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| Chapter 7.1 text revision |
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# Functional Decomposition and Design

## **Access network setup**

### Introduction and Overview

When powering up or activating, an access network has to be configured before becoming operational. Assuming that all configuration attributes of the network elements are set to some default value after power up, initial configuration consists of the adjustments of the base operational parameters of the network elements, and the establishment of the connections among the network elements of the AN and towards the associated SSs, ARs, NMS, and CIS of the AN. Depending on the realization of the AN, the configuration may also comprise adjustments to the radio interfaces, either to comply with regulatory requirements or to optimize radio resource usage.

Most of the IEEE 802 radio technologies for access networks are designed for operation in unlicensed bands, or for operation in TV white space (TVWS). TVWS is locally or temporarily unused spectrum assigned for TV broadcast and made available for general use through authorization procedures involving a spectrum database. According to FCC definitions, the TVWS spectrum is primarily assigned to provide TV broadcast service, or is used for the purpose of generating broadcast content, e.g., by making use through wireless microphones. Secondary users may leverage the designated TVWS spectrum for other kind of services only when the primary users are not demanding the spectrum and the general use of the spectrum at a geographic location is authorized by the spectrum database.

The following subsections describe the necessary actions for initiating access network operation, and the special procedures to adjust radio channels in unlicensed bands, or in TV white space (TVWS).

### Roles and identifiers

#### Terminal

Usually, the TE does not play a role in access network setup. However i

The generic role and identifiers of TE are defined in Section 6.3.

#### Access Network

AN denotes all the NAs, the BH and the ANC, that all have to be configured to enter operation of the AN. An AN usually defines an operational domain; however, spectrum access may vary over the regional area that the AN covers with its NAs. Within one AN, there may be different kind of NAs, and the NAs may operate in different frequency ranges, channel assignments, and spectrum regimes.

The AN is defined in Section 6.2

#### Node of Attachment

The NA provides the interface towards the TE and requires base configuration enabling the TE to discover the access network access and to initiate communication to establish a connenction. It is the device accessing the spectrum for radio transmissions to the TE; and it may sense the existence of neighboring radio systems either to enable shared access in a fair manner or to report spectrum usage to a central management entity. In the case of authorized access to shared spectrum, like TVWS, the NA either performs the necessary procedures by itself or it acts as an agent on behalf of a central management entity.

sare

#### Backhaul

BH consists of a number of bridges and transmission lines, which provide the means for setting up user connectivity between the NAs and the AR, which provides the network protocol anchor to the TE. Initial configuration does not only establish the PHY and MAC parameters of the communication links, but also brings the bridges into a clean state ready for setting up user connections.

The BH is defined in Section 6.5.

#### Access Network Control

The ANC performs the configurations to the access network elements to establish connectivity service delivery to terminals through processing and propagation of control and configuration information of TE, SS, AR, NAs, BH, CIS, and NMS. Usually ANC acts as agent for the NMS to retrieve the information about the AN infrastructure, and to forward the base settings to network elements, which are provided by the NMS.

If a central spectrum management entity is deployed in the ANC, it retrieves and stores the collected spectrum usage information of each NA and eventually helps NAs at boot-time to speed up or optimize the channel selection procedure in the NA.

In the case of operation in the TVWS, the ANC contains the function that is used to manage and control operations of TVWS-enabled NAs, such as setup, provisioning, and teardown in the authorized spectrum. The ANC also contains the functions to control spectrum sensing by the TEs, if available. The ANC also establishes a secure connection to the CIS to retrieve the geolocation specific spectrum usage information for its NAs and serving TEs.

The ANC may support the following functions for coexistence with primary services or other services in the authorized spectrum. (Support is not limited to these functions.)

* Coexistence management enables an NA to coexist with primary wireless devices in the authorized spectrum.
* Coexistence discovery and information (local) server is used to store the information used for deter­mining coexistence of NAs operating in the authorized spectrum shared with primary wireless ser­vices.

 general purpose and identifierare

#### Network Management Service

The NMS contains and provides the initial set-up of all network elements either directly to the network elements or by way of forwarding the information through the ANC. Initial configuration of the network elements is maintained in a permanent repository either as individual configuration for network elements, or as templates for types of network elements. The NMS also provides the parameters for the operation of the ANC.

