IEEE P802.19
Wireless Coexistence

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Abstract

This document is a submission to IEEE 802.19 TG1 proposing an update to clause 4.

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# Proposed update

*It is proposed to substitute the current clauses 4 and 5 by the text below.*

1. System description
	1. System architecture

The coexistence system has three logical entities and five logical interfaces, as shown in Figure 1. Each logical entity is defined by its functional roles and interfaces with other logical entities. System architecture is used to describe functional components of the coexistence system. The architectural descriptions are not intended to represent any specific physical implementation of the coexistence system.



Figure 1. System architecture.

The Coexistence Discovery and Information Server (CDIS) provides coexistence discovery service to the Coexistence Managers (CM). Within this service the CDIS informs the CMs about potential neighbors of the WSOs served by these CMs. Also, the CDIS supports the discovery of CMs by other CMs in order to open interfaces between them. In order to provide the coexistence discovery service, the CDIS obtains all necessary information and executes a coexistence discovery algorithm.

The CM provides either information or management service to the WSOs it serves. Within the information service the CM provides the WSO information about its potential neighbors including their operating frequencies, potential interference levels etc. Within the management service the CM provides the WSO reconfiguration requests that create such configuration of this WSO that its operation is improved according to some criteria. In order to provide these information and management coexistence services, the CM obtains all necessary information and executes a coexistence decision algorithm.

The Coexistence Enabler (CE) provides an interface between different types of WSOs and the coexistence system in a unified format.

Interface B1 between a CE and a CM, interface B2 between a CM and a CDIS, and interface B3 between two CMs are specified in this standard.

Interface A between a CE and its WSO is defined in a generic format and its implementation depends on the WSO type.

Interface C between a CM and a TVWS database is not defined in this standard and is implementation dependent. One of the implementation examples of the interface C is PAWS specification (footnote with reference is needed).

* 1. Reference model

The coexistence system reference model has two service access points: the coexistence transport SAP (COEX\_TR\_SAP) and the coexistence media SAP (COEX\_MEDIA\_SAP).

The COEX\_TR\_SAP provides means for a CE, a CM, and a CDIS to communicate with each other and with external entities by using transport services provided by underlying layers. The underlying layers could be application layer, transport layer, network layer, and link layer.

Example reference model of a CE and a CM describing example of using COEX\_TR\_SAP for interface B1 is shown in Figure 2. Information required for coexistence and reconfiguration commands that are exchanged between a CE and a CM over the interface B1 are forwarded to transport layer, for example, to TCP, for transmission. This is done using the COEX\_TR\_SAP of the CE and the CM.



Figure 2. Example of using the COEX\_TR\_SAP for interface B1.

The COEX\_MEDIA\_SAP defines the interface A between a CE and a WSO.

An example reference model of a CE describing an example implementation of the interface A inside a base station is shown in Figure 3. The left side of the Figure 3 shows a typical reference model of a radio interface including data, control and management planes for physical layer, MAC sublayer, and convergence sublayer. The middle part of the Figure 3 shows the WSO management entity. The right part of the Figure 3 shows the CE.

Typically, the radio interface is implemented in such a way that it provides a management interface for the WSO management entity. In Figure 3, such interface is represented by the PHY\_ME\_SAP, MAC\_ME\_SAP, and CS\_ME\_SAP, corresponding to the physical layer, the MAC sublayer, and the convergence sublayer. These SAPs can be used to obtain information from the radio interface and to request reconfiguration of the radio interface. Correspondingly, the CE can use these SAPs to implement the interface A using the COEX\_MEDIA\_SAP. Communication between the radio interface management service access points PHY\_ME\_SAP, MAC\_ME\_SAP, and CS\_ME\_SAP and the COEX\_MEDIA\_SAP is done via the WSO management entity. The WSO management entity provides the coexistence primitive mapping (CXPM) service. The CXPM converts COEX\_MEDIA\_SAP primitives into WSO-specific management/control primitives. A one-to-one mapping might be highly desirable to fully support this standard, but it depends on each WSO standard. The CXPM implementation is out of scope of this standard.



