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Wireless Coexistence

A coexistence decision approach proposal

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Author(s):

Name	Company	Address	Phone	email
Jari Junell	Nokia	Itämerenkatu 11-13, 00180 Helsinki, Finland	+358-718036575	jari.junell@nokia.com
Mika Kasslin	Nokia	Itämerenkatu 11-13, 00180 Helsinki, Finland	+358-718036294	mika.kasslin@nokia.com
Päivi Ruuska	Nokia	Visiokatu 1, 33720 Tampere, Finland	+358-718035433	paivi.m.ruuska@nokia.com

Abstract

This document is a submission to IEEE 802.19 TG1 about coexistence decision algorithms. The proposed solution is independent on the resource allocation algorithm. Several different algorithms may be used, but this coexistence decision procedure gives an unambiguous and consistent result. A balanced sharing in the context of the coexistence decisions is defined and the reasoning why it is very important in this kind of environment to attract WSOs to join the coexistence system and to accept the outcomes of coexistence decisions.

The contribution has two main sections from which the first one (Background information) discusses the reasons behind the proposal. The second section (Text proposal for the candidate draft) contains text that is being proposed to be incorporated into the latest candidate draft. The section contains some instructions to the technical editor to facilitate the editing work.

1 Background information

The latest candidate draft contains a set of alternative coexistence decision algorithms for CM implementations. We believe there is not an algorithm that is designed to work effectively in situations with spectrum scarcity.

2 Text proposal for the candidate draft

Editorial instruction: Have the following sub-sections added to the section 9 under the sub-section 9.4 and update the figure numbering as appropriate.

9.4.7 Algorithm H

9.4.7.1 Introduction

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.

9.4.7.2 Main flow of the coexistence decision process

Figure 1 is a high level illustration of the algorithm in form of a flow diagram. The flow starts when the CM identifies a need for a new resource allocation for a CE registered to it and subscribed to the coexistence management service. First, the CM shall check availability of any free channels from the available WSO's environment information data and coexistence set elements. The CM shall allocate a free channel to the WSO, if it satisfies the needs of the WSO. If free channels are not available or they don't satisfy the needs of the WSO, the CM shall continue to full resource allocation analysis.

The CM makes a resource allocation analysis to the coexistence set. For some members of the coexistence set the CM is allowed to make changes in resource allocation. The concept of Coexistence Value (CV) is used in this context. The CV illustrates a measure of WSO's eligibility to resources and the CM shall use it in the coexistence decision algorithm to assess eligibility of the WSO to the new resources. This coexistence decision algorithm is presented in the following sub-sections.

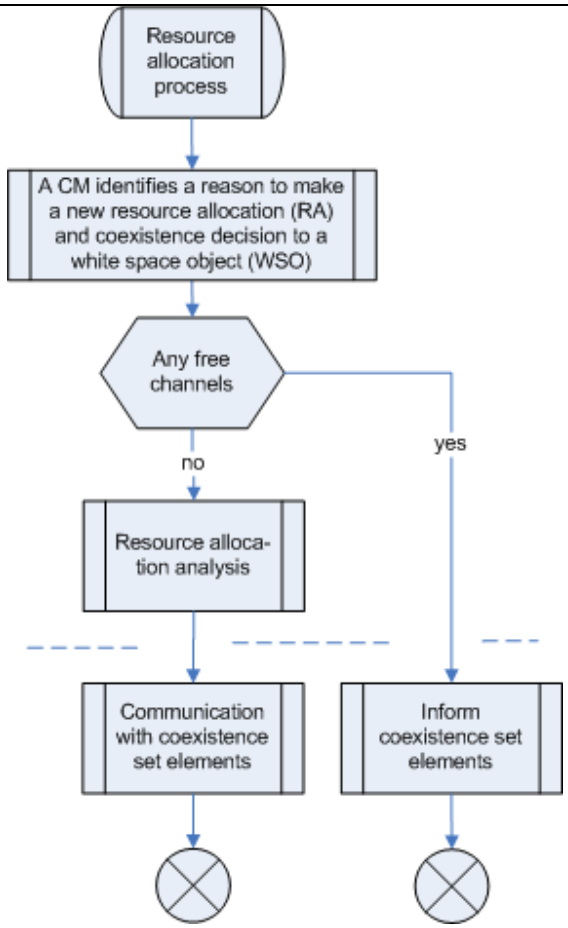

Figure 1: An example of resource allocation process with coexistence decision as a part of resource allocation analysis

9.4.7.4 Coexistence value

Coexistence value (CV) parameter defines a measure, which is used within a coexistence set to evaluate the coexistence set elements' eligibility to resources. Coexistence values are absolute values, all which are normalized to available resources within the coexistence set in the decision making procedure. The CV parameter value is based on three parameters: 1) number of nodes in the network of TVWS devices associated to the WSO, 2) the relation between the resources allocated to the WSO, and the resources used by the WSO, and 3) a possible regulatory preference. The WSO's resource usage shall be represented with a channel utility value. The first two parameters are evaluated over a certain period to get slowness into a change rate of a CV value.

