- | --- | --- |
| *Parameter* | *Data type* | *Value* |
| ***freqRankIndex*** | ***INTEGER*** | Shall be set to indicate priority index of frequencyRange in this table if available. |
| ***frequencyRange*** | ***FrequencyRange*** | Shall be set to indicate operating frequency range. ~~Operating frequency range~~ |
| ***txPower*** | ***REAL*** | Shall be set to indicate the transmission power of the GCO in ***frequencyRange***. |
| ***resolutionBandwidth*** | ***REAL*** | Shall be set to indicate the resolution bandwidth of available frequency where GCO is operating, if applicable.  |
| ***typeOfOperatingFrequency*** | ***TypeOfFrequency*** | Shall be set to indicate the frequency type if the regulatory specifies. |
| ***occupancy*** | ***REAL*** | Optionally present. If present, this parameter shall be set to indicate occupancy of the ~~WSO~~GCO frequency range. |
| ***energyDetectionInfo*** | ***EnergyDetectionInfo*** | Optionally present. If present, this parameter shall be set to indicate energy detection information. |
| ***modulationParameters*** | ***ModulationParameters*** | Shall be set to indicate modulation parameters. |
| ***sicDemodulationProcedure*** | ***SICDemodulationProcedure*** | Optionally present. If present, this parameter shall be set to indicate SIC demodulation procedures to be configured as shown in 7.2.2.13. |
| ***coChGCOLimit*** | ***CoChGCOLimit*** | Limit on the maximum number of co-channel GCOs that shall operate simultaneously within a given region and frequency |
| ***freqUtilizationPattern*** | ***FreqUtilizationPattern*** | Optionally present. If present, this parameter shall be set to indicate the parameters for estimation of frequency utilization pattern. |

The following table specifies the elements of ***FreqUtilizationPattern***.

|  |  |  |
| --- | --- | --- |
| *Parameter* | *Data type* | *Value* |
| ***frequencyRange*** | ***FrequencyRange*** | Shall be set to indicate operating frequency range to be estimated. |
| ***parameterType*** | ***ParameterType*** | Shall be set to indicate the parameter type of frequency utilization pattern  |
| ***timeThresholdForSuccessfulUsage*** | ***REAL*** | Shall be set to indicate the threshold of time duration for successful usage |
| ***windowStartTime*** | ***GeneralizedTime*** | Shall be set to indicate the start time of window |
| ***windowStopTime*** | ***GeneralizedTime*** | Shall be set to indicate the stop time of window |
| ***coverageArea*** | ***CoverageArea*** | Shall be set to indicate the coverage area associated with the frequency utilization pattern |
| ***parameterValue*** | ***INTEGER*** | Shall be set to indicate the value of frequency utilization pattern |

* 1. CE operation
		1. Profile 3
			1. ~~WSO~~GCO reconfiguration

*Revise the table of* ***listOfOperatingFrequencies*** *as follows*

|  |  |  |
| --- | --- | --- |
| *Parameter* | *Data type* | *Value* |
| ***freqRankIndex*** | ***INTEGER*** | Shall be set to indicate priority index of ***frequencyRange*** in this table if available. |
| ***frequencyRange*** | ***FrequencyRange*** | Shall be set to indicate operating frequency range. ~~Operating frequency range~~ |
| ***txPower*** | ***REAL*** | Shall be set to indicate the transmission power of the GCO in ***frequencyRange***. |
| ***resolutionBandwidth*** | ***REAL*** | Shall be set to indicate the resolution bandwidth of available frequency where GCO is operating, if applicable.  |
| ***typeOfOperatingFrequency*** | ***TypeOfFrequency*** | Shall be set to indicate the frequency type if the regulatory specifies. |
| ***occupancy*** | ***REAL*** | Optionally present. If present, this parameter shall be set to indicate occupancy of the ~~WSO~~GCO frequency range. |
| ***energyDetectionInfo*** | ***EnergyDetectionInfo*** | Optionally present. If present, this parameter shall be set to indicate energy detection information. |
| ***modulationParameters*** | ***ModulationParameters*** | Shall be set to indicate modulation parameters. |
| ***sicDemodulationProcedure*** | ***SICDemodulationProcedure*** | Optionally present. If present, this parameter shall be set to indicate SIC demodulation procedures to be configured as shown in 7.2.2.13. |
| ***intLeakageFactor*** | ***REAL*** | Optionally present. If present, this parameter shall be set to indicate interference leakage weighting factor. The details are shown in 7.2.2.12. |
| ***listOfSpecUsageInfoOfRefPoints*** | ***ListOfSpecUsageInfo*** | Optionally present. If present, this parameter shall be set to indicate the list of reference point locations. The details are shown in 7.2.2.14. |
| ***listOfSpecUsageInfoOfNeightborGCOs*** | ***ListOfSpecUsageInfo*** | Optionally present. If present, this parameter shall be set to indicate the list of co-channel neighbor GCOs location. The details are shown in 7.2.2.15. |
| ***coChGCOLimit*** | ***CoChGCOLimit*** | Limit on the maximum number of co-channel GCOs that shall operate simultaneously within a given region and frequency |
| ***freqUtilizationPattern*** | ***FreqUtilizationPattern*** | Optionally present. If present, this parameter shall be set to indicate the parameters for estimation of frequency utilization pattern.  |