Figure 3. Example reference model for the interface A.

Different logical entities of the coexistence system have different reference models. Figure 4 shows the CE reference model. Figure 5 shows the reference model for the CM and CDIS.



Figure 4. CE reference model.



Figure 5. CM and CDIS reference model.

* 1. System profiles and interoperability

The coexistence system defined in this standard has three logical entities: CDIS, CM, and CE. This standard defines several profiles determining operation of these entities.

The profiles are defined as follows. The standard defines common set of the data types, primitives, messages, and procedures. Each of the profiles uses only a specific part of the defined data types, primitives, messages, and procedures.

However, profiles are designed in such way that required level of interoperability is ensured among entities operating according to different profiles. The defined profiles follow the following principles:

* Any CDIS shall be able to provide coexistence discovery service to any type of CM
* Any CM shall be able to exchange information with any other type of CM
* Any CM shall support at least one profile
* Any CM shall support both management service and information service
* Any CE shall support at least one profile
* Any CE shall support at least management service or information service and may support both.
	1. Coexistence services
		1. Introduction

Coexistence services are services provided by the coexistence system to WSOs, as well as, services provided by the CDIS to the CMs. Correspondingly, the categories of the coexistence services are services provided to WSOs and services provided to CMs.

The coexistence services are illustrated in Figure 6.



Figure 6. Summary of coexistence services.

* + 1. Services for WSOs

The coexistence system provides coexistence services to a WSO via interface A. To obtain services from the coexistence system, a WSO needs to subscribe to the coexistence services and register to the coexistence system.

After the registration, the WSO may get information services and/or management services.

A WSO may be subscribed to only one service at a time.

Within the information service, the WSO gets coexistence report from the coexistence system. Such coexistence report provides enough information to the WSO to make autonomous coexistence decision on its operating parameters.

Within the management service, the WSO gets reconfiguration requests generated by the coexistence system. The WSO needs to provide information to the coexistence system while using this service. Also, the WSO needs to perform measurements according to requests from the coexistence system. Both the information and measurement reports are used by the coexistence system to make coexistence decisions.

* + 1. Services for CM

A CDIS provides coexistence services to CMs via interface B2. A CM gets coexistence discovery service from a CDIS after it has subscribed to the CDIS coexistence discovery service and has registered to the CDIS.

The coexistence discovery service provides coexistence set information to the CM for WSOs served by this CM. Two types of coexistence discovery service are provided by the CDIS to the CM. With one type of service, the CM gets coexistence set information only for those WSOs that are served by other CMs. This is called inter-CM coexistence discovery. With the other type of coexistence discovery service, the CM gets coexistence set information regardless of which CM serves the WSOs in the coexistence set. In this case the CDIS performs both inter-CM coexistence discovery and intra-CM coexistence discovery.

* 1. Coexistence algorithms
		1. Introduction

Coexistence algorithms are procedures executed inside the coexistence system in order to provide the coexistence services. The two classes of coexistence algorithms are coexistence discovery algorithms and coexistence decision algorithms.

Coexistence discovery algorithms are used by CDIS and CM to discover WSOs that may affect each other performance.

Coexistence decision algorithms are used by a CM to make coexistence decisions related to WSO reconfiguration.

The standard describes several algorithms for each class. Implementation is not intended to be limited to a particular algorithm.

* + 1. Coexistence discovery algorithms
			1. Algorithm based on statistical analysis of the expected interference

This coexistence discovery algorithm considers pairs of WSOs and determines whether they will provide harmful interference to each other when using the same or overlapping operating frequencies. Detailed description of this algorithm is given in (reference).

First, the cumulative distribution function of the potential interference from WSO B to WSO A is estimated by the coexistence system. The minimum interference level experienced by 90% of devices of the WSO A is then taken as the potential interference value from WSO B to WSO A. The potential interference value from WSO A to WSO B is determined in the same way.

