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Re:	Call for Contributions, IEEE 802.16h Task Group on License-Exempt Coexistence, IEEE 80216h-05/014
Abstract	Mechanisms proposal for a cooperative based co-existence resolution and negotiation protocol
Purpose	Provide flexible mechanisms for a fair and efficient sharing of the common MAC frame
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Proposal for credit tokens based co-existence resolution and negotiation protocol

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1 Introduction

This contribution proposes mechanisms for a cooperative based co-existence resolution and negotiation protocol. This contribution further extends the initial contribution [1] that has been discussed in session #37. The text of this new contribution is intended for inclusion in the IEEE 802.16h standard, within the section 7.2.2 ("Shared Radio Resource Management") in [2]. The elements related to the definition of messages required to support the proposed mechanisms are in *italic*.

2 Background

Spectrum sharing between several networks (NW) can be achieved through the sharing of a common MAC frame [2] between the different NWs as exampled by Figure 1. In such a MAC frame structure, dedicated portions (denoted as "master NW sub-frames") of the frame are periodically and exclusively allocated to a NW (denoted as the "master NW") respectively in the forward and reverse link. The terminology used hereafter defines a slave NW as a NW that may operate during the other master NWs sub-frames. With respect to this definition, the slave NW sub-frames are the time intervals operating in parallel of the master NWs sub-frames.

Additional flexibility can be provided by such a frame structure if: (1) the length of each master sub-frame can be dynamically adjusted as a function of the spatial and temporal traffic load variations of each NW; (2) the slave NWs sub-frames can be allocated with the same sub-carriers (co-channel) as the master NW during the master NW sub-frames transmissions.

Requirements (2) can be envisaged if provided that the master NW perceives a co-channel interference level lower than an admissible interference threshold explicitly agreed with the slave NWs to ensure master NW's QoS (QoS_{Master}) is guaranteed. Similarly, parallel transmissions can be envisaged if the slave NWs can negotiate with master NW to be provided with a guaranteed QoS (QoS_{Slave}) and if contention issues between slave NWs are resolved.

Given requirements (1) and (2), this contribution proposes the dynamic coordination of the frame structure sharing between BSs when several master and slave NWs compete to share this common shared MAC frame.

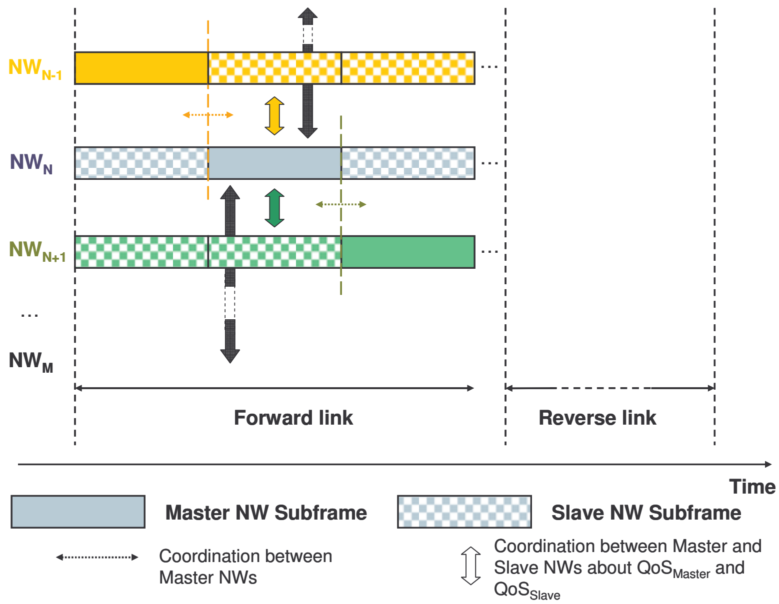

Figure 1: Example of TDD based MAC frame sharing structure between M NWs

3 General principle

The first step consists in defining credit tokens and designing appropriate reserve price auctioning and bidding mechanisms to solve contention access channel issues between NWs. Then, on the basis of the credit tokens based mechanisms usage, the second step consists in managing dynamically the bandwidth (in time and frequency) requests and grants mechanisms of the common shared MAC frame between BSs of master and slave NWs competing for spectrum sharing.

