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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Broadband Radio Access Networks (BRAN).

1 Scope

The present document describes the specific protocols for systems providing a throughput of 1 Gbit/s/km^2. Such systems include features such as self-backhauling in both licensed and un-licensed bands, cognitive-radio based self-organization, etc.

2 References

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

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2.1 Normative references

The following referenced documents are necessary for the application of the present document.

Not applicable.

2.2 Informative references

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ETSI TR 101 534 (V1.1.1) (2012): "Broadband Radio Access Networks (BRAN); Very high capacity density BWA networks; System architecture, economic model and derivation of technical requirements".

[i.2] S. Haykin: "Cognitive Radio: Brain-Empowered Wireless Communications", IEEE Journal on selected areas in communications, vol. 23, pp. 201-220, February 2005.

[i.3] R. S. Sutton and A. G. Barto: "Reinforcement learning: An Introduction", The MIT Press, 1998.

[i.4] Ana Galindo-Serrano, Lorenza Giupponi, Pol Blasco and Mischa Dohler: "Learning from Experts in Cognitive Radio Networks: The Docitive Paradigm" in Proceedings of 5th International Conference on Cognitive Radio Oriented Wireless Networks and Communications (CrownCom 2010), 9-11 June 2010, Cannes (France).

[i.5] M. N. Ahmadabadi and M. Asadpour: "Expertness based cooperative Qlearning", IEEE Transactions on Systems, Man, and Cybernetics, Part B, vol. 32, no. 1, pp. 66-76, February 2002.

[i.6] IEEE 802.16-2012: "IEEE Standard for Air Interface for Broadband Wireless Access Systems".

3 Definitions and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

DL-MAP: structured data sequence that defined the mapping of the downlink

self-backhauling: wireless links between HBS and ABS which may share a frequency channel with the access operation (in-band) and use in addition license-exempt spectrum such as 5 GHz or 60 GHz bands (out-of-band)

UL-MAP: structured data sequence that defined the mapping of the uplink

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

AAA	Authentication, Authorization, and Accounting
ABS	Access BS
ACK	Acknowledge
ARA	Adaptive Resource Allocation
ASN	Access Service Network
BS	Base Station
BS-BS	Base Station to Base Station
BSID	Base Station IDentifier
BWA user	Fixed, Nomadic or Mobile user
BWA	Broadband Wireless Access
CIM	Centralized Interference Mitigation
CINR	Carrier to Interference and Noise Ratio
CM	Conditional-Mandatory
CNR	Carrier-to-Noise Ratio
DCD	Downlink Channel Description
DFP	Dynamic Frequency Planning
DL	Downlink
DNS	Directory Name Server
FA	Frequency Assignment
FAID	Frequency Assignment ID
FFR	Fractional Frequency Reuse
FQDN	Fully Qualified Domain Name
GPS	Global Positioning System
GW	Gateway
HBS	Hub Base Station
HO	HandOver
HSPA	High Speed Packed Access
HSS	Subscriber Station connected to HBS
ICIC	Inter Cell Interference Coordination
ICS	Interference Control Server
ID	IDentifier
IE	Information Element
IP	Internet Protocol
IQ	Intelligence Quotient
LE	License Exempt
LRT	Last Reset Time
LTE	Long Term Evolution
MAC	Medium Access Control
MCS	Modulation and Coding Scheme
MIMO	Multi-Input-Multi-Output
MME	Mobile Management Entity
MS	Mobile Station

NBL	NeighBour List
NBR	NeighBour Relation
NBS	Neighbour BS
NDS	Neighbours Data Synchronization
NV	Non-Volatile
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
PHY	PHYsical
P-MP	Point to MultiPoint
RAN	Radio Access Network
RAT	Radio Access Technology
RB	Resource Block
REQ	Request
RF	Radio Frequency
RP	Recovering Protocol
RRA	Averaging/Reporting Period
RRC	Radio Resource Control
RRM	Radio Resource Management
RRM-E	RRM-Entity
RSP	Response
RSSI	Received Signal Strength Indicator
RTD	Round Trip Delay
SBS	Serving BS
SON	Self Organizing Network
SOTA	State Of The Art
SSDFA	Spectrum Sensing based Dynamic Frequency Assignment
TBS	Target BS
TLV	Type - Length - Value (data structure)
TS	Time Stamp
UCD	Uplink Channel Description
UL	Uplink

4 Introduction

The present document presents new possible protocols specific to wireless BWA network, as described in [i.1], including heterogeneous elements (a two tier approach), combined use of licensed and license-exempt spectrum, very low delay communications between network elements, enabling the operation of the network MIMO technology and of the self-organization approaches.

The description of the networking features is in general done using the WiMAX™ terminology, however should be no barrier in using the 3GPP network for implementing this network.

4.1 Architecture for the underlaying system

The architecture presented in [i.1] is summarized below, for easing the reader understanding. Its main features are:

- Multiple access links aggregation.
- Self-backhauling link aggregation.
- Network MIMO (for downlink and uplink).
- Radio Resource Management.
- Direct BS-BS or MS-MS communication.

The system architecture aims to offer a cost efficient capacity density of 1 Gbit/s/km^2. Here, a HBS serves several below-rooftop ABSs, which in turn serve the associated MSs. The HBS possesses several beams which are used to communicate with ABSs in its beam-space. ABSs can communicate with each other via the serving HBS.

The Femto-BS and their associated subscribers may also operate in the un-licensed spectrum.

To simplify the presentation, the HBS-ABS links, which are self-backhaul links inside this system, may be named in the present document "backhaul links". This naming should not be understood as HBS backhauling, which is outside of the scope of the present document.

The system presented in the present document has the following basic architecture:

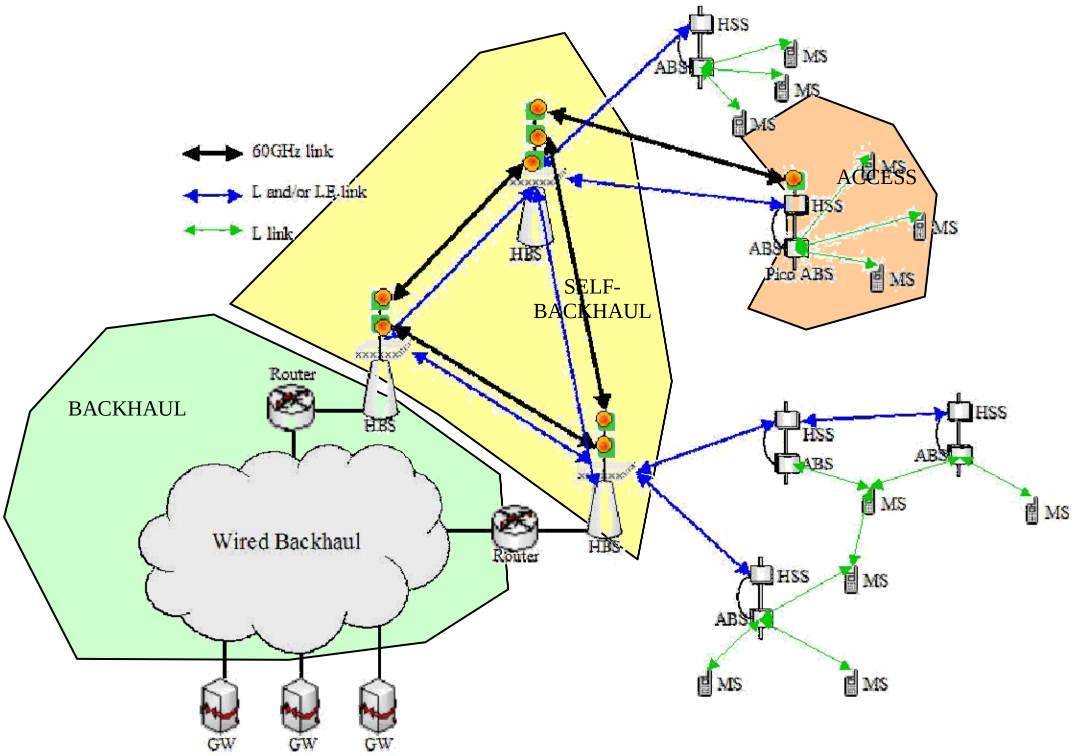

Figure 4.1: Basic architecture

The scheme in figure 4.1 provides an overview of most of the possible wireless links in the present document. At the top level of the architecture, HBSs are directly connected to the wired backhaul. If in some cases a wired link could not be done, this link should be replaced by LE high data rate connectivity.

An in-band backhaul link and a LE link between HBSs may not be systematically done but could offer additional networking capacities and an alternative, in case of a router failure for example.

At the ABS location there are two elements, which are the HSS and the ABS. The HSS component is associated to an HBS or to another HSS (for direct communication and collaborative MIMO). ABS provides connectivity for the BWA users.

To increase the coverage or to provide a larger throughput in a given area exists the possibility to deploy additional stations called pico-ABS. Those stations are basically similar to ABSs as they are providing connectivity to BWA users.

The lower level of the architecture shows mobile station connectivity possibilities. MS connects itself to ABS as in the standard P-MP architecture, but can also directly connect one to each other, and associate with two ABSs for MIMO support.

4.2 Radio resource management

This clause presents protocols and procedures related to RAN RRM and dynamic resource (frequency, power) assignment. The description relates to the air interface and the network interfaces and presents reference design for procedures and protocol primitives, required to support the aforementioned RRM mechanisms.

4.2.1 RRM functional decomposition in system architecture

The functional decomposition is based on the state-of-the-art WiMAX^{TM} and 3GPP standards, where Radio Resource Management (RRM) functional entity is located in the Base Station/eNodeB, while ASN GW/MME may act as a protocol relay function, but do not implement RRM-specific functions.

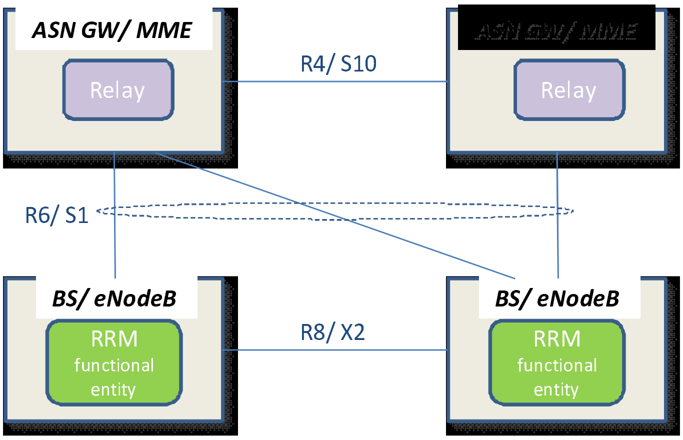

Figure 4.2: RRM functional entities in the SOTA WiMAX^{TM} and 3GPP LTE architectures

The RRM entity may implement both RRM Client and RRM Server entities, thus being able to issue information queries and to provide instructions. This is the de-centralized RRM approach, where there is no centralized entity controlling and coordinating the radio resource allocation in the particular geographical area with multiple BSs providing coverage and capacity. Coordination is done between RRM entities of different BSs over the R8/X2 reference points or over R6/S1 reference points via ASN GW/MME assuming "relay" functionality.

The following RRM features are considered in the present document and may be taking the advantage of the addressed system RRM split:

- Dynamic centralized and autonomous distributed frequency assignment.
- Cognitive and docitive power assignment.
- Support of advanced MIMO schemes.
- Self-Organization and Optimization features.

5 Frequency channel assignment

5.1 Dynamic centralized frequency assignment

5.1.1 Overall objectives

The centralized dynamic RRM protocol is based on an overall supervision of the radio network status, and tries to optimize radio link resources depending on interference levels, throughput load and architecture deployment.

Certain extent of information is required for this purpose, which mainly consist of different requests or triggered alarms informing the centralized RRM entity of the current status. The dynamic protocols act only by restraining or increasing stations resources, and providing local RRM segments the choice to optimize links to a more specific level. Coexistence is therefore easily ensured.

The centralized dynamic RRM entity (RRM-E) can be hosted either in HBS or in external equipment. It includes different operating functions realized on a proactive basis with regular survey or in a reactive fashion while receiving resource deficit alarms from the given sectors.

The knowledge of deployment topology allows Centralized RRM-E to perform initial distribution of frequency resources to the overlapping stations, with further iterative dynamic adaptations. This function is called *Dynamic Frequency Planning (DFP).*

In a second step, deployment topology awareness may allow it to realize adaptation of the network in case of a station failure. This function is called *Recovering Protocol (RP).*

In the case of significant interference detection, which cannot be compensated on the local level, the centralized RRM can impose a more robust link on specific network sections. This function is called *Centralized Interference Mitigation (CIM).*

Finally, for the purpose of user data throughput maximization in the given segment (cluster), the centralized RRM may dynamically redistribute radio resources, providing some selected stations with more resources while other stations are provided with fewer resources, resulting in lower capacities. This function is called *Adaptive Resource Allocation (ARA).*

5.2 Description of the algorithms

The procedures related to Dynamic Frequency Planning (DFP) should be performed automatically upon initial RAN segment activation and after that periodically or event driven to take into consideration global evolutions of the radio access network deployment characteristics. The main purpose of the cluster radio resource management is to minimize interference impact in the system's deployment providing Centralized RRM-E with information available in other distributed RRM entities, e.g. ABSs (for example, to report interferences at a cell edge).

The centralized RRM entity collects all useful information required to adapt the frequency planning and allow channels allocations suiting the traffic load requirements

To avoid the performance degradation, these periodic updates should be scheduled while network load decreases (at night or during off-load hours). However, an operator can force the centralized algorithm to operate and then to update the overall channels allocation for the different stations. This process can be relevant especially while a station is being removed, added or modified.

Figure 5.1 then explains the algorithm in its fundamental steps.

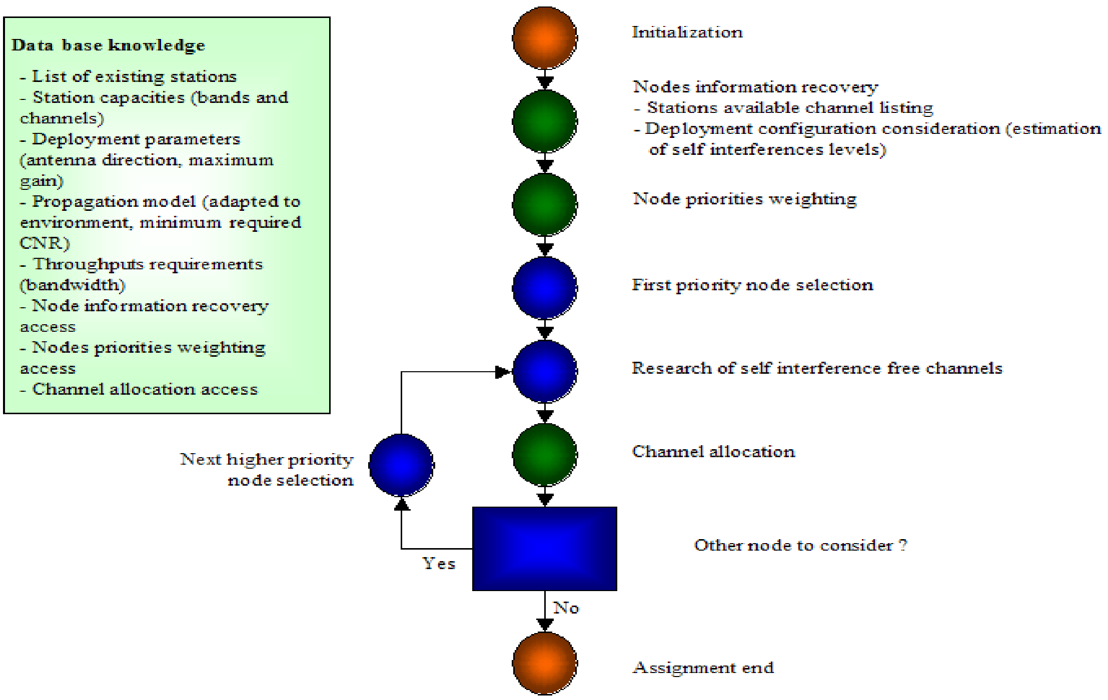

Figure 5.1: Dynamic frequency planning algorithm

As shown above, and apart from the initial state configuration, the process includes different sub-processes which will be depicted later. A certain amount of information about the network segment is required. Having prior fresh information will result in more effective channel allocation.