The NMS is defined in Section 6.3

#### Coordination and Information Service

The CIS enables access to common configuration parameters either provided by external means or established and shared across multiple ANs. The CIS may not only provide spectrum authorization information to the AN, but may also collect and forward spectrum usage information to external databases, such as the spectrum database in the case of TVWS. The information in CIS could include the following:

* available bands and channels in shared spectrum
* available shared spectrum with geolocation information
* allowed maximum transmit power in the authorized spectrum
* primary service provider and secondary service providers and their operating status
* potential neighboring services and their interference levels

The ANC queries the CIS for spectrum information and may have a local copy of it, which is periodically synchronized with CIS.

The CIS is defined in Section 6.4

### Use cases

#### Access network initialization

When the access network is powered up, the network elements receive their configurations from the ANC, which receives infrastructure and basic operational configuration values from the Network Management Service and other operational parameters for shared resources from the Coordination and Information Service. As part of the network initialization, also the connectivity to the associated SSs and ARs is established.

#### Access network re-configuration (re-initialization)

When major changes are applied to the configuration of the AN, it may be necessary to re-initialize the whole access network infrastructure to bring configurations into a consistent state. In this case, the access network initialization procedure is performed out of an operational state of the AN.

#### Radio channel adjustments

When the radio systems in the NAs are permanently checking the usage and availability of the used spectrum, the ANC or NA may decide to tune during operation to a different channel. Such reconfigurations do not require a complete re-initialization of the AN, but can be performed during a short service break of the NA for the reconfiguration of the radio parameters. To avoid termination of user sessions, the AN may inform connected TEs about the change beforehand, allowing the TE to reconnect to the NA on the new channel while maintaining the session.

#### Radio reconfiguration due to expired spectrum authorization

A reconfiguration of channel assignments may become necessary during the operation of the AN due to expiration of authorized spectrum, like the end of availability of a particular TVWS channel. In this case, the AN will either retrieve through the CIS a new spectrum authorization in a different band or channel and reconfigure the NAs to the new radio usage conditions after informing the connected TEs about the coming changes of radio configurations, or turn down the NAs operating in the expiring TVWS after informing the connected TEs about the coming service end.

### Functional requirements

#### Access network configuration

After the AN is powered up, the ANC communicates with the NMS of the access network to get its configuration information including the interconnection information about the CIS, and triggers the initial configuration of the network elements of the AN, which is either performed directly through the NMS or through the ANC based on information retrieved from NMS.

#### Access network interconnection

After establishing the basic operation of the network elements, the AN needs to establish the connections with the associated SSs and the ARs using the configuration parameters provided by the NMS for the interconnections to external functions.

#### Channel selection

Channel selection is part of NA radio configuration for tuning the receiver and transmitter to particular operating frequencies within unlicensed bands. Since unlicensed spectrum usually provides multiple channels, and radio devices can arbitrarily select one of these channels for operation, it may happen that several devices are operating in the same frequency channel in the same coverage area, such that interference among devices is inevitable. To reduce the interference with each other in the unmanaged environment, the NAs should select, during initial setup, the best operating channel with the least amount of interference.

When operating with a channel bandwidth of 20MHz, the 2.4GHz ISM band allows for three or four non-overlapping channels depending on the regulatory region. The 5GHz band for unlicensed operation provides more than 20 channels of 20MHz each. The channel selection procedure in the NA determines the channel with the least amount of interference of all available channels. The channel selection procedure in the NA may operate in a local manner, may communicate with the channel selection procedures in adjacent NAs, or may deploy a central entity in the access network control to speed up the selection process and generate more optimized results.

When the NA initiates its radio interface, the channel selection function of the NA should measure the channel occupancy or radio resource usage of all the channels in the unlicensed band. Based on those measurements, and potentially with further information and guidance from the neighbor NAs and the ANC, the NA selects the channel with the most appropriate properties and initiates the radio interface for that channel.

An NA may report the channel measurement results to the ANC. The ANC stores the collected spectrum usage information of each NA and eventually provides assistance to newly initiated NAs to speed up or to optimize the channel selection procedure in the NA.

#### Channel reselection

The NA may switch during operation to another channel if it detects that the current operating channel is heavily overloaded or interfered. Switching the operating channel can be performed as a functional extension to the channel selection procedure and may cause a service interrupt.

Since the ANC may store the operating channel information of each NA, it may provide assistance or coordination for reselecting a better operating channel in the coverage.

Before switching to another channel, the NA may need to de-associate the devices under its service to trigger them to search for the service in another channel—potentially the channel to which the NA tunes in. The disassociation causes the terminal to enter the network discovery and selection procedure, which contains a scanning function for discovery of potential NAs in the coverage area.

#### Mutual authentication of the entities involved in the dynamic spectrum authorization

Mutual authentication is used by ANC and CIS to provide strong security and protection before the AN provides authorized shared access.