The following table specifies the elements of ***FreqUtilizationPattern***.

|  |  |  |
| --- | --- | --- |
| *Parameter* | *Data type* | *Value* |
| ***frequencyRange*** | ***FrequencyRange*** | Shall be set to indicate operating frequency range to be estimated. |
| ***parameterType*** | ***ParameterType*** | Shall be set to indicate the parameter type of frequency utilization pattern  |
| ***timeThresholdForSuccessfulUsage*** | ***REAL*** | Shall be set to indicate the threshold of time duration for successful usage |
| ***windowStartTime*** | ***GeneralizedTime*** | Shall be set to indicate the start time of window |
| ***windowStopTime*** | ***GeneralizedTime*** | Shall be set to indicate the stop time of window |
| ***coverageArea*** | ***CoverageArea*** | Shall be set to indicate the coverage area associated with the frequency utilization pattern |
| ***parameterValue*** | ***INTEGER*** | Shall be set to indicate the value of frequency utilization pattern |

*Revise the table of* ***ReconfigurationResponse*** payload elements for one GCO *as follows*

|  |  |  |
| --- | --- | --- |
| *Parameter* | *Data type* | *Value* |
| ***gcoID*** | ***OCTET STRING*** | GCO ID |
| ***status*** | ***Status*** | status |
| ***listOfAvailableFrequencies*** | ***ListOfAvailableFrequencies*** | Shall be set to indicate the list of available frequency at the GCO’s location as per ***specRequestModification*** is included in the reconfiguration request. |
| ***freqUtilizationPattern*** | ***FreqUtilizationPattern*** | Shall be set to indicate the parameters for estimation results of frequency utilization pattern if the reconfiguration request included the estimation parameters of frequency utilization pattern. |

7 Coexistence mechanisms and algorithms

* 1. Coexistence algorithms
		1.
		2. Coexistence decision algorithms

***Insert the following text***

7.2.4.x Algorithm for coexistence service based on frequency utilization pattern

7.2.4.x.1 Introduction

This algorithm presents a coexistence service scheme that ranks frequencies based on frequency utilization pattern of GCOs. The frequency utilization pattern captures the behavioral pattern on the frequency usage of GCOs. The following subclauses describe the definition of the frequency utilization pattern, followed by estimation and utilization of such information to do resource allocation. At the last subclause, procedure of associated resource allocation algorithm is introduced.

7.2.4.x.2 Frequency utilization pattern

The parameter *frequency utilization pattern* is defined as a distribution of frequency usage event within a fixed interval of time and/or space. The frequency usage events can be classified into successful usage and failed usage. Successful usage of a frequency for a certain GCO is defined as that the desired QoS (e.g. expected packet error rate) is guaranteed and the communication lasts over a predefined time interval and/or in a given area. Otherwise, it is deemed as a failed usage.

Figure aa shows an example use case where frequency utilization pattern should be considered in coexistence management. In the use case GCO1~GCO4 distribute stably around an area A. There are two available frequencies F1 and F2, where F1 is used by GCO1, GCO3 and GCO4, while F2 is used by GCO2. Now a new entrant GCOa appears (or moves) into target area A. Before introducing *frequency utilization pattern*, only operational frequency sequence {F1, F2} are indicated to GCOa. Then it is probably that GCOa selects F1 to use firstly and thus suffering from lower spectrum efficiency before switching to F2. After introducing *frequency utilization pattern*, it helps to rank the operational frequencies in decreasing order of utilization efficiency as (F2, F1). When GCOa receives such ordered sequence, it can select the F2 to use from the beginning and thus achieving high spectrum efficiency.

 

Figure aa Example use case of frequency utilization pattern

The parameter *frequency utilization pattern* can be expressed in a variety of way. For instance, denote the event of frequency usage, successful usage and failed usage by $U$, $S$ and $F$, respectively. Define random variables as the number of frequency usage, successful usage and failed usage event, denoted by $N\_{U}$, $N\_{S}$ and $N\_{F}$, respectively. Then, the distribution can be expressed, for example, by mean or standard deviation of $N\_{U}$, $N\_{S}$ or $N\_{F}$ per unit time and/or per unit space.