This information list includes the following parameters:

- List of ABS stations
- For each of those stations:
  - Deployment parameters:
    - Location
    - Antenna type (among a known list, for gain, and aperture)
    - Antenna orientation
  - Station capacities (time stamped):
    - Available bandwidth
    - Available channels (with interferences levels of them)
    - CNR/CINR threshold
  - Required throughput (time stamped)
- The general propagation model for the Network surrounding environment

Two of those information elements are critical and have to be known:

- List of ABS stations the centralized RRM-E is responsible for
- The adapted propagation model

The aforementioned frequency assignment process results in configuration of the relevant stations with the channels allowed for their usage.

The process starts with the identification of the network segment requirements in terms of throughput. Based on this information, different priorities are assigned for the corresponding stations. The priority of the station is the determinant factor for the channel assignment protocol, as the nodes with higher priority will be the firsts to get channel assignments, and, correspondingly, will be less dependent on other stations assignments.

Once the station prioritization is accomplished, nodes are iteratively assigned with a frequency channel, one channel at a time, meaning that after all stations were assigned a primary channel, the process restarts with the top priority station assigning a secondary channel and so on. The process terminates when no available channels have been left.

Finally the Centralized RRM-E sends the requests to each station informing it about the assigned frequency channels.

Figure 5.2 presents the steps required for the stations information collection process.

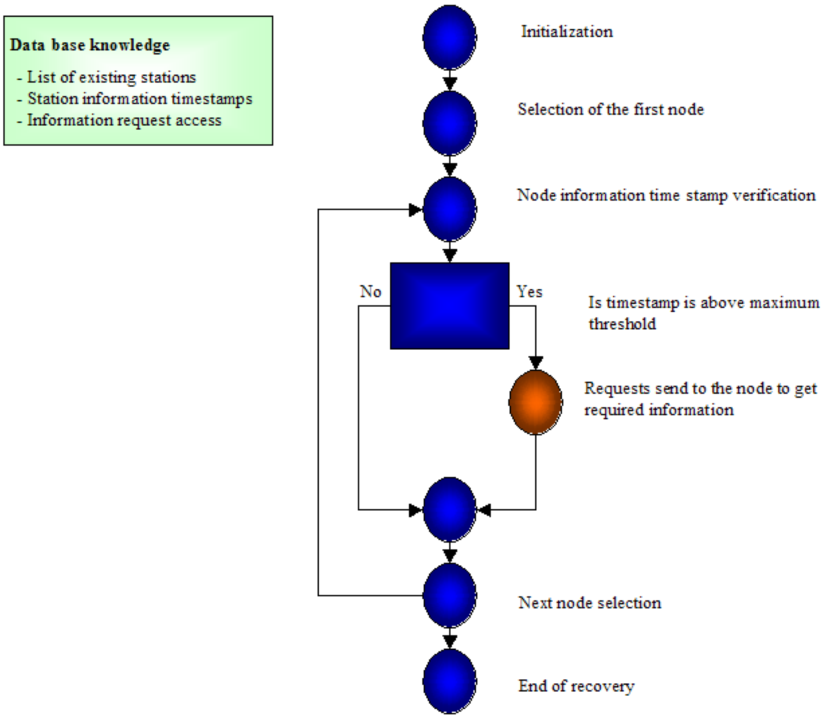

Figure 5.2: Stations information collection process

This process uses another set of primitives designed for the collection of information from the known stations. The details of those primitives are given in continuation.

In this process, the Centralized RRM-E is checking the timestamp of the data related to the corresponding node in order to ensure its freshness.

In the case of periodic information collection process, the delivered data may be suppressed, sending only the parameters that have been changed and thus reducing backhauling throughput requirements. Otherwise, if the process is event-driven, all the parameters have to be included in the response message.

Once the network database is updated, the stations are assigned with the priorities based on different kinds of parameters.

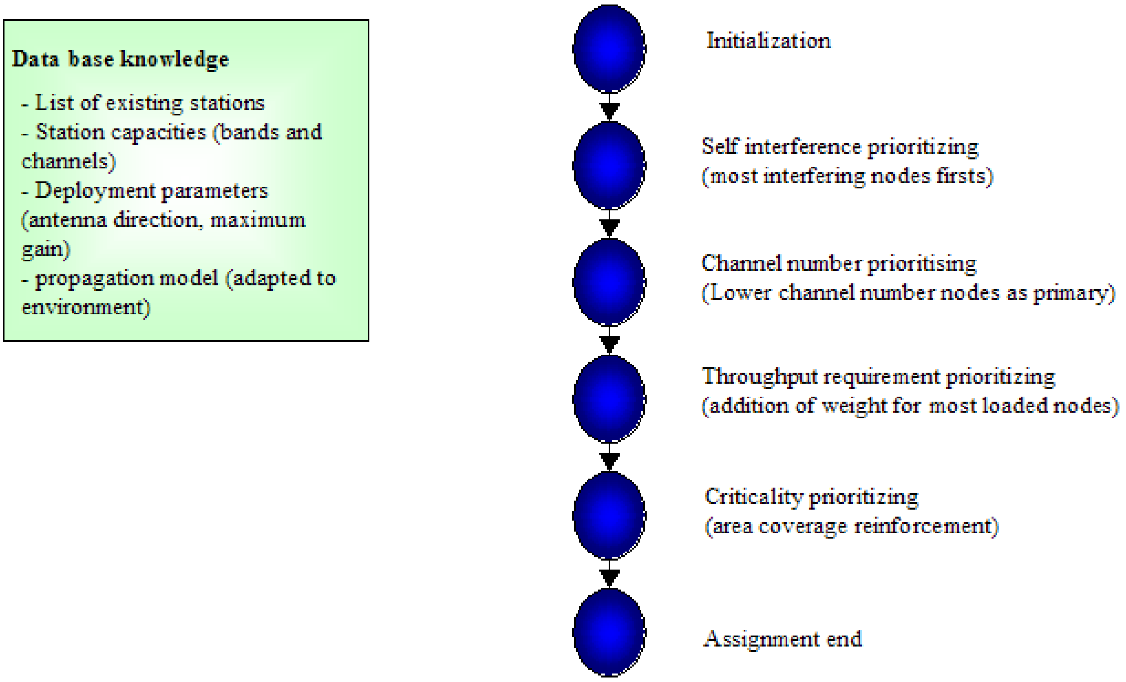

Figure 5.3: Stations prioritizing process

The first considered parameter is the level of interference with other stations of the list. Most interfering stations are assigned with higher priorities, so that they will be assigned with frequency channels before other stations.

This initial prioritization should be tempered with other operational requirements related to the stations location, coverage area, and their significance.

The priority value is increased for stations which have higher throughput needs (commercial areas, stadiums, etc.), stations having larger coverage (more risks of being jammed by external systems), or stations having a specific significance (serving the special events, providing coverage for the area with nearby station failure recovery, etc.).

Finally the stations are allocated with the frequency channels as depicted in figure 5.4.

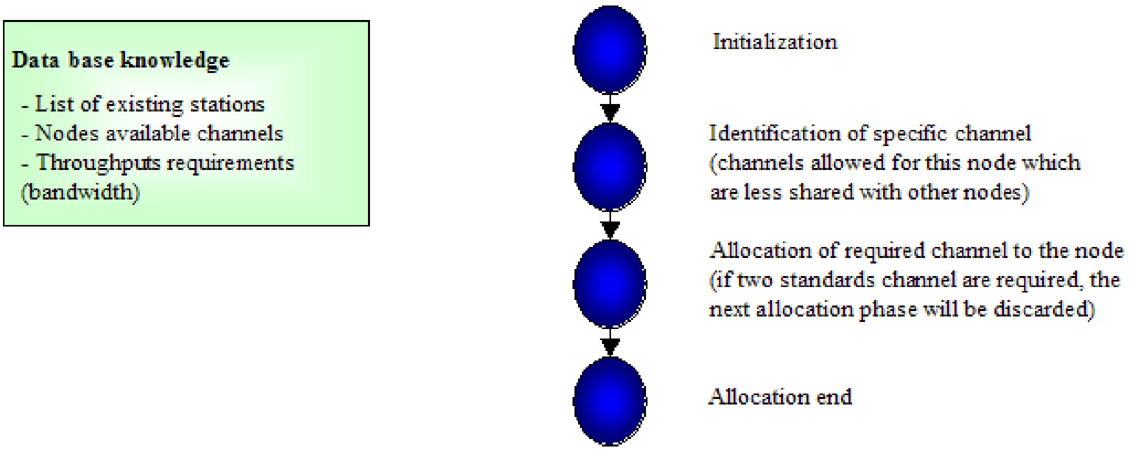

Figure 5.4: Channel allocation process

As presented above, the allocation process initially identifies if the considered station has more dedicated channels than others (channels with low interference, and not shared with neighbour stations). The dedicated channels are used before others to comply with the station bandwidth requirements. In order to avoid allocations with reduced channel spacing for a given node, channels should be allocated randomly inside the preferred frequency band.

After that, the actual allocation may be repeated depending on the station necessity for more bandwidth (e.g. two adjacent channels may be provided to increase the station capacity and peak rate).

5.2.1 Recovery procedure

The recovery procedure is based on the centralized dynamic frequency planning, with the additional aspect of station failure detection. In this procedure, stations status is periodically checked, just more frequently than the dynamic frequency planning.

This way the station failure can be detected quite quickly and the system can adjust to the new constraints. In the case of failure detection, the centralized RRM-E will firstly consider the neighbour stations power limitations, increase power if possible, and re-run the frequency channel assignment process.

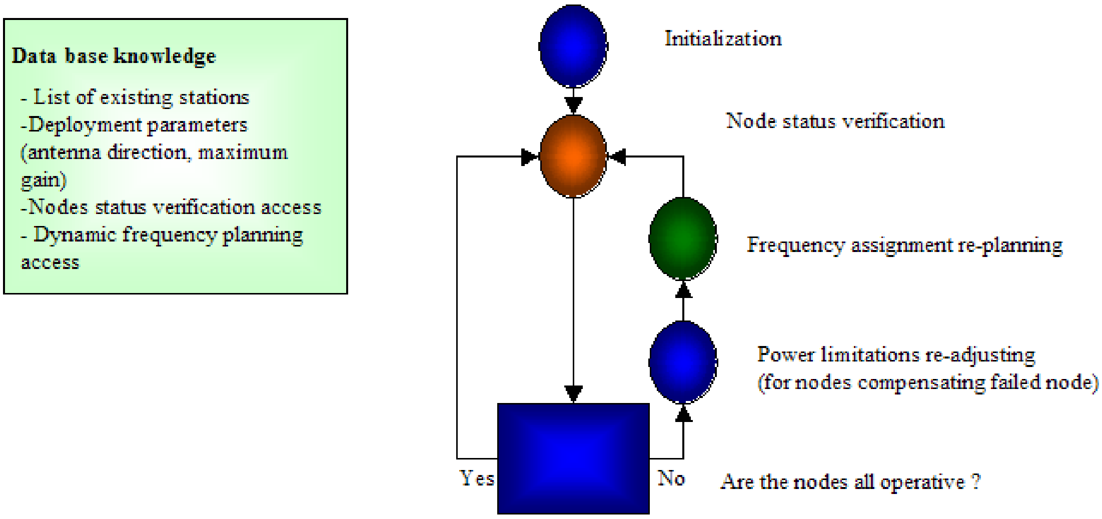

Figure 5.5: Station failure recovery procedure

5.2.2 Centralized interference mitigation

In the case that the station detects performance degradation below the threshold because of high interference level and no useable channels can be found locally with acceptable noise/interference levels, the request may be sent to the centralized RRM entity to readjust its dynamic frequency planning.

The request is sent including the node's current frequency channels. The subsequent frequency allocation procedure is performed considering the channels previously allocated to the given station as the lower priority channels. Then other resources will be selected and provided to the node for its local cognitive assignment decisions.

5.2.3 Adaptive resource allocation

In the case of some special events, such as New Year fests, throughput required in some hot-spots may drastically increase. The centralized RRM can then be triggered to readjusts its channel assignment model and to provide wider frequency bands to some ABSs. This process is basically the same as the dynamic frequency planning but with a direct wide band assignment for those stations.

5.2.4 Centralized RRM macro-application

The hierarchy of centralization nodes for radio resource management may be introduced because previously presented topology assumes centralized RRM entity for a number of Access Base Stations (e.g. collocating centralized RRM-E in HBS serving the associated ABSs). However, similar RRM-E function may be introduced at the higher level, managing multiple HBSs.

In the case of frequency bands sharing for backhaul and access tiers, the centralized RRM-E may be responsible for the channels distribution between HBSs and ABS. In this situation, the algorithm should be adjusted to consider backhauling tier propagation model (HBS multi-beam antenna, etc.). Also, the Backhaul Tier stations (HBSs) should be provided with higher priority than access base stations.

5.2.5 Control plane primitives

The following clause presents control plan message flows and primitives designed to support the centralized RRM-E concept.

5.2.5.1 Information request

The purpose of Information request procedure is to collect the radio-related measurements from the particular BS in order to provide the centralized RRM Entity with a clear knowledge of the current status.

The message flow corresponding to this request is illustrated in figure 5.6.

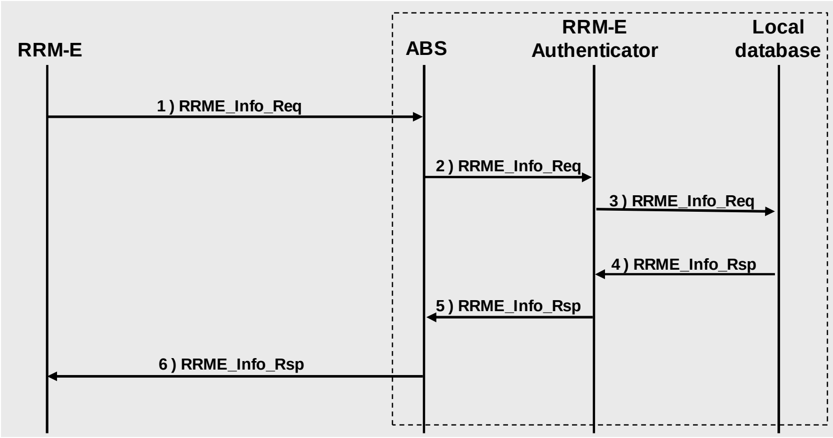

Figure 5.6: Information request message flows

Step 1

The centralized RRM-E sends an *RRM-E_Info_Req* message to each of its ABSs. Messages are forwarded through HBS and HSSs to reach ABSs.

Step 2

Each ABS forwards the request to its collocated RRM-E Authenticator, which checks the source RRM-E validity.

Steps 3 and 4

If authorized, the request is forwarded to the local RRM information database. The Response message is sent back with the *Status_Table* including the different available channels, measured interference levels, and deployment specificities.

Steps 5 and 6

The ABS sends back the successful response message to the RRM-E.

Table 5.1: RRM-E_Info_Req

Message purpose	Query RRM-related information from a node	
Trigger for the message generation	Triggered by the centralized RRM-E	
Source	Centralized RRM-E	
Destination	ABS	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
RRM-E_Id	M	The centralized RRM-E identifier to be recognized by ABSs.
ABS Id	M	The identity of the station, which information is requested.
Information Key	M	Bitmap indicating what information is requested.

Table 5.2: RRM-E_Info_Rsp

Message purpose	Delivers RRM related information (such as deployment and capacity information) to the centralized RRM-E	
Trigger for the message generation	Triggered by an Information request message (*RRM-E_Info_Req*)	
Source	ABS	
Destination	Centralized RRM-E	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
Status_Table	M	Contains ABSs deployment specificities (GPS location, antenna type and aiming direction), and RF capacities (available channels, output power, interferences levels if known).
Failure Indication	O	Failure indication providing the code of the corresponding error cause.

5.2.5.2 New station insertion indication

A new station insertion requires RRM adaptations. A new ABS acceding the access network and successfully recognized by the AAA server sends an insertion request to the centralized RRM entity.

The corresponding message flow is illustrated in figure 5.7.