#### Dynamic spectrum allocation

Dynamic spectrum operation is controlled by ANC. ANC queries the CIS to get the channel usage information and determine the operating channel in the TVWS spectrum for the radio system for the locations of the NAs. If there is an available channel in the TVWS spectrum, ANC would set up the NA to operate in that channel. Otherwise, if there is no available channel in the TVWS spectrum, the ANC should not turn on the NA radio.

#### AN shutdown

During operation in the authorized shared access spectrum, the ANC should continue monitoring or be notified of the status of shared access spectrum in CIS. If it detects information that the primary user of the TVWS spectrum would like to operate in the channel that is being used by the NA, the ANC should check whether there is another channel available or, if no other channel is available, disable services in the TVWS channel and turn off the NA radio.

#### Operation on various channels

Unlicensed bands usually consist of multiple channels. The NA should be able to operate on any of the channels of the band for which the radio interface is designed.

The NA may be equipped with a radio interface allowing operation in multiple unlicensed bands. In this case, the channel selection procedure should be able to operate across all the supported bands and select the least occupied channel of all the supported bands.

#### Multi-mode support

The NA should support all the different radio modes specified for compliance of its radio interface, to allow for adaptation of operational parameters to the radio environment in the chosen channel. Such adaptation allows for more efficient use of the shared spectrum and benefits the performance of the whole system.

#### Support for multiple access technologies

The dynamic spectrum allocation and access network setup procedure should be able to support different access network technologies.

#### Support for coordination among multiple access networks

The dynamic spectrum allocation and access network setup procedure should be able to support the operating of an access network coordinated through CIS with neighboring Ans.

### Access network setup-specific attributes

AN setup covers essentially all base configuration parameters of the IEEE 802 technologies as well as the base attributes describing the network structure.

For the authorized spectrum access in TVWS there are a few specific information elements:

* Geolocation
Describes the location of the AN requesting authorization make use of unused TV spectrum
* List of available channels with maximum allowed EIRP
Information provided by the spectrum database for authorized access to TVWS
* Spectrum sensing data
Measurement results delivered by the NAs and eventually by the TEs to the ANC for selection of the operating channel.
* Back-up channel list

List of channels, which can be used for the case, that the operating channel is heavily loaded or requires to be terminated.

### Access network setup-specific basic functions

Dynamic spectrum allocation and access network setup and configuration describe the procedure for operating one or multiple NAs in an authorized spectrum environment shared with primary wireless devices. The procedure includes the following basic functions:

* CIS discovery and mutual authentication
* Querying for authorized shared spectrum information
* Configuration of the radio access network for operation in the authorized shared access spectrum

#### CIS discovery and mutual authentication

CIS discovery and mutual authentication is the process through which an AN finds and authenticates the CIS used to store authorized shared spectrum usage information for a given area, before querying the CIS to get the information about authorized shared spectrum usage.

The ANC may be preconfigured with the IP address or URL of the CIS server.

When ANC is powered up, it may load the default shared spectrum list, and it automatically communicates with CIS using preconfigured CIS information. If ANC can not communicate with CIS server, radio operation in the shared spectrum is not allowed for the NAs.

The communication between ANC and CIS should follow the protocols specified by the R10 reference point.

Once ANC receives the response from CIS, it needs to start the mutual authentication with the CIS to make sure that the CIS being communicated with is the correct one.

#### Querying for authorized shared spectrum information

Querying for authorized shared spectrum information is the process by which information is acquired from CIS about authorized shared spectrum usage.

Before operating in authorized shared spectrum, the ANC needs to query the CIS to get information about authorized shared spectrum usage, using the protocols specified by the R10 reference point. Once it has received the usage status of authorized shared spectrum, the ANC can determine whether the AN can operate in a particular channel.

During operation in authorized shared spectrum, the ANC needs to constantly query the CIS to get usage status updates about the authorized shared spectrum.

#### Operating in authorized shared spectrum

Operating in authorized shared spectrum involves enabling the radio transmission of AN and informing the surrounding TEs about the operating channel, transmit power, and other radio parameters.

Once the AN is operating in the authorized shared spectrum, the ANC is responsible for controlling the radio transmission of NAs and TEs in the operating channels to meet the authorized shared access regulations in the given area.

### Detailed procedures

#### Access Network setup procedure

The access network setup procedure includes the initiation of the procedure by the ANC with retrieving its configuration parameters from NMS, the establishment of the communication links of the ANC to CIS, associated SSs, and associated ARs, the dynamic discovery and configuration of NAs and the configuration of the BH including the links to the associated ARs.