There is defined a time period Ts over which both the peak node number and channel utility value are evaluated. There are two other time periods: T1 including N1 Ts periods, and T2 including N2 Ts periods, see e.g. figure 2. From both periods, T1 and T2, the average values of node number and channel utility value are stored. T1 represents short time period dynamic part and T2 represents long term historic part. They are used in the calculation of CV.

A coexistence value is formulated as follows: CV = F1*F2*F3, where

- F1 is an average mapped node number calculated from formula (a*c1+b*c2)/(a+b)
  - a = b = 1 (weighting factors)
  - c1 = average mapped node number over all Ts periods within a period T1

- c2 = average mapped node number over all Ts periods within a period T2
- mapped node number = 0.2 (if number of nodes is 1), N-1 (if number of nodes N is 2,3,…,11) and 10 (if number of nodes N is >11)

- F2 is an average mapped utility value with respect to allocated resources calculated from formula (d*g1+b*g2)/(d+e)
  - d = e = 1 (weighting factors)
  - g1 = average mapped channel utility value of Ts over a period T1
  - g2 = average mapped channel utility value of Ts over a period T2
  - mapped channel utility value = 0.4 (between channel utility value of 0-0.3), 1 (between channel utility value of 0.8-1), linearly changing between 0.4 to 1 (between channel utility value of 0.3-0.8). Transmission buffer full is always full channel utility.
- F3 is a possible regulatory preference to a certain service. If no preferences are defined, then F3 is 1.

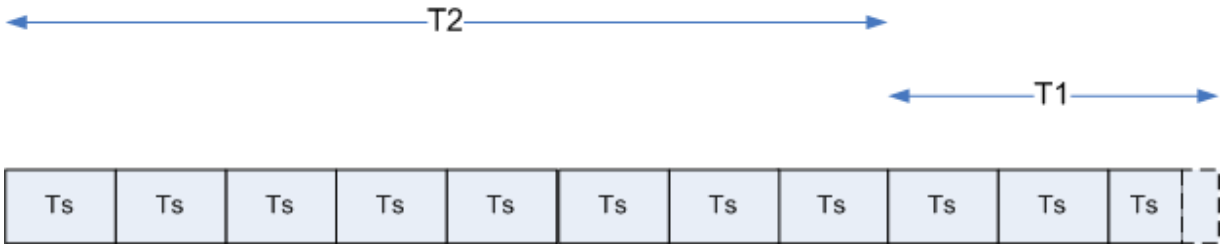

Figure 2: An example of relationship between Ts, T1 and T2

9.4.7.5 The coexistence decision procedure

The coexistence decision procedure within a CM of a WSO needing more resources includes several decision points. After the final step the outcome of the decision is communicated to relevant CMs to be forwarded to relevant CEs.

Figure 3 illustrates a principal flow of resource allocation analysis. A CM calculates resource allocations to a coexistence set in the extent defined by the services. The actual resource allocation calculation is not presented here. There can be several solutions using CVs to target to balanced sharing solution. The balanced sharing of the outcome is tested in decision point 1. If a balanced sharing solution has been found, then the process moves directly to the final coexistence decision. Otherwise depending on the used resource allocation algorithm a possibility to another configuration alternative in a resource allocation calculation is checked. If such an alternative is available, the same procedure is repeated. Otherwise the second decision point is entered. There the best resource allocations, which failed the balanced sharing test, are checked again and based on the outcome a preliminary solution is either found or not. With this result the process moves to the final coexistence decision.