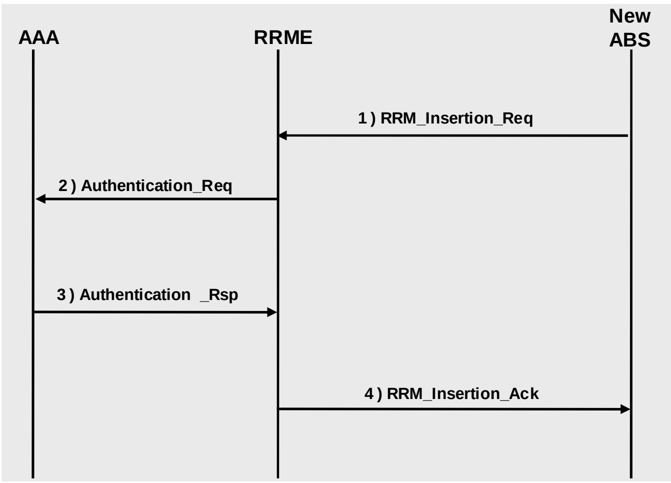

Figure 5.7: A new station insertion message flow

Step 1

The newly arrived ABS generates and sends *RRM_Insertion_Req* message to the Centralized RRM-E, including the deployment topology related information (such as e.g. a location, etc.) and its authentication parameters.

Step 2

Based on the ABS geo-location, the Centralized RRM-E decides whether it takes responsibility of the new coming station. If positive, the Centralized RRM-E authenticates the received request with AAA server by sending *Authentication_Req* message to AAA. Otherwise, the centralized RRM-E responds back with *RRM_Insertion_Ack* message with Failure Indication parameter indicating the error cause (e.g. "wrong domain").

Step 3

AAA authenticates the request message and if positive, sends *Authentication_Rsp* message, authorizing ABS operation to the Centralized RRM-E and providing the corresponding authorization parameters. If authentication fails, AAA returns "authentication failure" indication.

Step 4

The Centralized RRM-E responds to the ABS with *RRM_Insertion_Ack* message. If necessary, a new dynamic frequency planning will be performed. In the case "authentication failure" indication has been provided by AAA server, the Centralized RRM-E sends *RRM_Insertion_Ack* message with Failure Indication set to the value providing the error cause (e.g. "request authentication failure").

Table 5.3: RRM_insertion_Req

Message purpose	Request for a new station insertion in the access network	
Trigger for the message generation	Triggered by the new node/station activation	
Source	ABS	
Destination	Centralized RRM-E	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
ABS Id	M	The identifier of the ABS node.
Deployment Topology Info	M	The information blob including parameters related to the station deployment (such as e.g. station location, antenna pattern direction and tilt, etc.).
ABS Authentication Extension	M	Authentication extension providing the capabilities for message source authentication and possibly providing other security means (such as message integrity protection and non-repudiation).

Table 5.4: RRM_insertion_Ack

Message purpose	Respond for the new station insertion request, providing the result of operation and the station operational parameters	
Trigger for the message generation	Triggered by RRM_insertinon_Req message reception and request authentication transaction completion	
Source	Centralized RRM-E	
Destination	ABS	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
ABS Id	M	The identifier of the ABS node.
RRM-E_Id	M	The centralized RRM-E identifier to be recognized by ABSs.
Result Indication	M	Provides the result of the "insertion" operation (success, failure).
RRM Config	O	Radio configuration parameters to be used by the station. It includes the list of the selected frequency channels available for local assignment.
Failure Indication	O	Failure indication providing the code of the corresponding error cause.

5.2.5.3 Capacity overload indication

Overload alarm is sent by the station to the Centralized RRM-E to indicate increase in the node throughput requirements. If possible, the Centralized RRM-E will provide the node with a larger frequency band and/or better quality channels in order to improve its performance.

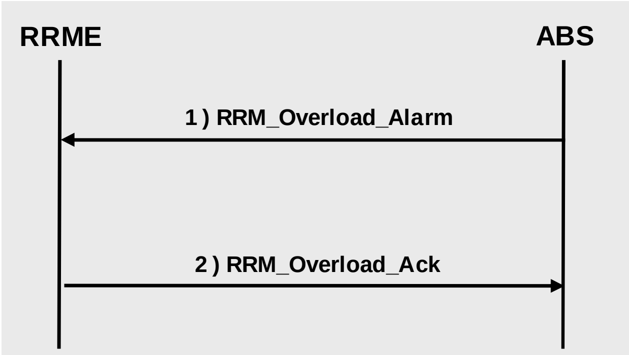

Figure 5.8: Overload alarm message flow

Step 1

While triggered by the threshold overstep, the ABS sends *RRM_Overload_alarm* message to the Centralized RRM-E. This message includes indication of its throughput needs.

Step 2

The Centralized RRM-E receiving the alarm, sends back an acknowledgment to the ABS. If possible, it will send later another message providing the ABS with the required resources.

Table 5.5: RRM_Overload_Alarm

Message purpose	Provides signal indicating the station throughput overload to the Centralized RRM-E	
Trigger for the message generation	Triggered by the station throughput crossing the predefined threshold	
Source	ABS	
Destination	Centralized RRM-E	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
ABS Id	M	The identifier of the ABS node.
RRM-E_Id	M	The centralized RRM-E identifier.
Current throughput	O	Current throughput level (indication for RRM-E to allocate sufficient bandwidth).
Required throughput	O	Indicates the station capacity demand.

NOTE: *RRM_Overload_Ack* message serves the purpose of the message transaction completion and does not include any parameters.

5.2.5.4 Station re-configuration request

The purpose of this message is to send the actual configuration parameters to the station.

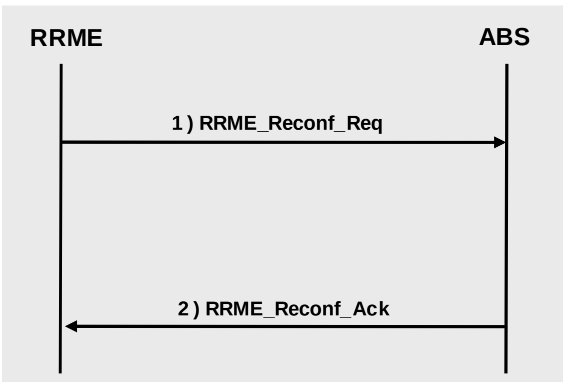

Figure 5.9: Re-configuration request message flow

Step 1

The RRM-E sends for each node under its responsibility a personalized message including the required configuration.

Step 2

The ABS checks that the originated RRM-E is the right one. If legitimate, the node will answer an acknowledgement to the re-configuration request and adapt its functional parameters.

Table 5.6: RRM-E_Reconf_Req

Message purpose	Delivers RRM configuration parameters to the ABS	
Trigger for the message generation	Triggered by successful DFP procedure completion	
Source	Centralized RRM-E	
Destination	ABS	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
RRM-E_Id	M	The centralized RRM-E identifier.
ABS Id	M	The identifier of the ABS node.
Reconfig Reason	M	Indicates the reason of the station reconfiguration.
RRM Config	M	Radio configuration parameters to be used by the station. It includes the list of selected frequency channels available for local assignment.

Table 5.7: RRM-E_Reconf_Ack

Message purpose	Response for *RRM-E_Reconf_Req* message	
Trigger for the message generation	*RRM-E_Reconf_Req* message reception	
Source	ABS	
Destination	Centralized RRM-E	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
Result Indication	M	Provides the result of the "re-configuration" operation (success, failure).
Failure Indication	O	Failure indication providing the code of the corresponding error cause.

5.3 Autonomous distributed cognitive radio dynamic frequency assignment

The primary goal of the presented system is to improve the overall capacity density of the mobile network to 1 Gbit/s/km^2 anywhere in the service area. In order to meet this ambitious goal, a number of novel advanced techniques have been introduced, including the application of a dual-hop system, multi-beam directional antenna, multi-beam assisted MIMO and collaborative MIMO, and cognitive radio techniques. The complex dual-hop architecture not only leads to a greater level of interference, but also requires a higher level of complexity in radio resource management. Spectrum decisions are therefore better to be made autonomously in a distributed fashion in order to achieve the aggressive target of 1 Gbit/s/km^2 throughput density. A cognitive radio based technique is a feasible approach for the joint design of the resource management of the access and self-backhaul networks. By combining the abilities of spectrum awareness, intelligence and radio flexibility, cognitive radio based approach is able to adapt the network itself to the changes in the local environment. Compared with conventional dynamic radio resource management approaches, cognitive radio based techniques have the potential to improve spectrum efficiency, reduce overall complexity, and enhance link reliability. The advantages of the reinforcement learning based schemes are clear that not only they have the potential to outperform non-learning schemes, but also the self-organizing features enabled by learning are particularly desirable the complex resource management tasks pertinent to this system.

The cognitive radio based approach for this system can be briefly illustrated by figure 5.10. There are mainly three steps in the communication process: Frequency Awareness, Frequency Resource Management and Action. After receiving a transmission request, the operating cognitive radio based base station/mobile user will firstly obtain the information of frequency availability either by monitoring channel utilization database or through spectrum sensing. Then a decision is made at the frequency resource management part. An intelligent frequency decision making process is enabled through learning and reasoning. After that, the system will adapt some of the parameters and then start to transmit data.

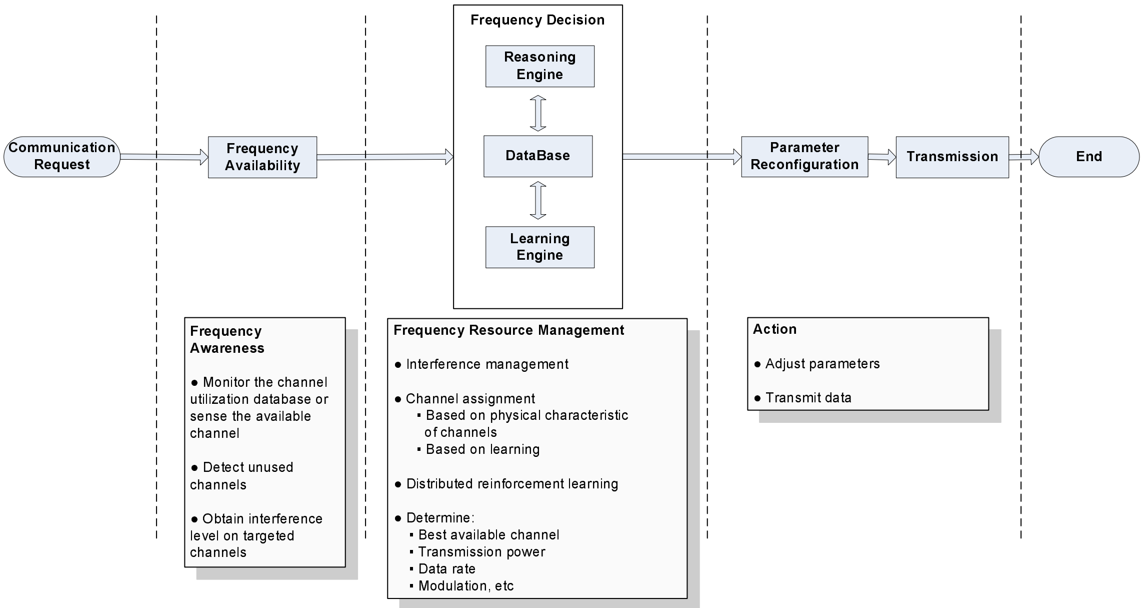

Figure 5.10: Cognitive radio based RRM

Cognitive radio frequency assignment techniques have been developed for all the entities in this system, including both access and in-band backhaul radio networks in principle, in relation to the use of un-licensed spectrum or the designated licensed spectrum. A basic spectrum sensing based dynamic frequency assignment approach is expected to perform better on the HBS - ABS links than on the ABS - MS links since the HBSs and ABSs are all spatially fixed and hence more stable. However, our research shows that the learning based cognitive radio algorithms works well in such scenario.

5.3.1 Spectrum sensing based dynamic frequency assignment

Spectrum sensing is a process where a cognitive radio scans the available frequency bands, estimating the interference level on each of them. Based on the interference estimation the cognitive device can then select the most appropriate frequency channel to use. This cognitive capability is one of the most distinguishing features of cognitive radio [i.2]. The spectrum awareness aspect helps capture the variations of the radio environment over a period of time or space. It provides the opportunity to fundamentally change the way we manage the radio frequency. Through this capability, the frequency opportunities will be identified distributedly, dynamically and autonomously. The available frequency band and the appropriate transmitting parameters can then be selected. This is the basis of the on-line interaction between cognitive radio and the unpredictable environment.

A low complexity spectrum sensing approach or a channel usage database is suggested for performing the frequency awareness process. Information of spectrum utilization is obtained either through a database or spectrum sensing. Perfect sensing may be not desirable, since there are still challenges in developing perfect spectrum sensing techniques, and such challenges may keep perfect sensing techniques years away from implementation. Limited sensing capability has the potential to deliver much of the required performance by combining it with other advanced techniques, like learning.

Note that the spectrum sensing based approach was described in [i.1]. It shows that the coverage of the pure frequency planning approach provided to the indoor MSs is poor, if no further means of indoor coverage (e.g. femto-cells) are assumed.

Thus, a low-cognition low-complexity spectrum sensing approach has been suggested to improve the coverage for the indoor and outdoor MSs. The details of the basic spectrum sensing algorithm are illustrated in figure 5.11.

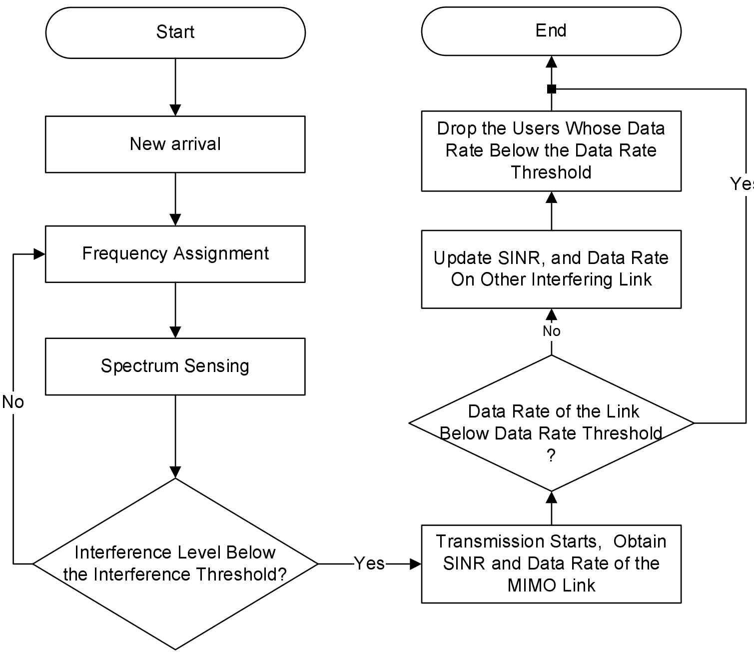

Figure 5.11: Cognitive radio based RRM

The difference between the Spectrum Sensing based Dynamic Frequency Assignment (SSDFA) and the pure frequency planning approach is that before initializing the transmission on the targeted sub-channels, a spectrum sensing is carried out on the targeted channel. The transmission will only be permitted when a satisfactory sub-channel has been discovered (interference level below threshold). It is assumed that the spectrum sensing is carried out at the receiver end of the wireless link. This system is designed primarily for a dense urban area where the propagation environment is very complex. The utilization of directional antennas in such areas makes it possible that the received signal power and the interference power vary significantly in a few meters in range. Thus, spectrum sensing at the transmitter is not accurate enough to identify the interference level on the targeted channel. Spectrum sensing at the receiver end therefore is the more desirable in this case. The performance of the SSDFA algorithm is compared with the pure frequency planning approach and the learning based approach in the following clause.

5.4 Learning based cognitive dynamic frequency assignment

5.4.1 Overview and general objectives

Cognitive techniques, such as spectrum sensing and learning, are able to provide a very aggressive frequency reuse while reducing the radio resource management complexity. The learning based cognitive radio algorithm, we introduced in this clause, completely removes the needs for any frequency plan. All frequency channels are equally available to all entities, and the channel decision will be made individually by the entities in a distributed fashion. Thus the complexity of radio resource management is significantly reduced.