An example distribution of frequency usage event on *F*1 for GCOis illustrated in Figure bb. Estimation window representing the time interval for the distribution, is determined by a start time of $T\_{windowStart}$ and a stop time of $T\_{windowStop}$. A threshold of time duration for successful usage on *F*1 is denoted by $T\_{th}^{1}$. Three frequency usage events on *F*1 distribute within the window, with time duration of $TD\_{1}^{1}$, $TD\_{2}^{1}$ and $TD\_{3}^{1}$, respectively. Compared with the threshold $T\_{th}^{1}$, $TD\_{1}^{1}$ and $TD\_{3}^{1}$ are successful usage, and $TD\_{2}^{1}$ is a failed one. Then, $N\_{U}=3$, $N\_{S}=2$, and $N\_{F}=1$ are obtained for the estimation window. And the number of every event per unit time can be obtained through dividing $N\_{U}$, $N\_{S}$ or $N\_{F}$ by the duration of estimation window, i.e. $T\_{windowStop}-T\_{windowsart}$.

 

Figure bb Example distribution of frequency usage event

## 7.2.4.x.3 Frequency ranking methodology based on frequency utilization pattern

Frequencies to be utilized by a new entrant GCO can be ranked based on the frequency utilization pattern in the target area where the new entrant GCO operates. In the frequency ranking process in this algorithm, high efficiently utilized frequency is ranked at the top, where the interference constraints among GCOs are also guaranteed.

After receiving the frequency utilization information for the target area, CM can initiate the frequency ranking based on frequency utilization information with the above ranking process. The frequency ranking process includes the following steps:

1. Modeling the GCOs by weighted interference graph based on prospective interference level of GCOs

2. Sorting the frequencies and GCOs in the weighted interference graph based on the frequency utilization pattern

3. Abstracting the frequency ranking result.

For step 1, prospective interference level of GCOs is calculated, and then weighted interference graph is derived by the calculated prospective interference level. One example of weighted interference graph *G* is shown in Figure cc, where Figure cc(a) shows the scenario of GCOs distribution and Figure cc(b) shows the generated graph for the scenario. In the graph, each vertex represents a GCO. The weight on each arc represents the prospective interference, which exceeds a predefined threshold, denoted by $I\_{tail\rightarrow head}$. The operational frequencies of each GCO are treated as weight for corresponding vertex. Especially, frequency utilization pattern information is in connection with the associated operational frequency. Based on modeling the system with weighted interference graph, graph theory can be utilized to solve the resource allocation among the involved GCOs.

 

Figure cc Example of weighted interference graph

For step 2, the GCOs in this weighted interference graph *G* are sorted by a greedy algorithm. The greedy algorithm sorts the frequencies and GCOs in some ordered sequence. Then estimate each frequency along the frequency sequence. For each frequency, estimate along the GCO sequence to see if each GCO can be added to a vertex set, which can use the identical operational frequency for all element vertices and can satisfy interference constraints among the elements. In sorting the frequencies and GCOs, the following rules are adopted.

(a) The high-efficiently utilized frequency shall be treated as higher rank than the other frequencies;

(b) The GCO utilizing frequency high-efficiently shall be treated as higher rank than the other GCOs.

In these rules, the utilization efficiency is represented by the ratio of the *number of successful usage per time unit* to the *number of frequency usage per time unit*. The higher the value of the utilization efficiency, the more efficiently the frequency is used. For example, in Figure cc(b), the frequencies are sorted as (F2, F1). For F2, the GCOs are sorted as (Va, Vc). For F1, the GCOs are sorted as (Vb, Va, Vc). Then, for F2, estimate each vertex to generate a set of {Va, Vc}. For F1, estimate each vertex to generate a vertex of {Vb, Va}. The result in this process is illustrated in Figure dd(a), where each row includes the vertices using an identical frequency; the rows are listed based on the used frequency in decreasing order of utilization efficiency from top to bottom; and in each row the vertices are sorted in decreasing order of utilization efficiency on the used frequency from left to right.



Figure dd Example frequency ranking result

During the sorting process, each GCO is sequentially assigned to different vertex set associated with different allocated frequency. Then, for step 3, a ranking result (***freqRankIndex***) within operational frequency list for each GCO is abstracted accordingly. For example, in Figure cc(b), the GCOa has been assigned to the vertex set in the sequence associated with (F2, F1). Then, as illustrated in Figure dd(b), the ordered frequency sequence (F2, F1) is allocated to GCOa. In the same way, (F1) is allocated to GCOb and (F2) is allocated to GCOc.

7.2.4.x.4 Algorithm description

The flowchart of the algorithm is depicted in Figure ee. The processes are as follows.

* (P#1):

P#1 is the procedure operated at the CDIS where the CDIS recieves the information, including the updated frequency utilizaiton pattern of GCO via CM through the GCO registration procedure in 5.2.2.1 or the GCO reconfiguration procedure in 5.2.10.1.