Then, the potential interference value from WSO B to WSO A is compared to a threshold. If the interference value is greater than the threshold, then WSO B is potential interferer to WSO A and is included into the coexistence set of WSO A. Similar rule is applied for inclusion of the WSO A into the coexistence set of WSO B.

Updated coexistence set of a WSO is then announced to the CM serving this WSO.

* + - 1. Algorithm based on coverage and interference analysis

This coexistence discovery algorithm considers pairs of WSOs and determines whether they will provide harmful interference to each other when using the same or overlapping operating frequencies. Detailed description of this algorithm is given in (reference).

First, the normalized distance between WSO A and WSO B is calculated based on geographical distance and estimated coverage areas.

Then the normalized distance is compared to the specific thresholds. The thresholds depend on the radio interface type of WSOs A and B. If they use different technologies, then threshold for potential interference from WSO A to WSO B could be different than from WSO B to WSO A. If the normalized distance between WSOs A and B is less than the potential interference threshold from WSO B to WSO A, then WSO B is included in the coexistence set of the WSO A. Similar for the coexistence set of WSO B.

Updated coexistence set of a WSO is then announced to the CM serving this WSO.

* + 1. Coexistence decision algorithms
			1. Algorithm based on operating channel selection

The channel classification and channel set transition algorithm uses TV channel classification and channel set transition to maintain channel availability information by the CM. All TV channels are classified in the following sets:

* disallowed channels,
* allowed channels,
* available channels,
* protected channels,
* restricted channels,
* unclassified channels,
* operating channels, and
* coexistent channels.

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

The allowed set is a set of channels allowed for WSOs. It is provided by TVWS database and is updated as necessary. All WSOs 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 WSOs.

The restricted set is a set of channels restricted to use with limitations due to regulation. It is be used by WSOs 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 (less than 40 mW 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 WSOs.

The unclassified set is a set of channels has not been classified as one of disallowerd set, available set, or protected set.

The operating set is a set of operating channels being used by each WSO. If each WSO has a different operating channel, then spectrum etiquette, i.e., FDM (frequency division multiplexing), among WSOs is achievable.

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

Figure 7 shows Venn diagram of TV channels.



Figure 7. Venn diagram of TV channels

The operating channel selection algorithm allocates a proper operating channel to WSOs. The following three channel allocation methods for operating channel selection are considered:

* individual TV channel allocation,
* shared TV channel allocation by WSOs of the same type, and
* shared TV channel allocation by WSOs of the dissimilar type.

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

In shared TV channel allocation, two or more WSOs share the one or more TV channels. If a TV channel is shared by WSOs of the same type, self-coexistence mechanisms are applied to mitigate co-channel interference. If a TV channel is shared by WSOs of the dissimilar type, inter-system coexistence mechanisms are applied to mitigate co-channel interference.

* + - 1. Algorithm based on negotiation among CMs

The negotiation among neighbor CMs algorithm enables the coexistence system to share the frequency bands effectively in a case where two or more WSOs may affect each others performance and they are served by different CMs. Then the WSOs are registered to the different CMs and interfere with each other when operating in 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 determining the operating channel list, round-robin mode parameters and competition mode parameters.

When all neighbor CMs allow independent use of the channels, the coexistence set elements served by different CMs use independent operating channels, which is referred to as an etiquette mode. On the other hand, when some neighbor CMs disallow the independent use, the coexistence set elements served by different CMs share operating channels. Based on this technique, time slots are assigned sequentially to all coexistence set elements served by different CMs, which is referred to as round-robin mode, or assigned to particular coexistence set elements served by different CMs through competition among those coexistence set elements, which is referred to as competition mode.

* + - 1. Resource allocation with fairness constraint

This algorithm shall be applied to coexistence set elements which are subscribed to the management service and registered to different CMs. In this case fair resource allocation between coexistence set elements is important. This algorithm addresses fairness by employing Jain’s fairness index and Max-min algorithm.