Reinforcement learning [i.3] is a machine learning approach where an agent learns from trial-and-error interactions within unknown environment. It can be configured in a distributed way, where the learning depends only on localized information. Therefore, reinforcement learning is perfectly suited to distributed decision making. The reinforcement learning based RRM approaches presented in this clause have been developed for both of the self-backhaul network and the access network. In other works, we primarily concern with the end-to-end link performance (HBS-ABS-MS link). Available frequency bands are periodically monitored, through a channel utilization data base or spectrum sensing. Learning techniques will then utilize the information gained in sensing. In this case a single learning engine processes the information for both hops of the wireless link simultaneously as shown in figure 5.12. The goal is to enable an efficient autonomous spectrum sharing between entities through a reliable dynamic channel assignment algorithm.

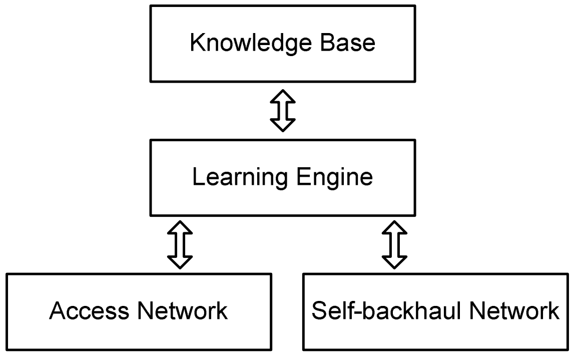

Figure 5.12: Learning Engine for Beyond Next Generation Mobile Network

The state of the environment and the learning system is extremely difficult to define in a fully distributed system scenario. Thus a single-state reinforcement learning approach is highly desirable for system's distributed RRM. A linear reward single-state reinforcement learning based cognitive radio channel assignment approach is proposed for in this clause. The channel assignment algorithm described in [i.1] is shown in figure 5.13. Subchannels are allocated based on the level of interference on the subchannels and the experience gained through learning. We consider E_i is entity i in the described system. E_i is element of E and E is the entity set that contains all reinforcement learning based BS and MS. By randomly choosing subchannels, the operating entity E_i will explore the spectrum space first. After a number of used subchannels have been discovered, the user will then exploit high weight subchannels with a higher priority.

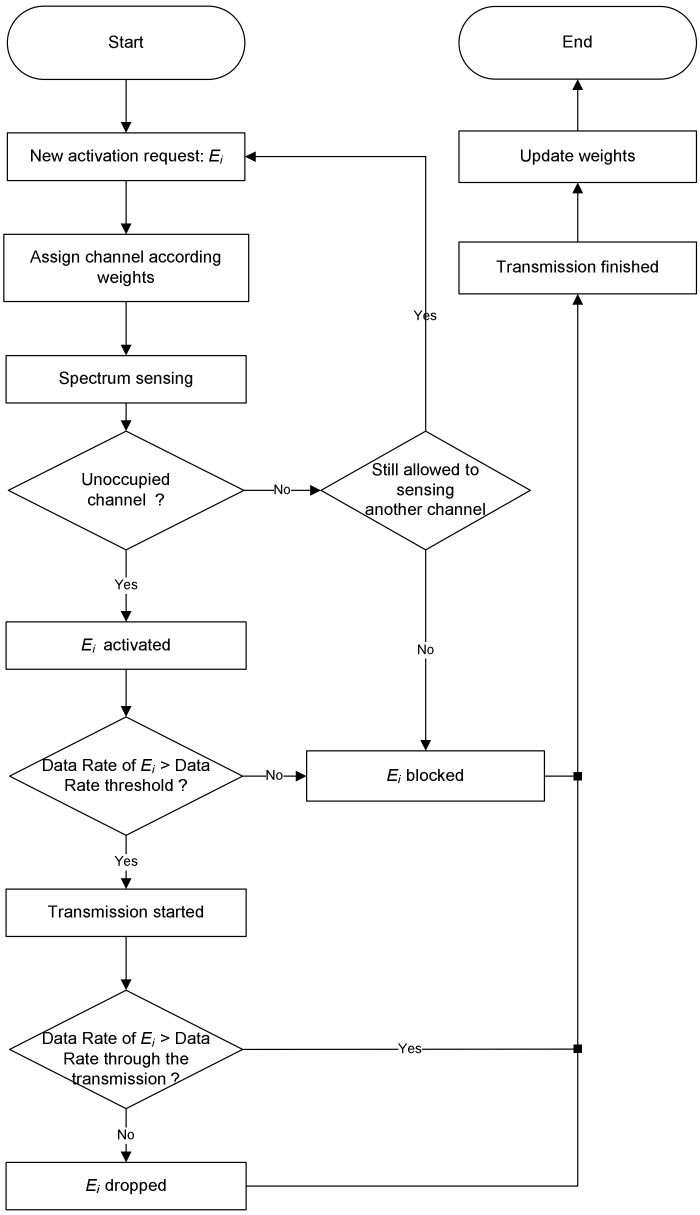

Figure 5.13: Reinforcement learning based channel assignment algorithm

By using reinforcement-based learning, entities in this system will assess the success level of a particular action. This, in our scenario, is whether the target channel is suitable for the considered communication request. According to the previous judgments, a reward is assigned in order to reinforce the weight of the physical resource. The concept of "weight" is a number assigned to a resource, and the number reflects the importance of the resource to a certain entity. Entities select channels to use based on the weights assigned to the spectral resources - resources with higher weights are considered higher priority.

A key element of reinforcement learning is the value function.

The protocol needs to be properly defined to support the fully distributed cognitive functions in terms of the end-to-end links. A certain amount of control information needs to be exchanged between the transmitter and the receiver. The control information overhead incurred in the Cognitive Radio Dynamic Channel Assignment process is not expected to be high. A downlink transmission request with the available subchannel information to the receiver and an uplink response back to the transmitter with the subchannel discovered in sensing are the information that needs to be exchanged.

Spectrum Sensing is a process where Cognitive Radio device scans the available frequency band, in this system's case subchannels, estimating the interference level of one or more of the entities within the band. It is suggested for this system that full spectrum sensing is periodically carried out at the base stations, i.e. ABSs and HBSs. Limited spectrum sensing is carried out at the MS, in order to verify that the channels selected at the ABS for downlink transmission are suitable.

MS devices are assumed to have only basic cognition capabilities, in order to facilitate the operation of the protocol (to protect against hidden terminals). The RRM decision is made at the ABS side for the access network, with the subchannels selected at the ABS being checked prior to use for excessive interference.

All leaning based devices are assumed to learn in a fully distributed fashion and learning is assumed at both HBS-ABS link and the ABS-MS link for Cognitive Dynamic Frequency Assignment.

The learning data base is assumed to be kept at ABSs for both self-backhaul network and the access network.

5.4.2 Functional decomposition and message flows

Cognitive Dynamic Frequency Assignment (Sensing and Learning): learning will only prioritize the available subchannels for individual entities distributedly based on the weight information gained by the entities. The weight is updated according to successful or unsuccessful transmission attempts based on the flowcharts in figures 5.14 and 5.15. The weight information is practically a vector of weight values of different subchannels for each MS. The weight vector and the available channel list are the information required to be exchanged between the transmitter and the receiver of a wireless link in order to support the Cognitive Dynamic Frequency Assignment techniques.

The message flows of the end-to-end links are illustrated in figures 5.14 and 5.15.

- Uplink:
  - ABS-MS link:
    1) MS sends transmission request to the associated ABS.
    2) ABS obtains the interference measurements (from periodic sensing) on the available subchannels and makes a decision according to the weight vector stored at the ABS.
    3) ABS sends an acknowledgement back to the MS which contains the selected subchannel indices. (The acknowledgement could be replaced by the uplink broadcasting map).
  - HBS-ABS link:
    1) ABS (HSS) sends transmission request to the HBS with the weight vector.
    2) HBS obtains the interference measurements (from periodic sensing) on the available subchannels and makes a decision according to the weight vector.
    3) HBS sends an acknowledgement back to the ABS (HSS) which contains the selected subchannel indices. (The acknowledgement could be replaced by the uplink broadcasting map).

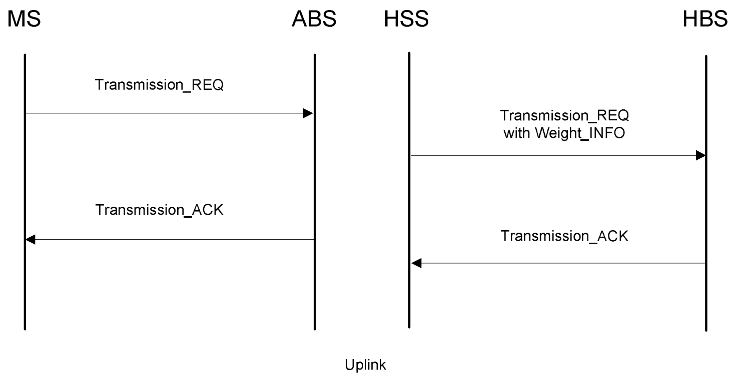

Figure 5.14: Uplink Message Flow

- Downlink:
  - HBS-ABS link:
    1) HBS sends a sensing request to the targeted ABS (HSS) with the available subchannel list.
    2) ABS (HSS) obtains the interference measurements (from periodic sensing) on the available subchannels.
    3) ABS (HSS) sends a sensing response back to the HBS which contains the interference measurements and the weight information stored at the ABS.
    4) HBS makes a decision and assigns subchannels to the transmission.
  - ABS-MS link:
    1) ABS initially selects best available subchannels for the new transmission according to the weight vector stored at the ABS and the interference levels on the available subchannels.
    2) ABS sends a sensing request to the targeted MS with the selected subchannel indices.
    3) MS verifies the selected subchannels and sends a response back to the ABS.
    4) ABS makes a decision and assigns subchannels to the transmission.

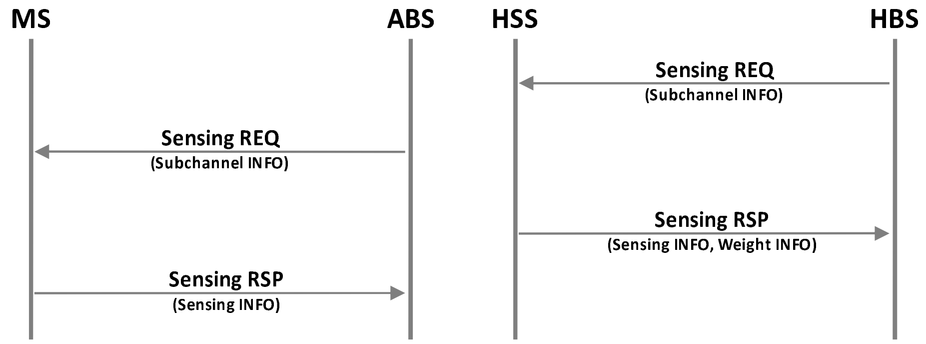

Figure 5.15: Downlink Message Flow

5.4.3 Control plane primitives

Table 5.8: Transmission_REQ

Message purpose	Indicates that new transmission is needed	
Trigger for the message generation	When uplink transmission needs to be initiated	
Source	RRM entity in HSS, or MS	
Destination	RRM entity in targeted ABS or HBS	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
Transmitter_ID	M	Identifier of the entity sending the message.
Receiver_ID	M	Identifier of the entity receiving the message.
Weight Info	O	Used in *Transmission_REQ* sent from ABS (HSS) to HBS to exchange learning information (weights of subchannels) between ABS and HBS. Includes Weight-vector values of the available subchannels.

Table 5.9: Transmission_ACK

Message purpose	Acknowledges the *Transmission_REQ* and completes the service initiation process	
Trigger for the message generation	*Transmission_REQ* has been received	
Source	RRM entity in HBS or ABS	
Destination	RRM entity in MS or HSS	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
		No IEs are required.

Table 5.10: Sensing_REQ

Message purpose	Indicates spectrum sensing is needed from the receiver	
Trigger for the message generation	When a downlink transmission needs to be initiated, interference measurements need to be obtained at the receiver	
Source	RRM entity in HBS, ABS	
Destination	RRM entity in targeted HSS, MS	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
Transmitter_ID	M	Identifier of the entity sending the message.
Receiver_ID	M	Identifier of the entity receiving the message.
Subchannel Info	M	Subchannels list used to notify the receiver of the available subchannels. Included in *Sensing_REQ* message sent from HBS to ABS (HSS) or from ABS to MS and contains IDs of the available subchannels.

Table 5.11: Sensing_RSP

Message purpose	Delivers spectrum sensing measurements back to the transmitter base station	
Trigger for the message generation	*Sensing_REQ* has been received	
Source	RRM entity in HSS, MS	
Destination	RRM entity in HBS, ABS	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
Transmitter_ID	M	Identifier of the entity sending the message.
Receiver_ID	M	Identifier of the entity receiving the message.
Sensing Info	M	Interference measurements on the scanned subchannels.
Weight Info	O	Used in *Sensing_RSP* sent from ABS (HSS) to HBS to exchange learning information (weights of subchannels) between ABS and HBS. Includes Weight-vector values of the available subchannels.

5.5 Cognitive and docitive RRM

This clause forms a general introduction to docition and learning from a control and signalling point of view. We introduce the basic features of learning and docition and stress the features that are critical for control and signalling. We based this clause in the learning and docition introduced in [i.1]. The learning procedure we are considering here is from the decentralized type that is that the learning entity (ABS) does not need information from any central entity to decide for the best RRM policy. Additionally, we focus on docition, that is when the ABS share information in order to increase the speed of convergence of the learning algorithms. We assume that there are no direct radio communications between ABSs, as a consequence we assume that the ABSs communicate each other through the HBS. Next clause deals with the joint learning of power and sub-channel and is thus a specific case of the general case presented here.

5.5.1 Feature overview

The main features we want to study are: Learning and Docition. In the following we briefly introduce them:

Learning is an iterative procedure by means of which an ABS is able to learn an RRM policy. The learning procedure is totally distributed, which means that the RRM policy decision is done independently at each ABS. Here we focus on the case where the ABS only needs information available at their MS and at the ABS itself to draw intelligent decisions. Additionally, we assume that RRM entity of the ABS knows the set of available channels which have been previously provided to the ABS by any of the mechanism. In order to carry on the learning procedure, the ABSs need to estimate the access capacity that is the MS-ABS channel capacity. We assume that no extra-signalling or information is needed to estimate said capacity beyond the regular ACK and MCS reports used in most of the standards like LTE or WiMAX™. We assume that the RRM policy consists of selecting the power level and a subchannel, the learning is done dynamically and it adapts to the network changes. We assume that when an ABS detects a drop in performance, it is able to start a new learning procedure and find again the optimal RRM policy.

Docition is complementary to learning; it assumes that the ABSs are able to exchange information concerning the learning procedure in order to speed-up the learning and reach higher performance. We consider the case of Strat-up docition which is used when a new ABS joins the network or when there is drop in performance due to a network state change. Strat-up docition is done before starting a learning procedure. Description of the main docitive elements considered in this clause is provided below:

- **IQ value:** it contains information about the "intelligence" of the ABS, it is usually related to the performance of the RRM SON engine in the ABS. There are several methods to gauge IQ value, concerning the specific SON algorithm used by the ABS, in [i.4] and [i.5] there are several examples.

- **Docitive info:** is referred to internal states of the RRM SON engine in the ABS. Specifically, in Q-learning, it refers to the Q-values estimates of the Q-table. In case of other SON algorithms it refers to information related to the internal SON policy.

5.5.2 Functional decomposition

The learning capabilities of the ABS allow the ABS to dynamically adapt its MCS, subchannel used and power transmitted. In here we focus only in the subchannel and transmit power case. In the case of the ABSs switching the transmit subchannel the ABS RRM entity should inform the MS RRM entity of that change.

Docition: the learning ABS requests the HBS for docitive information, the HBS asks other ABSs for docitive information and sends the best docitive information to the learning ABS. It can be partitioned in two parts:

- Docition: RRM Client in ABS requests the RRM Server in HBS to send docitive information. The RRM Server in HBS sends the best docitive information to the RRM Client in ABS.

- Request IQ: the HBS requests the associated ABSs in the network to send their IQ values, after that the HBS selects the ABS with better IQ value which is requested to send docitive information to the HBS.