* (P#2):

In P#2, CM obtains the frequency utilization pattern and the information required for calculating prospective interference levelfor each target GCO. The information shall be obtained through the GCO Registration Procedure in 5.2.2.1. When there are multiple CMs, the information shall be obtained through the Obtaining Operating Frequency Information procedure in 5.2.18 or Obtaining Operating Frequency Information procedure over Coordination Enabler in 5.2.19.

* (P#3):

 In P#3, CM calculates the prospective interference level and uses the calculation result as well as frequency utilization pattern to rank the list of frequencies to be used by the target GCO.

* (P#4):

In P#4, CM uses the GCO Reconfigure procedure in 5.2.10.1 to send the ordered sequence of frequencies to the target GCO, or uses the Sending reconfiguration request in 6.3.4.11 from CM to another CM to send such information to another CM. New frequency utilization pattern request (***freqUtilizationPattern***) could be involved in the reconfiguration request. The request comprises investigated frequency range (***frequencyRange***), parameter type (***parameterType***) to be estimated, threshold of time duration for successful usage (***timeThresholdForSuccessfulUsage***), related time window determined by start time (***windowStartTime***) and stop time (***windowStopTime***), related coverage area (***coverageArea***), and parameter value field (***parameterValue***) to store initial or historical value of the parameter as a reference.

* (P#5):

In P#5, CE sends reconfiguration request to GCO and reports the GCO’s reconfiguration result as well as updated frequency utilization pattern to CDIS via CM. The newly result of frequency utilization pattern has been stored in the parameter value field (***parameterValue***) to generate a frequency utilization pattern response (***freqUtilizationPattern***).



Figure ee Flowchart of frequency utilization pattern based coexistence management

## A.2 Data types for IEEE 802.19.1a

--List of operating frequencies

ListOfOperatingFrequencies ::= SEQUENCE OF SEQUENCE{

 --Priority index of *frequencyRange*

 freqRankIndex INTEGER OPTIONAL,

--Frequency range

 frequencyRange FrequencyRange OPTIONAL,

 --Transmission power [dBm]

 txPower REAL OPTIONAL,

 --Resolution bandwidth [Hz]

 resolutionBandwidth REAL OPTIONAL,

 --Type of operating frequency

 typeOfOperatingFrequency TypeOfFrequency OPTIONAL,

 --Occupancy if known [fractional value between 0 and 1]

 occupancy REAL OPTIONAL,

 --Energy detection information

 energyDetectionInfo EnergyDetectionInfo OPTIONAL,

 --Modulation parameters

 modulationParameters ModulationParameters OPTIONAL,

 --Demodulation procedure

 sicDemodulationProcedure SICDemodulationProcedure OPTIONAL,

 --Interference leakage weighting factor

intLeakageFactor REAL OPTIONAL,

 --List of reference point locations.

listOfSpecUsageInfoOfRefPoints ListOfSpecUsageInfo OPTIONAL,

--List of co-channel neighbor GCOs location

listOfSpecUsageInfoOfNeightborGCOs ListOfSpecUsageInfo OPTIONAL,

--Co-channel GCO limit

coChGCOLimit CoChGCOLimit OPTIONAL,

--Frequency utilization pattern parameter

freqUtilizationPattern FreqUtilizationPattern OPTIONAL

...

}

--Frequency utilization pattern

FreqUtilizationPattern ::= SEQUENCE {

 -- Range of investigated frequency

 frequencyRange FrequencyRange OPTIONAL,

 -- Parameter type of frequency utilization pattern

parameterType ParameterType OPTIONAL,

 -- Threshold of time duration for successful frequency usage

 timeThresholdForSuccessfulUsage REAL OPTIONAL,

-- Window start time

 windowStartTime GeneralizedTime OPTIONAL,

-- Window stop time

 windowStopTime GeneralizedTime OPTIONAL,

-- Coverage area

 coverageArea CoverageArea OPTIONAL,

-- Frequency utilization pattern value

 parameterValue INTEGER OPTIONAL

}

--Parameter type of frequency utilization pattern

ParameterType ::= ENUMERATED{

-- Number of frequency usage per time unit

numberFrequencyUsagePerTimeUnit,

-- Number of successful usage per time unit

numberSuccessfulUsagePerTimeUnit,

-- Number of failed usage per time unit

numberFailedUsagePerTimeUnit,

-- Number of frequency usage per time unit and per area unit

numberFrequencyUsagePerTimeUnitPerAreaUnit,

-- Number of successful usage per time unit and per area unit

numberSuccessfulUsagePerTimeUnitPerAreaUnit,

-- Number of failed usage per time unit and per area unit

numberFailedUsagePerTimeUnitPerAreaUnit

}