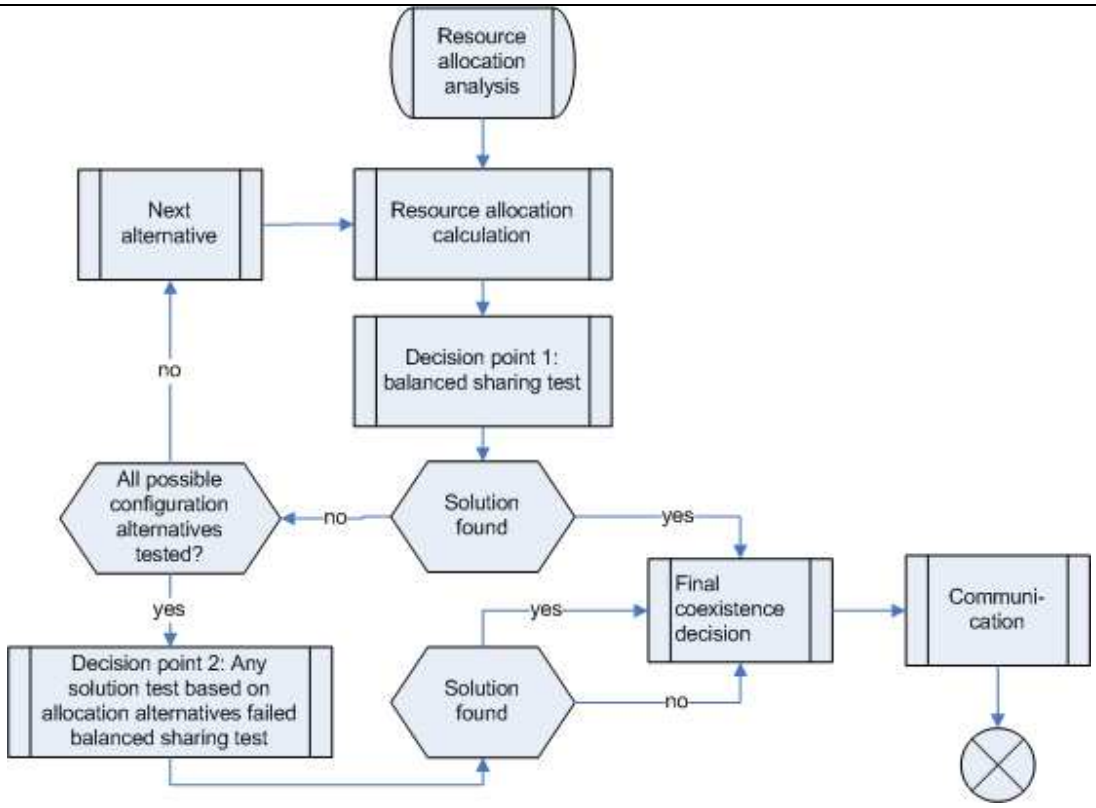

Figure 3: An illustrative example of resource allocation calculation and coexistence decision procedure

The preliminary coexistence decision algorithm takes following parameters as input:

- Coexistence set and white space object needing more resources
- Resource allocation proposal from resource allocation algorithm
- Requested and existing resource(s)
- Entitlement to resources: Coexistence values (CV)

The main steps in a preliminary coexistence decision algorithm, decision point 1, are:

- Coexistence set elements have the amount of resources they requested/currently have => a balanced sharing solution (as itself)
- Otherwise calculate if a balanced sharing solution is met in a resource allocation proposal

The calculation of a balanced sharing solution shall have the following steps:

- For each WSO within a coexistence set is calculated a quality factor value (and normalized), which is a ratio of the allocated resources to a value that represents the amount of resources to which the coexistence user is entitled to. The resource entitlement value is represented by a coexistence value (CV)
- Two values are calculated from these normalized quality factor values
    - Spread, e.g. a variance
    - Max width, e.g. difference of extremes
- A balanced sharing solution: a sum of the spread factor and square of the width factor is less than a pre-defined threshold defined as follows:

  $\varepsilon < \sigma^2 + \Delta^2$, where

- σ^2 = variance of normalized quality factor values
- Δ^2 = max difference between normalized quality factor values
- R_i = planned resource allocation of a WSO i
- CV_i = Coexistence value of a WSO i
- Quality factor q of network i = R_i / CV_i
- Normalization value nv = $\Sigma(R_i / CV_i)$
- Normalized quality factor value for network i = $n*q_i/nv$, n = number of CSEs

Decision point 2 checks the existence of any solution, if a balanced sharing solution is not found. The closest to balanced sharing allocation is chosen. After decision point 2 the procedure moves to the final coexistence decision.

The final coexistence decision algorithm is illustrated in Figure 4. As an input it gets the outcome of the preliminary coexistence decision, parameters related to preliminary coexistence decision such as its input parameters and quality factor values, and a trigger, which initiated the resource allocation calculation. The possible outcomes of preliminary coexistence decision and triggers for resource allocation are listed below.