The flow diagram of both docition and learning is depicted in figure 5.16 where the bluish boxes require extra control messages and are explained in the following clauses.

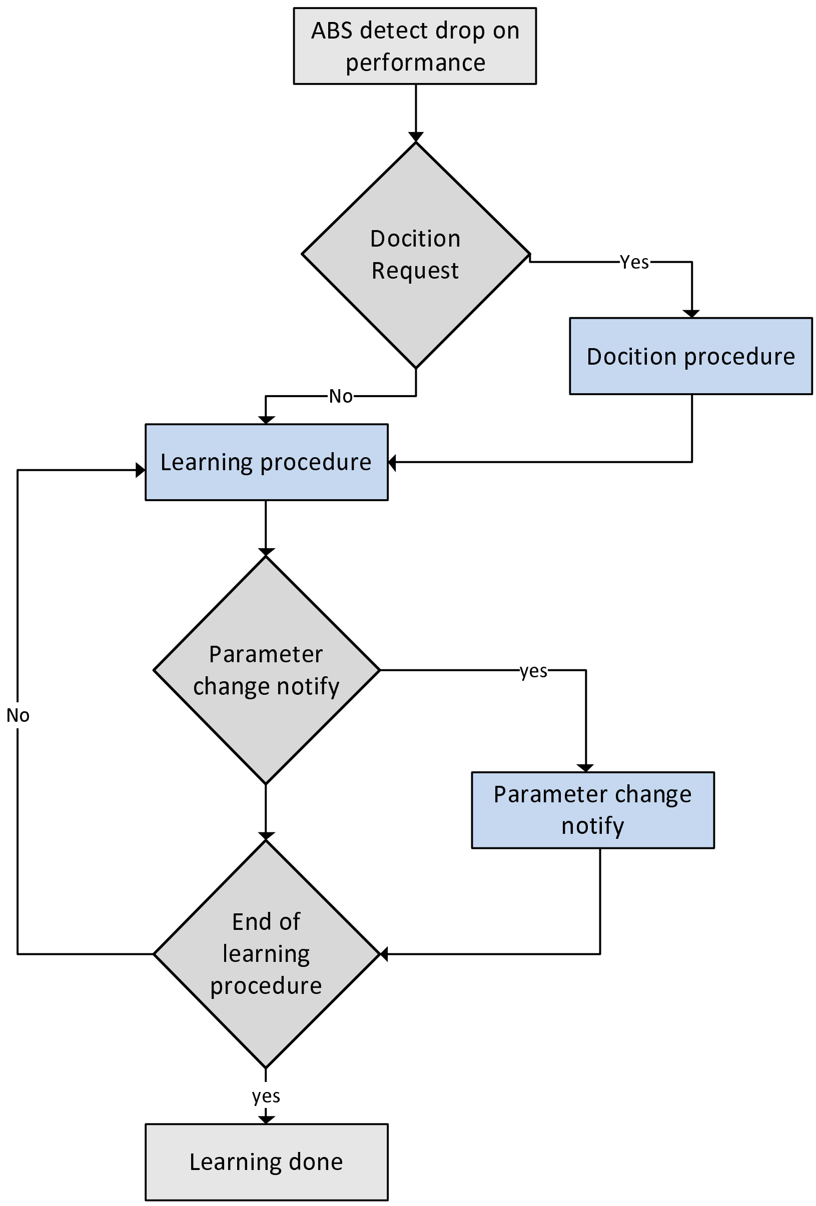

Figure 5.16: Flow diagram of learning and docition procedures

5.5.3 Message flows

The following clauses present the relevant message flows for the Learning and Docition procedures.

Learning procedure

ABS detects a drop on performance and decides to not get docition.

1) ABS may decide to request docition or directly start the learning procedure.
2) ABS starts learning procedure.
    i) ABS estimates the channel capacity and decides best power-subchannel to transit through.
    ii) In case ABS changed the transmit channel, ABS send to MS the new parameters.
3) ABS finishes learning procedure.

As we have mentioned before, the learning procedure is fully-decentralized and, as a consequence, there are no additional control messages to send between ABS and the other entities except in the case when the ABSs changes the transmit subchannel, which is studied in detail in the next clause.

Docition procedure

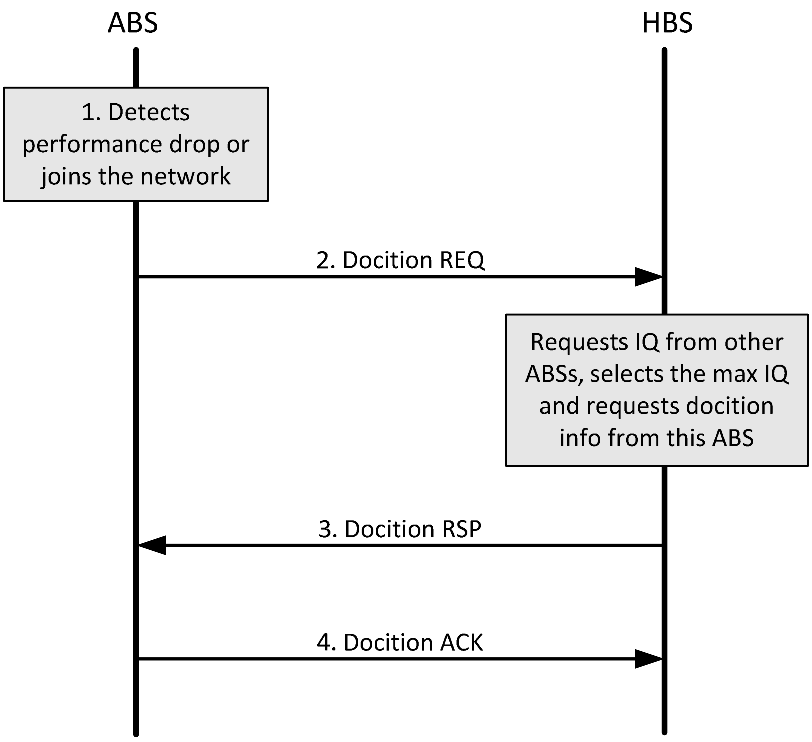

Figure 5.17: Docition procedure

1. ABS detects drop of performance or ABS joint the network.
2. ABS request HBS to send docitive info.
3. HBS sends to ABS docitive info. (REQUEST IQ).
4. ABS sends conformation on the docitive info completing the communication transaction.

Request IQ procedure

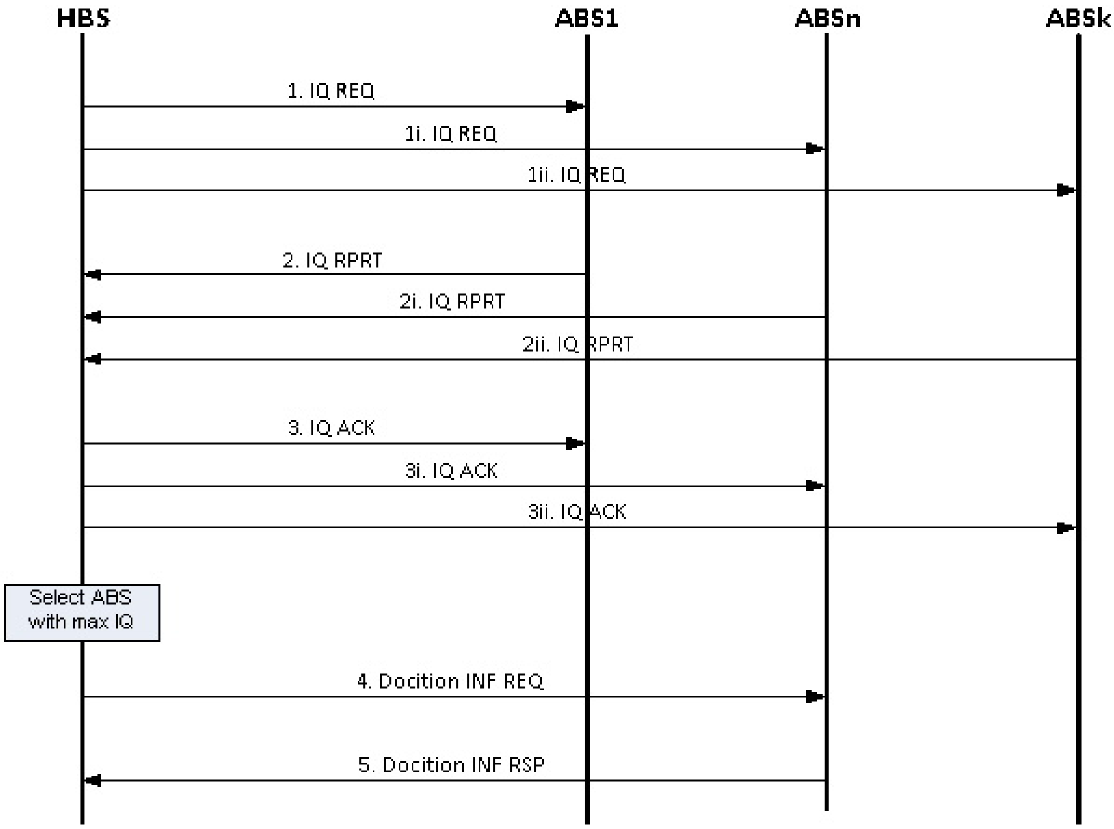

Figure 5.18: Request IQ procedure

1. HBS requests IQ value from all the associated ABSs by sending *IQ_REQ* message.
2. ABSs send IQ values in *IQ_RPRT* message.
3. HBS confirms the received IQ values and transaction completion by sending *IQ_ACK* message. Then, HBS selects the ABS with max IQ value.
4. HBS requests higher IQ ABS to send its docitive info using *Docition_INF_REQ* message.
5. Higher IQ ABS sends docitive info to HBS in *Docition_INF_RSP* message.

5.5.4 Protocol primitives description

Table 5.12: IQ_REQ

Message purpose	Indicates the ABS to compute and send the IQ value to the requesting HBS	
Trigger for the message generation	Triggered by *Docition_REQ* message reception from ABS - when a Hub BS is required to start docition	
Source	RRM entity in Hub BS	
Destination	RRM entities in the associated ABSs	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
Source ABS Id	M	Identifier of the ABS that sends the message Docition_REQ.
IQ Id	M	Indicates the type of IQ value required.

Table 5.13: Docition_REQ

Message purpose	Indicates the HBS that ABS requires docition	
Trigger for the message generation	When an ABS starts up or detects a drop on performance and requires docition	
Source	RRM entity in ABS	
Destination	RRM entity in Hub BS	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
IQ Id	M	Indicates the type of IQ value required.

Table 5.14: Docition_INF_REQ

Message purpose	Once an HBS has collected IQ values from several ABSs and selected the ABS with max IQ value, an HBS requests the best ABS to send docitive info	
Trigger for the message generation	After evaluating the IQ values of the ABSs received in the *IQ_RPRT* messages	
Source	RRM entity in Hub BS	
Destination	RRM entity in ABS	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
Doc_Id	O	Indicates the type of docitive info required.

Table 5.15: IQ_RPRT

Message purpose	An ABS reports its IQ value to the HBS	
Trigger for the message generation	Triggered by receiving *IQ_REQ* message from HBS	
Source	RRM entity in ABS	
Destination	RRM entity in Hub BS	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
IQ	M	IQ value of the ABS.
Failure Indication	O	Failure indication providing the code of the corresponding error cause.

Table 5.16: Docition_INF_RSP

Message purpose	An ABS sends docitive info to the HBS	
Trigger for the message generation	Triggered by receiving a *Docition_INF_REQ* message	
Source	RRM entity in ABS	
Destination	RRM entity in Hub BS	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
Doc_info	M	Docitive information (i.e. Q values).
Doc_Id	O	Indicates the type of docitive info transmitted.
Failure Indication	O	Failure indication providing the code of the corresponding error cause.

Table 5.17: Docition_RSP

Message purpose	A Hub BS sends the selected docitive info to the ABS	
Trigger for the message generation	Triggered by receiving a *Docition_INF_RSP* message providing docitive info from the "best" ABS	
Source	RRM entity in Hub BS	
Destination	RRM entity in ABS	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
Doc_info	M	Docitive information (i.e. Q values).
Doc_Id	O	Indicates the type of docitive info transmitted.
Failure Indication	O	Failure indication providing the code of the corresponding error cause.

Table 5.18: IQ_ACK

Message purpose	The HBS acknowledges the reception of the IQ value in the *IQ_RPRT* message	
Trigger for the message generation	Triggered by receiving a *IQ_RPRT* message	
Source	RRM entity in Hub BS	
Destination	RRM entity in ABS	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
Failure Indication	O	Failure indication providing the code of the corresponding error cause.

Table 5.19: Docition_ACK

Message purpose	The ABS acknowledges the reception of the docitive information	
Trigger for the message generation	Triggered by receiving *Docition_RSP* message	
Source	RRM entity in ABS	
Destination	RRM entity in HBS	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
Failure Indication	O	Failure indication providing the code of the corresponding error cause.

6 RAN self-organization and optimization support

This clause presents the reference protocol design for RAN SON mechanisms.

In order to collect sufficient information about its surrounding for RRM protocols operations, and to supply the served MSs with a list of potential HO candidates, a self deployable BS should be aware of its neighbouring BSs. This is the objective of Neighbour discovery mechanism - targeting that the given station will be able to enter the Network without any preliminary topology planning, with only minimum deployment information provided to the BS during the initial installation process. The following clauses define the surrounding topology awareness upon BS start-up and periodic data synchronization process.

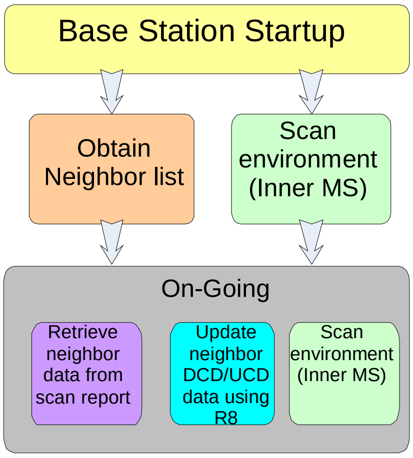

Figure 6.1: BS Self configuration

6.1 Automatic neighbours discovery

Implementation of this functionality is outlined in terms of WiMAX^{TM} technology, however the proposed concept is relevant to LTE and HSPA as well.

This functionality provides for the generation of Neighbour list (NBL) in the BS. There are two mechanisms for identification of potential neighbour entities - one is that the BS periodically polls the MSs about other (neighbour) BSs visible to the MSs. Another one - is based on proximity reports issued by an MS to the serving BS (SBS) every time when the MS enters or leaves the proximity of a neighbour BS. Additionally, a DNS sever is used to provide the BS IP address resolution based on the corresponding BSID knowledge. This information can be reached by the BSs to map BSIDs of their neighbours onto IP addresses for further communication.

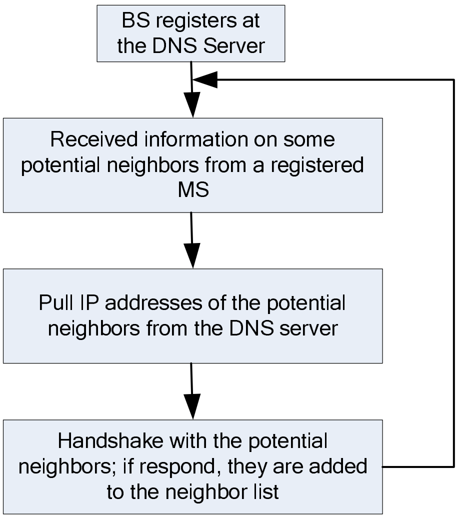

Figure 6.2: Automatic Neighbours discovery process

The generic message flow is presented on figure 6.3.