Based on the credit tokens transactions (selling, purchase and awarding), these two steps provide the mechanisms to enable spectrum efficiency and a fair spectrum usage in a real time fashion, while ensuring both the master and slave NWs QoS. These two steps enable to manage spectrum sharing between master NWs themselves, and also between master and slave NWs. The result is the dynamic shaping of the MAC frame structure sharing as a function of the space time traffic intensity variations, admissible co-channel interference, and the dynamic credit tokens portfolio account of both the master and slave NWs. The transaction mechanisms are detailed in the following sections.

4 Credit tokens assignment and usage principles

- Each NW is initially allocated with a given credit tokens account.
- Negotiation for spectrum sharing between NWs is based on credit tokens transactions.
- Credit tokens transactions occur dynamically between a seller (master NW owner of the radio resources during the active master sub-frame) and one or several bidders (the other master NWs or slave NWs).
- The negotiation occurs dynamically either:
    - Between master NWs (denoted “Case 1” in the following) to agree the length of each master sub-frame as a function of the spatial and temporal traffic load variations need of each master NW (refers to above requirement (1) of section 2).

- Between master and slave NWs (denoted “Case 2” in the following) to select the slave NWs allowed operating in parallel of the master sub-frame based on QoS_{Slave} and QoS_{Master} (refers to above requirement (2) of section 2).

5 Negotiation between master NWs (case 1)

Two sub-cases of “case 1” can be considered: the negotiation can be triggered by the master NW seller (“case 1a”), or can be triggered by the master bidder (“case 1b”).

For “case 1a”, the proposed mechanisms are:

- The master NW_N (seller) advertises that its periodic assigned master sub-frame is open for renting (Figure 2) from starting time T_{Start} to ending time T_{End} for a fraction ($\mathbf{T_{Renting}/T_{Msf}}$) of its master sub-frame duration $\mathbf{T_{Msf}}$.
- The master NW_N proposes a reserve price auction ***RPA*** for this renting. The ***RPA*** is expressed as a number of credit tokens per time unit (**CT**).
- The interested contiguous (NW_{N-1} and NW_{N+1}) and non contiguous (NW_{N-i} and $NW_{N+i,}$ i> 1) master NWs of NW_N make bidding on this auction. The bid (BID_k) of each bidder k is a vector including the following information:
  - The amount of bided credit tokens per time unit (CT_k),
  - The fraction x_k of $T_{Renting}$ his bid CT_k applies for,
  - The time interval [$T_{Start\ k}$, $T_{End\ k}$] his bid applies for. $[T_{Start\ k}, T_{End\ k}] \subset [T_{Start}, T_{End}]$.

  $BID_k = \{CT_k, x_k, T_{Start\ k}, T_{End\ k}\}$
- Based on the different biddings BID_k received:
  - The master NW_N partitions [T_{Start}, T_{End}] into contiguous time segments {$\mathbf{TS_i}$} on the basis of the time intervals set {[$T_{Start\ k}$, $T_{End\ k}$]}. Each $\mathbf{TS_i}$ corresponds to a time window (integer number of $\mathbf{T_{Frame}}$) in which a subset of intervals of {[$T_{Start\ k}$, $T_{End\ k}$]} overlaps. In each $\mathbf{TS_{i,}}$ each involved bidder k competes with his respective $\mathbf{BID_k}$.
  - For each $\mathbf{TS_{i,}}$ master NW_N calculates the payoff $\mathbf{P_k} = CT_k * x_k * T_{Renting} * \mathbf{N_{Frame\ i}}$ for each bidder k. $\mathbf{N_{Frame\ i}}$ is the number of frames within $\mathbf{TS_i}$ ($\mathbf{N_{Frame\ i} = TS_i/T_{Frame}}$).
  - The master NW_N searches the subset of {k} such as sum(x_k) = **1** and sum($\mathbf{P_k}$) is maximal.
- The clearing price auction ($CPA_{i,k}$) is derived by the master NW_N for each $\mathbf{TS_i}$ and each k. $CPA_{i,k}$ is expressed as a number of credit tokens per time unit (**CT**). Different methods can be applied here to define $CPA_{i,k}$ (more on that in section 9).
- Each k of the selected list {k} on $\mathbf{TS_i}$ pays the price $Pr_k = CPA_{i,k} * x_k * T_{Renting} * \mathbf{N_{Frame\ i}}$. Provided that Pr_k does not exceed the credit tokens account of user k, each winning bidder k is then assigned with the corresponding granted resources (all pool of frequencies) during $x_k * T_{Renting}$ time unit of NW_N and for $\mathbf{N_{Frame\ i}}$ frames.