* + - 1. Master CM selection

Master/Slave CM selection algorithm is focused on providing a method to re-organize CMs autonomously.

Other benefits from selecting master CM and making slave CMs are:

* load balancing among CMs, and
* to reduce communication overhead among CMs.
	+ - 1. Channel priority allocation

This mechanism is intended for a target WSO subscribed in information service which has no interference-free channels such as available or restricted channel and has operating channels occupied by its coexistence set elements. In this case, performance of the target WSO is degraded by interference of coexistence set elements. Thus, the operating channel priority information is useful to select appropriate operating channels for the target WSO employing operating channels occupied by its coexistence set elements.

This operating channel priority allocation shall be initiated by a CE which is subscribed to the information service and CM shall provide prioritized channel information to the corresponding CE. The channel priority allocation shall consist of two stages, i.e., coarse channel priority and fine channel priority. The coarse channel priority shall use selection criterion of license type, network technology, total occupancy and the number of coexistence set elements. The fine channel priority shall use selection criteria of interference level. The specific explanation of two-stage channel priority allocation is given in following sub-sections.

* + - 1. Algorithm based on neighbor report and radio environment information

In the coexistence report and radio environment information algorithm the CM first selects one WSO. Next the CM selects the WSO with the maximum unsatisfied demand for resources. Finally, the CM tries to allocate necessary spectrum resources to the selected WSO.

The algorithm considers at most coexistence elements of coexistence elements of the selected WSO to keep the complexity low. The algorithm takes into account operational frequency bands, interference margins, total interference level from coexistence elements, transmit powers, and support for scheduling.

The key principle of the algorithm is to enable acceptable performance for all WSOs while minimizing the number of required reconfigurations. Following this principle, the CM checks the possibility to reconfigure the selected WSO only. If this is impossible, the CM tries solutions that require reconfiguration of coexistence elements.

Priority is given to the solutions that do not reduce the capacity of currently operating WSOs. Also, power control is left to the last stages of the algorithm because providing the largest range for devices is desirable.

The result of the algorithm is the operating frequencies, transmission power limits, channel sharing, and sharing schedule to the selected WSO and to other affected WSOs.

* + - 1. Algorithm based on per-coordinate optimization

This algorithm allows a CM to decide operating parameters of the WSOs served by this CM and subscribed to the management service. Also, it allows negotiating with the neighbor CM on possible reconfiguration of the neighbor WSOs.

The algorithm uses several iterations to select the WSO operating parameters. Also, within each iteration, all WSO operating parameters are optimized on per WSO basis.

Two target functions are used as examples: total throughput and total interference target functions.

* + - 1. Algorithm H

This is algorithm H for coexistence decisions in a CM that builds upon a basic concept according to which the CM serves both the CEs subscribed to it and the CEs in the coexistence sets the CM has for its own CEs. The CM shall make coexistence decisions on those CEs that are subscribed to the management service. Those CEs that are subscribed to the information service or other coexistence decision algorithms are taken into account in the coexistence decisions but for them coexistence decisions are not made.

This coexistence decision algorithm has been designed to be effective in the situations with scarcity of spectrum. As a part of the algorithm the CM estimates whether the resource allocation outcome to the CE and to the elements of its coexistence set meets the balanced sharing criterion. This algorithm is based on the Coexistence Value (CV) parameter and considers balanced sharing in the coexistence decisions on the CE and its coexistence set elements (CSEs). The design is intended to avoid a WSO to take resources of another WSO even if it is not eligible to those resources. Similarly the algorithm is designed to avoid a WSO to keep too many resources when other WSOs are lacking resources. This algorithm also generates slowness to resource changes in the environment.

* + - 1. Temporarily released resource

A CE that is subscribed to the management service may release in temporary manner a portion of the resources that are allocated to it and to the WSO which it represents. This is done by using three following mechanisms:

* The mechanism for temporary resource release
* The mechanism to use temporarily released resources
* The mechanism for reclaiming the temporarily released resources.