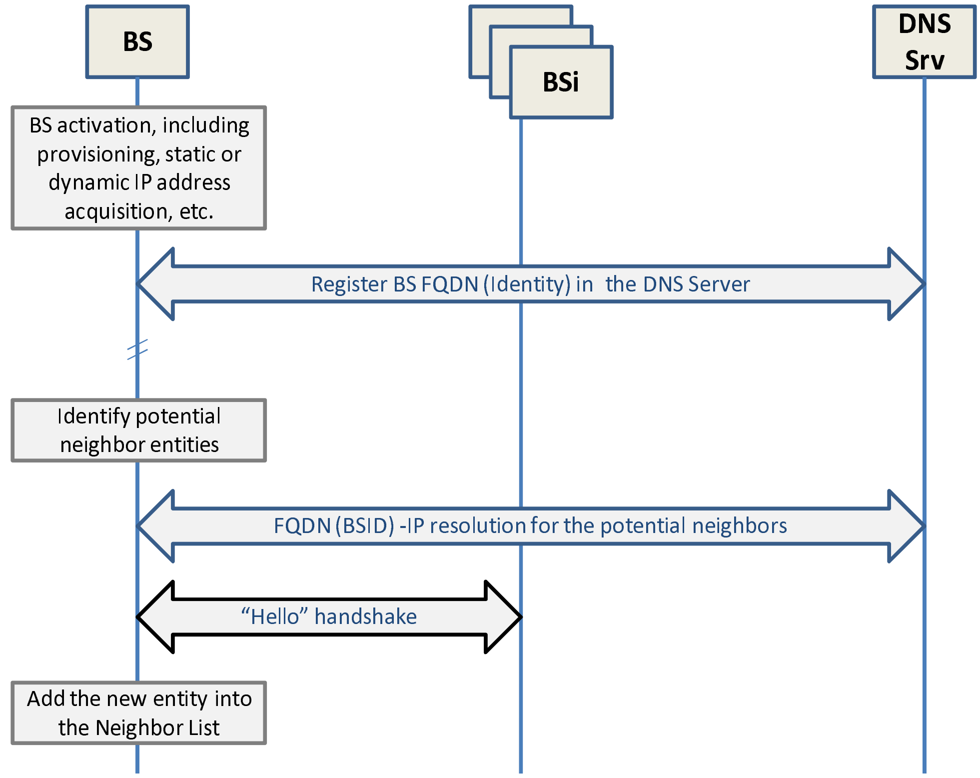

Figure 6.3: Automatic Neighbours discovery message flow

Processing of the collected information is outside of the scope of this clause.

6.1.1 Polling

Every MS normally has periods of scanning wireless media to get knowledge of neighbour BSs. This information is kept in the MS for a certain time.

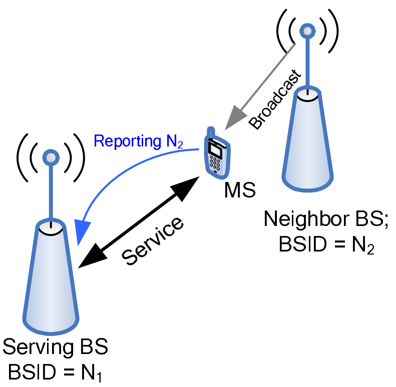

Figure 6.4: Neighbour detection

The BS periodically polls the serviced (registered) MSs to pull this info. The following are the parameters of the request message:

Table 6.1: Polling Request

Message purpose	MS polling for scanning reports	
Trigger for the message generation	Polling timer expiry	
Source	RRM entity in a BS	
Destination	MS	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
T	O	Time period for which the reports are requested. If not provided, use the default value.
CINR	O	Threshold for reporting: BS CINR mean. If below this value, the result should not be reported.
RSSI	O	Threshold for reporting: BS RSSI mean. If below this value, the result should not be reported.
RTD	O	Threshold for reporting: Round trip delay (RTD) of the air interface. If above this value, the result should not be reported.
R_BSIDs	O	List of BSIDs for which the reports are requested.
P_BSIDs	O	List of BSIDs for which the reports are prohibited.

The response message contains one or more records, per neighbour BS, with every record including the following parameters (at least one measurement should be present):

Table 6.2: Polling Report

Message purpose	MS response to polling	
Trigger for the message generation	Reception of Polling Request message	
Source	MS	
Destination	RRM entity in a BS	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
Report Type	M	Report type: response to polling.
TS	M	Time stamp: the end of the last measurement interval.
Interference Report	M	Information blob including interference parameters per interference source. Multiple such blobs may be included in the report message.
BSID	M	The Identity of the interferer.
CINR	O	BS CINR mean.
RSSI	O	BS RSSI mean.
RTD	O	Round trip delay (RTD) of the air interface.
I	O	DL Interference level, based on measurement of the received wideband power, within the bandwidth.
Interference interval	O	Optional information blob that identifies contiguous time interval where interference was detected. Multiple such information blobs may be included in the message.
>> IFstart	CM	Start of the contiguous time interval where interference was detected. Should be included if the parent TLV is present.
>> IFend	CM	End of the contiguous time interval where interference was detected. Should be included if the parent TLV is present.

6.1.2 Proximity reports

This functionality is based on proximity reports issued by a MS to the serving BS (SBS) every time when the MS enters or leaves the proximity of a neighbour BS. The SBS can collect information on proximity Enter and Leave events that occurred in the time intervals when the MS was not registered at the SBS; then information on recorded events is delivered. In this case the SBS can be one of the BSs that triggered the events.

6.1.2.1 Proximity reports configuration

The process starts from configuration parameters that can be either broadcasted by the SBS (then they are valid for all the registered MSs) or delivered to an individual MS in a unicast message.

Table 6.3: Proximity Report Configuration

Message purpose	Proximity reports configuration message	
Trigger for the message generation	Periodic	
Source	RRM entity in a BS	
Destination	MS	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
T	O	Time period for which the reports are requested. This parameter can point to the time interval when the MS was not registered at the SBS yet; then information on recorded events is delivered.
CINR_Enter	O	The threshold for reporting: BS CINR mean. If above this value, the Proximity Enter report should be issued.
CINR_Leave	O	The threshold for reporting: BS CINR mean. If below this value, the Proximity Leave report should be issued.
RSSI_Enter	O	The threshold for reporting: BS RSSI mean. If above this value, the Proximity Enter report should be issued.
RSSI_Leave	O	The threshold for reporting: BS RSSI mean. If below this value, the Proximity Leave report should be issued.
RTD_Enter	O	The threshold for reporting: BS RTD. If below this value, the Proximity Enter report should be issued.
RTD_Leave	O	The threshold for reporting: BS RTD. If above this value, the Proximity Leave report should be issued.

6.1.2.2 Proximity reporting

The report message contains one or more records; every record contains the following parameters. Each record describes a certain Proximity event.

Table 6.4: Proximity Report

Message purpose	Proximity report message	
Trigger for the message generation	Proximity report timer expiry or explicit response to proximity report configuration message	
Source	MS	
Destination	RRM entity in a BS	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
PROX	M	Proximity report record information blob.
TS	M	Time stamp.
BS ID	M	The ID of the BS that triggered the event.
Event type	M	One of the following: PROXIMITY_ENTER PROXIMITY_LEAVE.
Metric	M	The metric that triggered the event; one of the following: CINR RSSI RTD.
CINR	O	The measured value of the CINR mean that triggered the event.
RSSI	O	The measured value of the RSSI mean that triggered the event.
RTD	O	The measured value of the RTD that triggered the event.
I	O	DL Interference level, based on measurement of the received wide band power, within the bandwidth.

6.1.3 Neighbour BS "Hello" handshake

Once neighbouring entity is detected, the BS initiates "BS Hello handshake" procedure, intended to establish communication channel between the two entities and optionally create consistency awareness between the two (e.g. by tracking the Last Reset Time of the peer entity).

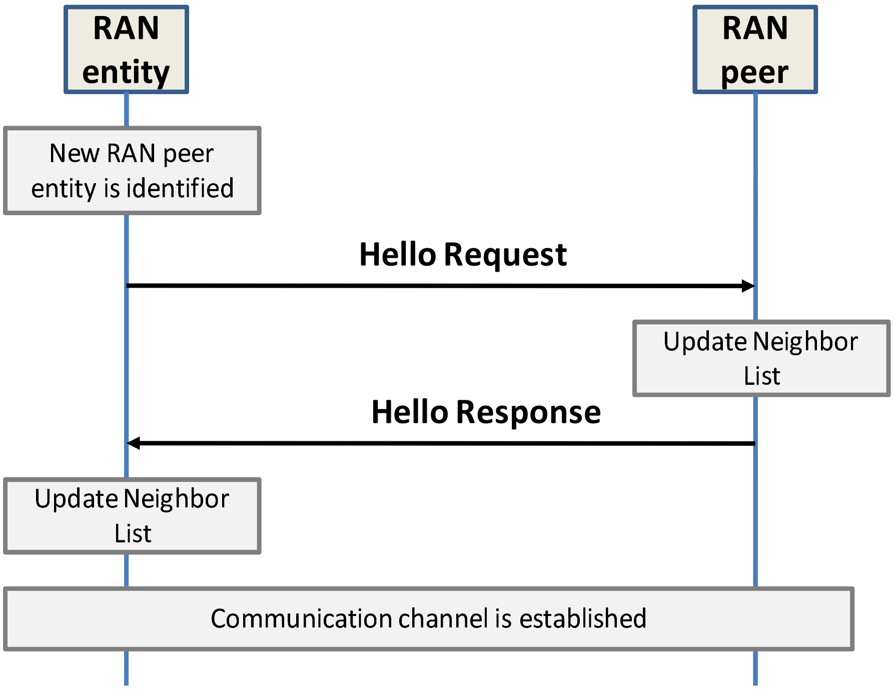

Figure 6.5: "Hello" handshake

The BSs may exchange their physical location information, based on GPS data or some preconfigured information.

6.1.3.1 Hello request

Hello Request message is initiated by the RAN entity detecting a new RAN peer in its proximity and wishing to establish communication channel with this entity.

Table 6.5: Hello Request

Message purpose	Establish the communication channel with the peer	
Trigger for the message generation	Identification of the new neighbour entity	
Source	Source RAN entity	
Destination	Peer RAN entity	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
Sender ID	M	The identity of the entity sending the request message (e.g. BSID). Multiple IDs may be included in the case they share the same IP address (e.g. in the case the BS implements multiple collocated sectors with different identities).
Sender IP	M	The IP address of the entity sending the request message.
Sender GPS Info	O	Provides physical location of the sender RAN entity based on the GPS data (if available) or preconfigured information.
Sender LRT	M	Last Reset Time of the sender. May be used as a communication consistency reference by the peer entities. If the RAN entity identifies that LRT of its peer has been changed, it may need to trigger configuration update process.
Peer ID	M	The identity of the peer RAN entity, to which the message is destined (e.g. BSID).
Peer IP	O	The IP address of the peer RAN entity, to which the message is destined.

6.1.3.2 Hello response

Hello Response message is sent in response to Hello Request.

Table 6.6: Hello Response

Message purpose	Establish the communication channel with the peer	
Trigger for the message generation	Reception of the Hello Request message	
Source	Peer RAN entity	
Destination	Source RAN entity	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
Peer ID	M	The identity of the entity sending the response message (e.g. BSID). Multiple IDs may be included in the case they share the same IP address (e.g. in the case the BS implements multiple collocated sectors with different identities).
Peer GPS Info	O	Provides physical location of the peer RAN entity based on the GPS data (if available) or preconfigured information.
Peer IP	O	The IP address of the peer RAN entity.
Peer LRT	M	Last Reset Time of the peer entity. May be used as a communication consistency reference by the peer entities. If the RAN entity identifies that LRT of its peer has been changed, it may need to trigger configuration update process.

6.2 Neighbours data synchronization

Implementation of this functionality is outlined in terms of WiMAX™ technology however the proposed concept is relevant to LTE and HSPA as well.

6.2.1 Overview

The Neighbours Data Synchronization (NDS) mechanism automatically distributes relevant configuration of the BS (e.g. UCD/DCD) to its neighbours BSs, enabling handover between the BSs. In order to provide service continuity, MS uses Handover (HO) procedure when migrating form one cell (serving BS - SBS) to a new cell (Target BS - TBS). The serving BS should inform its MSs of the neighbour BSs for the purpose of handover. For this, the BS needs to keep and maintain a list of its neighbouring BSs (Neighbour List or NBL).

Each BS regularly broadcasts the Neighbour List to all the served MSs to enable the MSs to scan neighbour BSs and evaluate them as possible handover targets. The broadcast information provides the MS with PHY and MAC information for quick DL synchronization during scanning and proper evaluation of the neighbouring BSs.

BS uses special air-interface message (e.g. MOB_NBR-ADV message in IEEE 802.16 [i.6]) to inform each user entering the sector (through handover, power-on, etc.), with an updated neighbour list. The list may be transmitted on unicast basis - through the primary management connection of each MS or on a broadcast basis to prevent high bandwidth overheads when the BS is experiencing high load of incoming MSs (many users, fast moving users).

Automatic Neighbours Discovery described in clause 6.1 allows for identification of neighbour BSs. Neighbours Data Synchronization is based on direct backhaul communication between BSs (R8 reference point for WiMAX^{TM}, X2 for 3GPP/eUTRAN). Each BS obtains up-to-date radio configuration information, including UCD/DCD settings, from all its NBSs using R8 messages. Each BS can then compare the NBS UCD/DCD settings with its own UCD/DCD settings and derive a list of "delta UCD/DCD", i.e. the NBS UCD/DCD fields that are not identical to those in the BS. The BS will then transmit the list of delta UCD/DCD for each NBS in the NBR-ADV message.

The aforementioned NDS solution combined with Automatic Neighbour Discovery mechanism provides significant simplification in network setup and optimization processes, especially impacting mobility. The NDS comprises of the following functions:

UCD/DCD count update

This function detects the need for configuration exchange. The function updates the BS UCD/DCD count each time the BS UCD/DCD content is changed.

According to the IEEE 802.16 [i.6], the BS transmits two fields called DCD count and UCD count that are incremented by one each time the DCD and UCD contents respectively change. These fields are transmitted as part of the DCD and UCD messages, and in the DL-MAP and UL-MAP respectively. In the DCD and UCD messages the DCD and UCD count are transmitted in the Configuration Change Count field.

The DCD message contains the BS restart count TLV that is incremented by one every time the BS restarts, therefore the DCD messages change each time the BS initializes so the DCD count should be incremented at that time. To implement this, the BS should save BS restart count and DCD count in NV memory and increment this value when the BS initializes.

Radio configuration exchange

This is actual data exchange between NBS. The Radio configuration is exchanged between BSs using two mechanisms:

- Push: When radio configuration changes (in particular after BS initialization) the BS sends an unsolicited Radio_Config_Update_Rpt messages to all its NBSs containing its up-to-date radio configuration.
- Pull: Periodically, the BS may send all its NBSs a *Radio_Config_Update_Req* message asking every NBS to send a *Radio_Config_Update_Rpt* message including its radio configuration.

NBR-ADV construction

It is construction of new/updated NBR message. The BS will go over all the fields in the NBS UCD/DCD. If a field is not present in the BS UCD/DCD or if the field is present but the value has changed, the BS will add this field to the list of delta UCD/DCD. Then the BS will construct the NBR-ADV message including the neighbour BS-ID, preamble index, and delta UCD/DCD settings.

6.2.2 Functional decomposition

The NDS feature is implemented in RRM entity in the BS. The RRM Entity includes NDS Client and NDS Server; every NDS Client communicates with the NDS Server of every peer BS via the R8 (X2 in LTE).

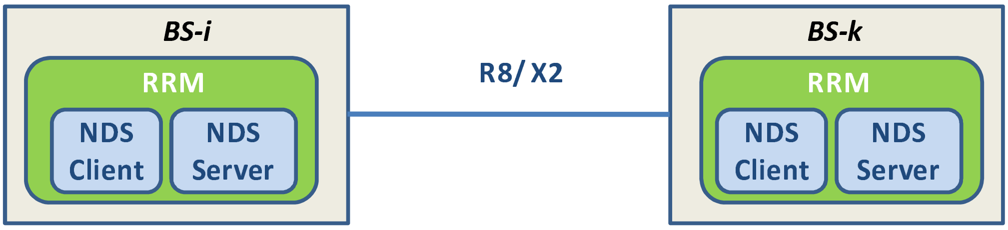

Figure 6.6: NDS functional decomposition

Functions of the NDS Client:

- Maintenance of the list of neighbour BSs (Neighbour List) that includes their properties. The list is created by the Automatic Neighbour Discovery function.
- Sending Radio_Config_Update_Req.
- Storage of information about neighbour BSs.
- Aging of the information about neighbour BSs.