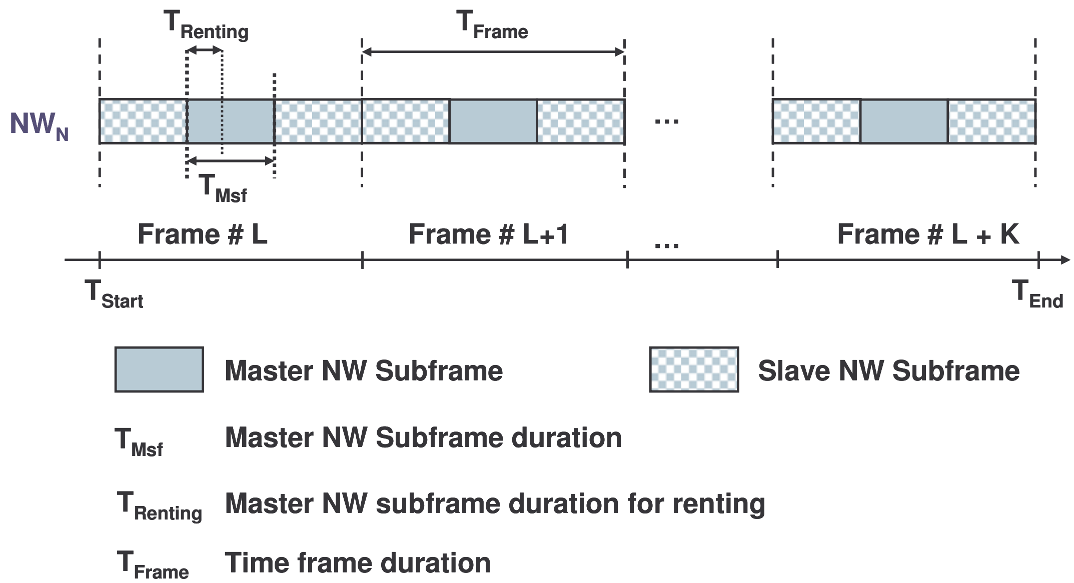

Figure 2: Simplified MAC frame structure illustrating master NW sub-frame renting principle and associated notations

Note: The same mechanisms as "case 1a" apply in "case 1b". In addition to "case 1a", in "case 1b" the master NWs bidder candidates can trigger themselves the other master NW that could potentially rent some spectrum. This triggering can be made by one of the approaches presented in section 8.

6 Negotiation between master and slave NWs (case 2)

The proposed mechanisms for this case are an extension of the mechanisms of section 5 to take into account admissible co-channel interference levels for both the master NW (QoS_{Master}) and the slave NWs (QoS_{slave}). The QoS_{Master} and QoS_{slave} criteria modify the auctioning and bidding process as follows:

Advertising phase

- The master NW_N (seller) advertises that its periodic assigned master sub-frame is open for renting for a secondary parallel co-channel usage. This renting applies from starting time $\boldsymbol{T_{Start}}$ to ending time $\boldsymbol{T_{end}}$ for a fraction ($\boldsymbol{T_{Renting}}/\mathbf{T_{Msf}}$) of its master sub-frame duration $\mathbf{T_{Msf}}$.
- The slave NWs candidates are provided with the sub-carriers id list $\{\boldsymbol{sc_{id}}\}$ that can be used during $\boldsymbol{T_{Renting}}$.

Admissible co-channel interference control phase

- Based on this information, each slave NW_k candidate listens to each sub-carrier and measures the amount of co-channel interference experienced.
- Based on these measurements, the slave NW_k candidate assesses whether this interference level is admissible to fit with its required $QoS_{Slave\ k.}$
- The slave NW_k candidate identifies the sub-carriers id set $\underline{\boldsymbol{id_k}}$ he is interested in among the available list $\{\boldsymbol{sc_{id}}\}$.
- The slave NW_k candidate informs the master NW_N about his interest to use $\underline{\boldsymbol{id_k}}$.