- Outcome of the preliminary coexistence decision
  - A balanced sharing solution
  - A solution from failed balanced sharing test
  - No solution

- Trigger for resource allocation
  - Request for excess resources
  - A new WSO
  - Appearance of incumbent in a channel used currently by a WSO
  - Unknown increase of interference

The CM shall make a decision, to whom and what are communicated from the final coexistence decision, which is based on the inputs presented above. The outcome criterion of the final coexistence decision is shown below:

- Excess resource as a trigger
  - A balanced sharing solution & requesting WSO gets more resources: Communicate the resource allocation to CMs of coexistence set
  - A solution from failed balanced sharing test & accepted revised check & requesting WSO gets more resources: Communicate the resource allocation to CMs of coexistence set
  - Other cases: Inform requesting WSO that it is not eligible to new resources

- Other causes as a trigger
  - A balanced sharing solution or any solution from failed balanced sharing test: Communicate the resource allocation to CMs of coexistence set
  - No solution: Inform WSO that no solution is found

The accepted revised check is done when a balanced sharing solution is not found and the trigger has been an excess resource need by a WSO. It takes into account all coexistence set elements, which are not satisfied to resource allocation proposal, i.e. there resource allocation is less than the current one. The revised check is accepted, if in all these cases the normalized quality factor value is more than an average.

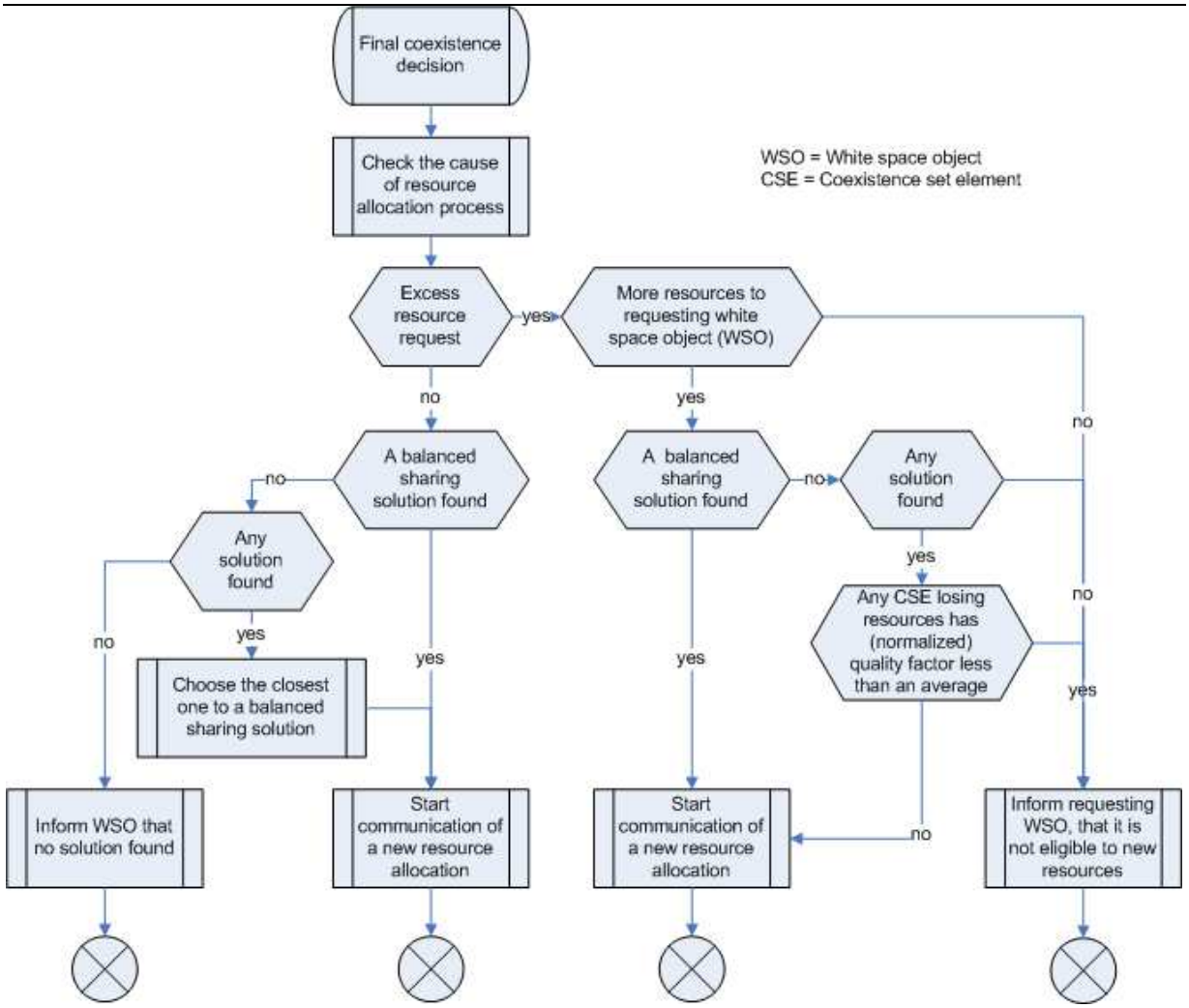

Figure 4: The flow to make the final coexistence decision and related communication