Functions of the NDS Server:

- Responding to Neighbour information request.

6.2.3 Message flows

NDS feature is implemented using a symmetric protocol between BSs to update each other of their parameters.

Every BS periodically polls the neighbour BSs with information requests (pull mode). The polled BSs respond to the requests. The response includes GPS reading by the BS. If yes, the info is copied from the response to the storage.

In addition to that, in case when any property of the BS changed, the BS may send its updated info to the neighbours in an unsolicited form (push mode).

6.2.3.1 Radio configuration update (Pull)

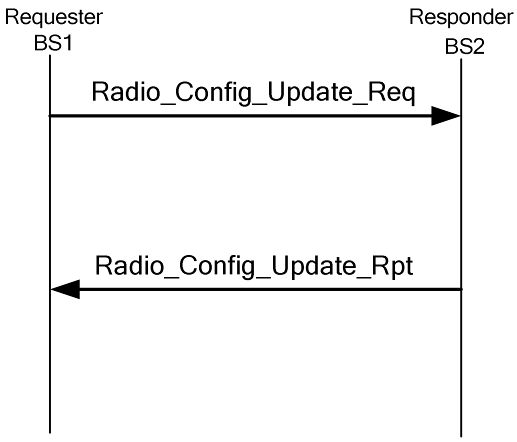

Figure 6.7: Radio Configuration update (Pull)

6.2.3.2 Radio configuration unsolicited update (Push)

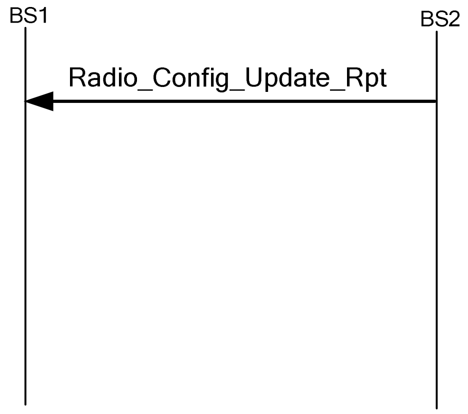

Figure 6.8: Radio Configuration unsolicited update (Push)

6.2.4 Protocol primitive description

The following parameters are carried in the messages.

6.2.4.1 Neighbour information request

Table 6.7: Radio_Config_Update_Req

Message purpose	Request for radio configuration update parameters	
Trigger for the message generation	Periodic	
Source	NDS Client in RRM entity in a BS	
Destination	NDS Server in RRM entity in a Neighbour BS	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
Sender ID	M	The Identity of the Requester (e.g. BSID).
Sender IP	O	The IP address of the Requester.

6.2.4.2 Neighbour information response

Table 6.8: Radio_Config_Update_Rpt

Message purpose	Radio configuration update message	
Trigger for the message generation	In response to Radio_Config_Update_Req message or unsolicited, triggered by the radio parameters change	
Source	NDS Server in RRM entity in a BS	
Destination	NDS Client in RRM entity in a peer BS	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
TS	M	Time Stamp.
Reporter ID	M	The Identity of the reporting entity (e.g. BSID).
Configuration Change Count	M	A counter incremented every time when any element of the configuration is changed.
PHY Profile	M	Frequency Assignment (FA) index. Preamble Index. Reuse factor index.
FAID	M	FA identification.
DCD_CCC	M	DCD Configuration Change Count.
UCD_CCC	M	UCD Configuration Change Count.
Services descriptor	O	Identifies supported services.

6.2.4.3 UCD/DCD count update

The BS transmits two fields called DCD count and UCD count that are incremented by one each time when DCD and UCD contents respectively change. These fields are transmitted as part of the DCD and UCD messages, in the DL-MAP and UL-MAP respectively using the Configuration Change Count field.

The DCD message contains the BS restart count TLV that is incremented by one every time the BS restarts, therefore the DCD message changes each time the BS initializes and so the DCD count should be incremented at that time. To implement this, the BS should save BS restart count and DCD count in NV memory and increment this value when the BS initializes. Both values should be factory initialized to 255 (such that after the first BS initialization they will both equal zero).

If the UCD or DCD are changed without BS restart (runtime changes), the UCD or DCD count should be immediately incremented in the UCD or DCD message and, after UCD or DCD transition interval, in the UL-MAP or DL-MAP correspondingly.

6.2.4.4 UCD/DCD configuration exchange

Upon initialization or changes in its radio configuration, the BS should send an unsolicited Radio_Config_Update_Rpt message including all the relevant parameters to all the NBSs in its neighbour list (NBL).

A BS should send a *Radio_Config_Update_Req* message to all the NBS at preconfigured intervals. These intervals should not be synchronized between BSs. For instance, each BS can initialize a periodic timer at BS startup and send the *Radio_Config_Update_Req* messages when the timer expires. The *Radio_Config_Update_Req* first transmission should be immediately after BS initialization.

When a *Radio_Config_Update_Rpt* message is received from an NBS, the BS should verify the following conditions:

1. UCD count differs from last UCD count received from the NBS.
2. DCD count differs from last DCD count received from the NBS.
3. Preamble index differs from last preamble index received from the NBS.

If at least one of these conditions is true, the BS should:

- Update the stored UCD/DCD count and preamble index for this NBS with the ones in the message.
- If the message includes UCD and DCD settings, update the stored UCD and DCD settings for this NBS with the ones in the message.

In addition if MIMO mode or neighbour-specific triggers in *Radio_Config_Update_Rpt* differ from stored values, BS should update stored values with those received.

When the UPD_REQ timer has expired, the BS should rebuild the NBR-ADV message it transmits.

BS should acknowledge all the received *Radio_Config_Update_Rpt* received messages by sending a *Radio_Config_Update_Ack* message back to the sender.

If the BS does not receive a *Radio_Config_Update_Rpt* from the NBS after having sent a *Radio_Config_Update_Req*, it should retransmit the *Radio_Config_Update_Req* according to the same retransmission rules as for other R8 messages.

If the BS does not receive a *Radio_Config_Update_Ack* from the NBS after having sent a *Radio_Config_Update_Rpt*, it should retransmit the *Radio_Config_Update_Rpt* according to the same retransmission rules as for other R8 messages.

The BS should ignore *Radio_Config_Update_Rpt* messages from an NBS that is not in its NBL.

When a *Radio_Config_Update_Req* message is received from any BS, the receiving BS should send a *Radio_Config_Update_Rpt* message back to the sending BS.

A BS behaviour as described in this clause is illustrated in figure 6.9 (note that it does not include message retransmission state machine).

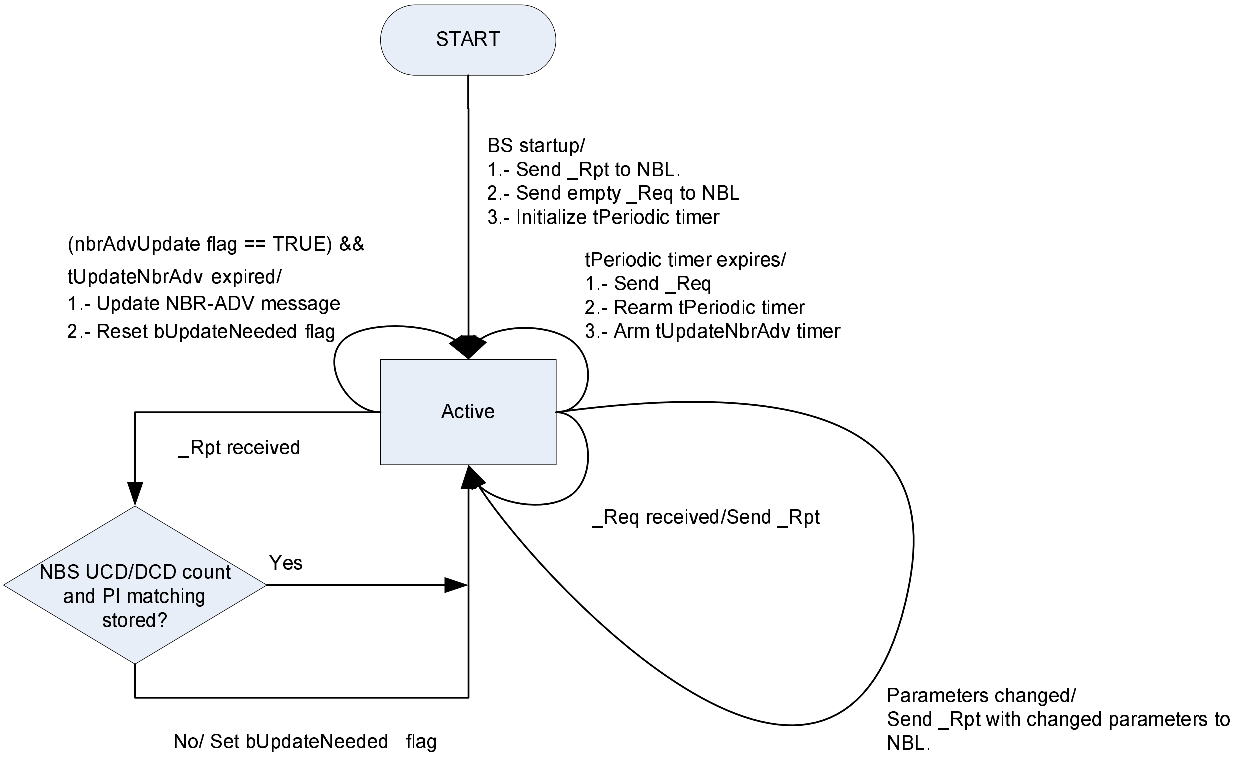

Figure 6.9: BS radio configuration message state machine

6.2.4.5 NBR-ADV construction

This clause specifies only the steps of NBR-ADV construction affected by the reception of new NBS parameters via *Radio_Config_Update_Rpt* messages.

As specified above, *Radio_Config_Update_Rpt* messages contain the following parameters:

- NBS BS-ID
- NBS preamble index
- NBS UCD and DCD count
- NBS UCD and DCD settings

NBS BS-ID, preamble index and UCD/DCD count are directly inserted in the homonymous fields of the NBR-ADV message. As for NBS UCD and DCD settings, the BS executes the following pseudo code to create a list of "delta UCD settings" and "delta DCD settings" containing the differences between the NBS and the BS UCD and DCD settings respectively (for simplicity, pseudo code shows UCD operations only).

Delta UCD settings = empty

For (all fields in received NBS UCD settings)

```
{
    If NOT (field exists in BS UCD and value is the same as in NBS UCD field)
        Add field to delta UCD settings
}
```

The DCD Trigger TLV is a compound TLV and for the purposes of the above logic it is treated as a unit, i.e. if one of the nested TLVs differs (NBS vs. BS), the entire trigger TLV is added to the delta DCD settings.

Delta UCD/DCD settings is a list of TLVs, using the same format as in the UCD/DCD messages. Fixed fields in UCD message, i.e. ranging backoff start/end and request backoff start/end, are encoded in the delta UCD settings TLVs.

As long as a BS has not received UCD/DCD settings from a NBS since BS startup, the BS should not include this NBS in the NBR-ADV message.

NBR-ADV configuration change count is incremented by one every time message contents change.

6.3 Automatic FFR regulation for reuse 1

6.3.1 General FFR approach

Fractional Frequency Reuse (FFR) means that every BS is using a part of the channel e.g. for OFDM technology composed of certain subset of subcarriers. In addition to that, the BS can split the frame interval into two or more zones where different subsets are used.

Figure 6.10 shows a fragment of FFR based deployment. In this 3-cell/3 sector example:

- F means allocation of all subchannels
- F1 means first 1/3 of all sub-channels
- F2 means second 1/3 of all sub-channels
- F3 means third 1/3 of all sub-channels

The following rule is used by the BSs for selection of terminals serviced in the cell:

- The terminals that are close to the cell centre
  - All sub-channels are allocated to each sector (F)
- The terminals that are close to the cell edge
  - Sector # 1 gets F1 (1/3 of all sub-channels)
  - Sector # 2 gets F2 (1/3 of all sub-channels)
  - Sector # 3 gets F3 (1/3 of all sub-channels)

Such scheme is often referred to as 1/3/3. It provides a reasonable balance between resources allocated to cell centre vs. cell edge users and includes provisions for reducing inter-cell interference: terminals in two different cells that use same set of subcarriers (subchannels) are distant from each other. For example, in two adjacent sectors of cell 1 and cell 2 the edge terminals use different sets F3 and. F1 correspondingly. The centre terminals are using the same set F, but they are comparatively distant from each other.

In case of 802.16 OFDMA, additional interference reduction is achieved by using random sub-channelization schemes where users in adjacent cells switch sub-carriers based on different pseudo-random sequences.

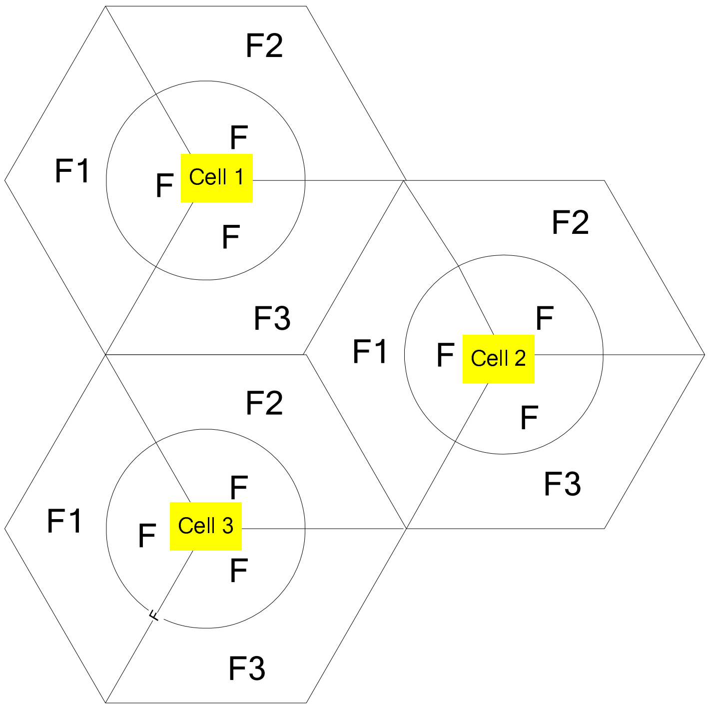

Figure 6.10: Example of FFR

The following shows example of time-frequency resource allocation in 802.16 OFDMA frame.

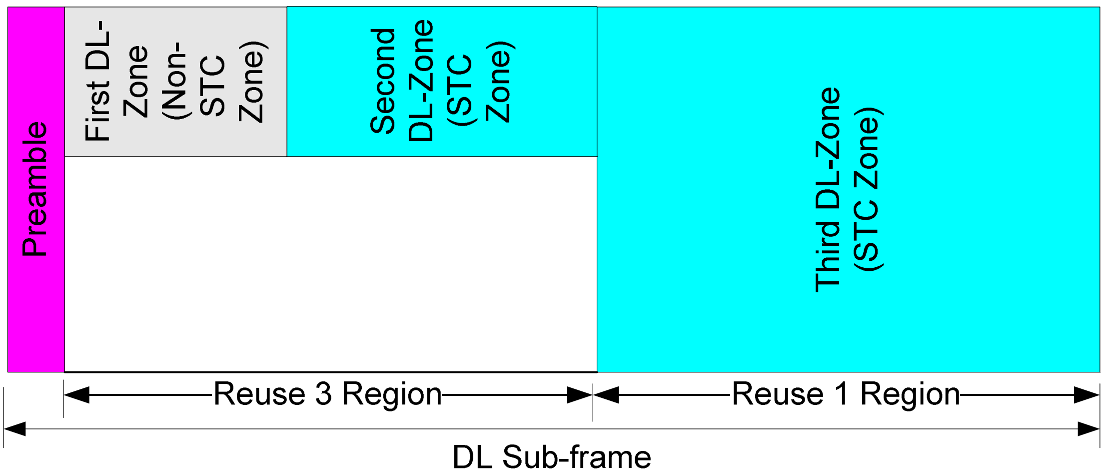

Figure 6.11: Example of FFR frame structure

6.3.2 Inter-cell FFR coordination

Inter-Cell FFR Coordination refers to a coordination of operations of adjacent cells, targeting reduction of mutual interference. This functionality can improve cell edge throughput and area reliability. Service providers may consider using FFR/segmentation and ICIC to fine-tune their network performance.