- The master NW_N coordinates with the slave NW_k candidate to enable master NW_N to assess whether the additional co-channel interference generated by the slave NW_k candidate on $\underline{id_k}$ is admissible to fit with its required $QoS_{Master\ N}$.
- In case both the $QoS_{Master\ N}$ and $QoS_{Slave\ k}$ are guaranteed, the slave NW_k candidate is selected for the *Auctioning/bidding phase.*

Auctioning/bidding phase

- The master NW_N proposes a reserve price auction ***RPA*** for this renting. The ***RPA*** is expressed as a number of credit tokens per time unit and per sub-carrier unit (**CT**).
- The slave NW_k (for all k) make bidding on this auction. The bid (BID_k) of each bidder k is a vector including the following information:
    - The amount of bided credit tokens (CT_k) per time unit and per sub-carrier unit. CT_k takes into account the level of $QoS_{Slave\ k}$ guarantee. In particular, CT_k can be calculated as a function of the robustness and efficiency of the burst profiles (coding, modulation schemes) the slave NW_k can be provided with.
    - The fraction x_k of $T_{Renting}$ to use $\underline{id_k}$ and for which his bid CT_k applies for.
    - The time interval $[T_{Start\ k}, T_{End\ k}]$ his bid applies for. $[T_{Start\ k}, T_{End\ k}] \subset [T_{Start}, T_{End}]$.

  $BID_k = \{\underline{id_k}, CT_k, x_k, T_{Start\ k}, T_{End\ k}\}$
- Based on the different biddings BID_k received:
    - The master NW_N partitions $[T_{Start}, T_{End}]$ into contiguous time segments $\{TS_i\}$ on the basis of the time intervals set $\{[T_{Start\ k}, T_{End\ k}]\}$. In each TS_i, each involved bidder k competes with his respective BID_k.
    - For each TS_i, master NW_N calculates the payoff $P_k = CT_k * x_k * T_{Renting} * N_{Frame\ i} * \mathbf{Card}\ (id_k)$ for each bidder k. $N_{Frame\ i}$ is the number of frames within TS_i ($N_{Frame\ i} = TS_i/T_{Frame}$).
    - The master NW_N searches the subset of {k} such as sum(x_k) = **1** and sum(P_k) is maximal.
- The clearing price auction ($CPA_{i,k}$) is derived by the master NW_N for each TS_i and each k. $CPA_{i,k}$ is expressed as a number of credit tokens per time unit and per sub-carrier unit (**CT**). Different methods can be applied here to define $CPA_{i,k}$ (more on that in section 9).
- Each k of the selected list {k} on TS_i pays the price $Pr_k = CPA_{i,k} * x_k * T_{Renting} * N_{Frame\ i} * \mathbf{Card}\ (id_k)$. Provided that Pr_k does not exceed the credit tokens account of user k, each winning bidder k is then assigned with the corresponding granted sub-carriers $\underline{id_k}$ during $x_k * T_{Renting}$ time unit of NW_N and for $N_{Frame\ i}$ frames.

7 Credit tokens awarding

The contribution also proposes some means to award master NWs making effort to rent their master sub-frame/spectrum for a secondary usage. The award is based on granting these master NWs with a number of credit token awards **CTA**. This mechanism provides the means to give incentive to each master NW to release his master sub-frame totally or partially if it is unused or underused. The awarding mechanism applies for both "case 1" and "case 2".

- In "case 1", the CTA_N granted to the master NW_N can be expressed as a function of rented time $T_{Renting}$ over the time interval $[T_{Start}, T_{End}]$ as follows:

$$CTA_N = w_{time}(t,s) * [T_{Renting} * (T_{End} - T_{Start}) / T_{Frame}]$$

$\mathbf{w}_{time}$ is a weight factor (scalar) that be can adjusted/tuned to control the number of awarded credit tokens per rented time duration. **w** is a function of time (t) and space (s) and therefore can be dynamically adjusted as a function of the space time traffic intensity variations.