6.3.2.1 Resource blocks categories

Inter-cell FFR coordination function manages radio resources in time-frequency domain such that inter-cell interference is kept under control. This mechanism is inherently a multi-cell RRM function that needs to take into account information (e.g. the resource usage status and traffic load situation) from multiple cells.

Elements managed by this function are resource blocks (RBs) defined as {Time Zone x Subchannel}.

The time zone is defined as integer number of symbol intervals, DL or UL; subchannel is a predefined set of subcarriers.

Every resource block as observed by a BS can be in the following states:

- Private
- Shared
- Prohibited

These blocks follow certain pattern through the sequence of radio frames.

The RRM function should assign every RB at every BS to one and only one category i.e. if a RB is Private it can be neither Shared nor Prohibited.

Normally the RRM function should not assign a Private RB of certain cell (sector) to be at the same time a Private or Shared RB at a neighbour cell (sector), see for example figure 6.12.

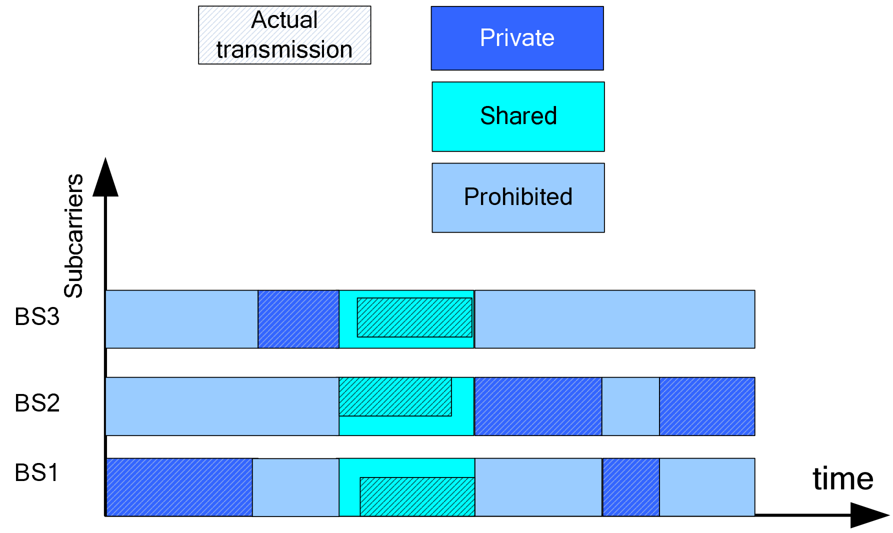

Figure 6.12: Example of allocation of Private, Shared and Prohibited resource blocks

The pattern is configured by the centrally located or distributed RRM function based on measurement results received from terminals.

6.3.2.2 Measurements

Every terminal performs measurements per category of RBs, e.g. as follows:

Table 6.9: Measurement types

Code	Measurement type
1.	Private RBs of the serving cell
2.	Shared RBs of the serving cell
3.	Prohibited RBs of the serving cell
4.	Private RBs of the neighbour cells
5.	Shared RBs of the neighbour cells
6.	Prohibited RBs of the neighbour cells

The measurements are reported to the Serving BS.

NOTE: Same RBs can belong to several categories, for example, a RB can be at the same time a Private RBs of the cell A and a Prohibited RB of the neighbour cell B.

6.3.2.3 RRM function

The RRM function can be centrally located or distributed. In the latter case every BS includes an instance of the RRM function. The functional split of RRM functions is presented in clause 4.2.1.

6.3.2.4 Protocol

The following messages are used for communication between RRM functions.

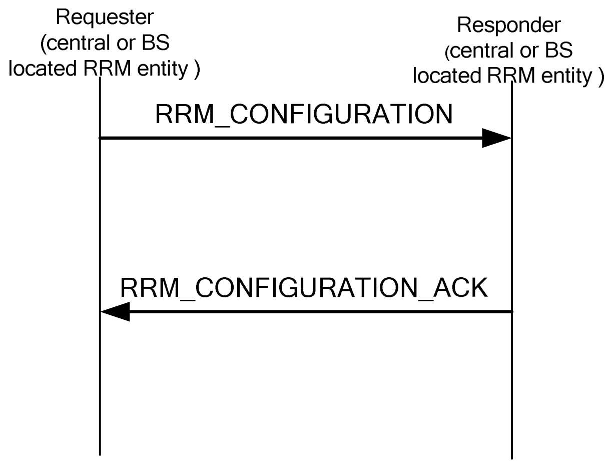

Figure 6.13: Generic RRM communications

Using these messages, the RRM function can negotiate with neighbours the optimal use of the radio resources.

Table 6.10: RRM_Configuration

Message purpose	Delivery of RRM related information and commands	
Trigger for the message generation	RRM configuration triggers	
Source	RRM entity in a BS or Centralized RRM entity	
Destination	RRM entity in a BS	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
Source ID	M	Identity of the entity sending the request.
Destination ID	M	Identity of the destination entity.
Command Code	M	Command instruction for the destination entity: • Configuration update request; • Interference Match request; • Information query; • Information delivery; • Etc.
Configuration Data	O	Information blob representing configuration parameters for scheduling/power boosting decisions by the BSs.
Configuration structure type	CM	Should be present if Parent TLV is present. Bitmap, indicating the configuration structures for which update is requested.
PHY parameters	O	Information blob representing PHY-specific configuration parameters.
Scheduler parameters	O	Information blob representing Scheduling-specific configuration parameters.
Mobility Thresholds	O	Information blob representing Mobility-specific configuration parameters.
…	O	More Compound TLVs may be introduced.
Measurement Data	O	Information blob representing configuration data for certain categories of measurements performed by terminals including modes and parameters of measurement results delivery.
Averaging/Reporting Period	O	Used by a BS (RRA) to indicates: • the measurement interval for producing the information requested by RRC, when included in the request for measurements; or • the reporting period, if included in the measurements report.
RRM Reporting Type	O	Used to indicate: • Single reporting; • Periodic reporting; • Event-driven reporting; • Stop reporting.
Reporting Event	O	Indicates the requested reporting events.
Interference Report	O	Information blob including interference parameters per interference source. Multiple such blobs may be included in the report message.
Interference interval	CM	Information blob that identifies contiguous time interval where interference was detected. Should be included if the parent TLV is present.
>> IFstart	M	Start of the contiguous time interval where interference was detected.
>> IFend	M	End of the contiguous time interval where interference was detected.

Table 6.11: RRM_Configuration_ACK

Message purpose	Acknowledgement to the *RRM_CONFIGURATION* message	
Trigger for the message generation	Sent in response to *RRM_Configuration* message	
Source	RRM entity in a NBS	
Destination	RRM entity in a BS	
List of Information Elements		
IE Name	**MANDATORY/OPTIONAL**	**Description**
Result Code	M	Result code of the requested operation: • Successful; • Failure.
Failure Indication	O	Error code for the requested operation. Mandatory, if Result Code = Failure.
Measurement Data	O	Information blob representing configuration data for certain categories of measurements performed by terminals including modes and parameters of measurement results delivery.
Interferer ID	O	The Identity of the Potential Interferer (e.g. BSID). Should be included if the Result Code = "Successful" for RRM_Configuration Command Code = "Interference Match request".
Interferer IP	O	The IP address of the Potential Interferer.

6.4 Technology-independent network protocols for coexistence support in LE bands

There are number of assumptions that should be satisfied to make this functionality operational - all or some potential interferers are connected to the backbone network, all or some potential interfering entities implement common protocol and state machine for coexistence support and that information of their IP addresses, geo location and transmit power is available for the Interference Control Server (ICS).

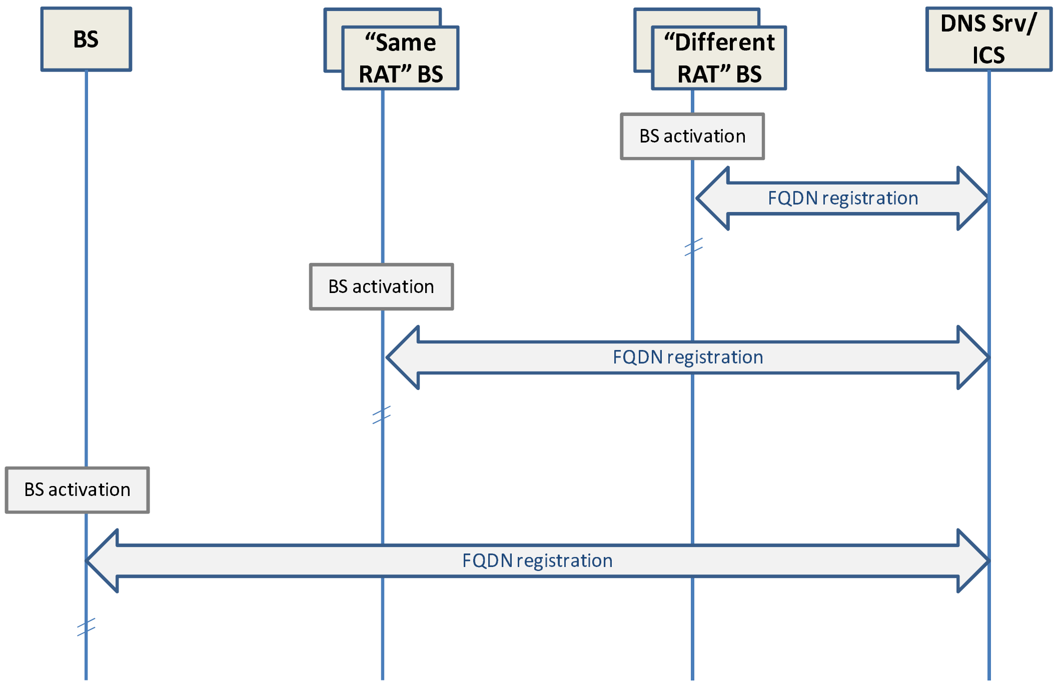

Figure 6.14: Technology-independent coexistence - BS registration

6.4.1 Interference detection

The BS estimates total interference and interference from neighbour BSs using MS reports as described in clause 6.1.

The BS can further estimate interference from same-RAT neighbour BSs based on the interference figures and estimated interference from neighbour BSs using MS reports described in clause 6.1.

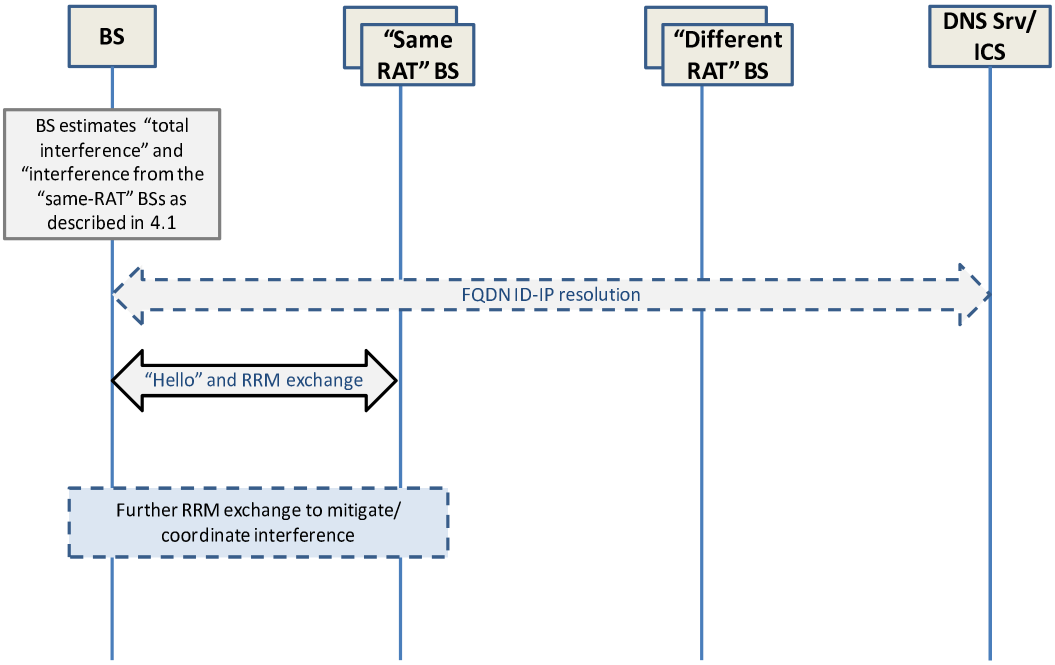

Figure 6.15: Interference detection

6.4.2 Discovery of interference source

After the BS identified same-RAT neighbour BSs, detected and measured interference from neighbour BSs, the BS can then guess that remaining interference can be caused by sources from other RATs. This is presented in figure 6.16, step (1).

6.4.3 Association of neighbour and interference

The BS requests from the ICS data of nearby transmitters to narrow down the list of potential interferers. The BS thus creates a list of potential interferers. This is presented in figure 6.16, steps (2) and (3).

Next step is to probe all or some of the potential interferers using "generic RRM language" with data {IFstart, IFend} received from the terminals. The entity that received such request checks whether this data matches the history of its own transmissions and responds with positive (in case of match) or negative acknowledgement. *RRM_Configuration* message should use the Command Code = "Interference Match request" indicator set. If using positive acknowledge in *RRM_Configuration_ACK* message, the Interferer should include also Interferer ID/IP TLVs, which may be necessary, if multiple transmitters (e.g. BS sectors) share the same physical platform.

6.4.4 Communication exchange between neighbours to avoid or mitigate interference

After the BS identified the interferers, it can update its locally managed "list of interferers" and negotiate with them the frequency channel and/or transmit power used by every transmitter, using "generic RRM language" - as presented in figure 6.16, steps (7) and (8).

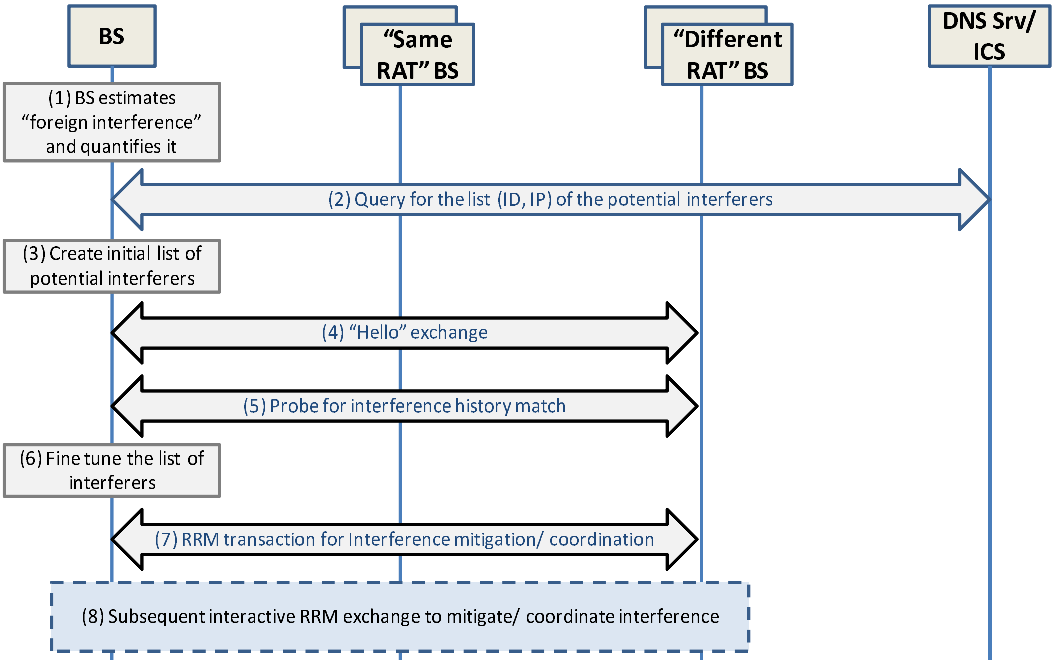

Figure 6.16: Interferer matching, discovery and interference coordination

Annex A: Bibliography

BuNGee deliverable D3.2: "BuNGee RRM protocol suite".

List of figures

List of tables

History

Document history		
V1.1.1	July 2013	Publication