- In "case 2", the CTA_N granted to the master NW_N can be expressed as a function of rented time $T_{Renting}$ over the time interval [T_{Start}, T_{End}], the new admissible $QoS_{Experienced\ Master\ N}$, the admissible $QoS_{Experienced\ Slave\ k}$, and the number of subcarriers rented BW_{Rented} to the winning slave bidders {k}, as follows:

$$CTA_N = \mathbf{w}_{time}(t,s) * [T_{Renting} * (T_{End} - T_{Start}) / T_{Frame}] + \mathbf{w}_{frequency}(t,s) * BW_{Rented} + \mathbf{w}_{QoS\ Master}(t,s) * (QoS_{Interference\ free\ Master\ N} - QoS_{Experienced\ Master\ N}) + \mathbf{w}_{QoS\ Slave}(t,s) * [1 / \sum(QoS_{Interference\ free\ Slave\ k} - QoS_{Experienced\ Slave\ k})]$$

  - $\mathbf{w}_{time}$ is a weight factor (scalar) that can be adjusted/tuned to control the number of awarded credit tokens per rented time duration.
  - $\mathbf{w}_{frequency}$ is a weight factor (scalar) that can be adjusted/tuned to control the number of awarded credit tokens per rented bandwidth BW_{Rented}. $BW_{Rented} = [\sum Card(\underline{id_1} \cap \ldots \cap \underline{id_k} \cap \ldots \cap \underline{id_Q})] * \mathbf{bw}$. **bw** is the bandwidth of one sub-carrier.
  - $\mathbf{w}_{QoS\ Master}$ is a weight factor (scalar) that can be adjusted/tuned to control the number of awarded credit tokens as a function of the difference between (i) the QoS experienced ($QoS_{Interference\ free\ Master\ N}$) by the master NW_N when no sharing occurs (interference free period) and (ii) the degraded QoS experienced ($QoS_{Experienced\ Master\ N}$) by the master NW_N due to additional co-channel interference when sharing spectrum with slave NWs.
  - $\mathbf{w}_{QoS\ Slave}$ is a weight factor (scalar) that can be adjusted/tuned to control the number of awarded credit tokens as an inverse function of the difference between (i) the QoS experienced ($QoS_{interference\ free\ Slave\ k}$) by the slave NW_k when no sharing occurs (interference free period) and (ii) the degraded QoS experienced ($QoS_{Experienced\ Slave\ k}$) by the slave NW_k due to additional co-channel interference when sharing spectrum with the master NW_N.
  - $\mathbf{w}_{time}$, $\mathbf{w}_{frequency}$, $\mathbf{w}_{QoS\ Master}$ and $\mathbf{w}_{QoS\ Slave}$ are functions of time (t) and space (s) and therefore can be dynamically adjusted as a function of the space time traffic intensity variations.

Note: Above CTA_N expressions are some examples and are not limitative.

8 Inter BSs communication

The proposed above mechanisms require inter BSs communication between different NWs. This inter BS communications is necessary to exchange the parameters related to the *Advertising phase,* the *Admissible co-channel interference control phase* and the *Auctioning/bidding phase.* It is assumed that these parameters are stored into the regional LE DB and into the local database of each LE BS. The information exchange between these databases and the RADIUS/CIS servers can be either supported by secured over the air signalling, or by IP communication between the networks.

9 Auctioning and bidding strategies

Depending on metrics like the number of bidders or the available time to make the transactions, different auctions and bidding strategies can be supported by the proposed mechanisms to better fit each specific context. In particular, if time permits, multi-stages strategies could be implemented to enable competing slave NWs to negotiate by several iterations.

10 Conclusion

The proposed mechanisms facilitate the co-existence among license exempt based 802.16 systems in a fair fashion. These mechanisms are also applicable to the co-existence of license exempt based 802.16 systems with primary systems like IEEE 802.11. These mechanisms have been presented in the case of a specific repetitive pattern (i.e. for a given MAC sub-frame structure type), but are also applicable to any type of the repetitive patterns of section 2.1.1.1 in [2]. Finally, the proposed principles are also applicable to the following cases during the "community entry of new BS" phase: (i) selection of an interference free master sub-frame, and (ii) creation of a new master sub-frame by a new BS.

References

[1] IEEE C802.16h - 05/010 - Market based policies for channel coexistence in 802.16 LE, 2005-04-28
[2] IEEE 802.16h - 05/013 - pre- draft Working Document for P802.16h, 2005-06-06