…

NA

NMS

2. PowerUp Request

ANC

3. PowerUp Response

4. Join Request

6. Update Response

1. Access network
power-up

5. Update Request

7. Join Response

Figure 25—An example of access network setup procedure

Figure 25 shows an example of procedure of access network setup.

1. Access Network setup procedure starts when the AN is powered up and ANC is booting up.
2. When the ANC is booted up, the ANC sends a PowerUp Request message to the NMS which is assigned to the access network. The ANC knows about its assigned NMS through a locally stored address or identifier.
3. After receiving the PowerUp Request message, the NMS sends the PowerUp Response message with the information for the ANC to configure itself and its communication with CIS, associated SSs and ARs.
4. Once the ANC retrieved the basic configuration information from the NMS, it accepts Join Request messages from powering-up NAs.
5. The ANC registers the NA in its network element database and forwards the information about the NA in an Update Request message to the NMS, to register it and to retrieve its configuration parameters.
6. The NMS adds the information about the new NA to its repository of management information and responds to ANC with and Update Response message containing the basic configuration parameters for the NA.
7. The ANC amends the configuration information retrieved from NMS with locally generated configuration information and sends the complete basic configuration set to the NA, which activates the configuration and enters its operational state indicating to TEs the possibility to connect.

It can happen during the operation of the NA, that new NAs are connected and powered up. After power-up, the new NAs send Join Requests to the ANC, and the ANC handles the basic configuration during operation the same way as in the initial setup procedure.

#### Access Network release procedure

There are two ways to release the access network: access network is released by itself, or it is released by the access network operator through the NMS. In any case, the ANC orderly terminates the operation of the network elements before shut-off of the AN.

NA

NMS

ANC

2. Release Response

1. Release Request

3. ShutDown Requ

5. ShutOff Request

4. ShutDown Resp

6. ShutOff Response

(a)

NA

NMS

ANC

2. Release Confirm

1. Release Indication

3. ShutDown Requ

5. ShutOff Request

4. ShutDown Resp

6. ShutOff Response

(b)

Figure 26—An example of access network release procedure

Figure 26 shows examples of access network release procedure for the two cases. The access network could be released by the ANC as shown in Figure 26(a), or by the access network operator through NMS as in Figure 26(b).

1. In some exceptional cases, such as at certain abnormal conditions, the access network may have to initiate access network release under the control of ANC as shown in Figure 26(a). In such case, the ANC will inform the NMS that the access network will be going down through a Release Request message.

ssending a Release Indication message to the ANC

1. When AN release was requested by the ANC, the NMS responds with an Release Response message indicating that the NMS is aware of the ongoing tear-down of AN operation.
When AN release was initiated by NMS, the ANC responds with an Release Confirm message to notify that the request has been received and the AN operation will be terminated shortly.
2. The ANC pursues the AN release through sending ShutDown Request messages to each of the NAs of the AN, to achieve an orderly termination of the service.
3. After termination of the user sessions going over R1 through disassociation of the terminals, the NAs inform the ANC about the end of the service through ShutDown Response messages.
4. When all user traffic has stopped and all network elements terminated its operations, the ANC notifies the NMS about the end of the AN operation through a ShutOff Request message.
5. When receiving the ShutOff Response message from the NMS, the ANC can finally stop its operation through shutting off the power supply.

The ANC of a released AN may stay in a hibernated state listening to potential messages coming from the NMS. Such hibernated state of the ANC reduces the time to re-invoke an AN.

#### AN setup for authorized shared spectrum access



Figure 27—Detail procedure of AN setup for authorized shared spectrum access

1. After boot-up, the NA should establish a secure connection to the ANC, report its geolocation based on the preconfigured information, and configures the port to the BH.
2. The ANC generates an access request message on behalf of the NA containing the geolocation and other related information. The access request message is sent from the ANC over R10 to the valid CIS. After receipt of an access request message, the CIS starts the EAP message exchange with the ANC. When the identifier of ANC is known and requested access can be granted, the CIS informs the ANC with an access accept message of the allowed access. The pairwise master key is delivered in the access accept message from the CIS to the ANC.
3. Once the authentication process succeeds, the ANC can query the CIS via sending the SA information request message that allows the ANC to request a list of available channels and maximum allowed EIRP per channel from the CIS. After receipt of an SA information request message, the CIS returns an SA information response message to the ANC providing the requested information.
4. Based on the retrieved information, NA can be initially switched on and perform a spectrum sensing procedure on the specified channels. The result of the above sensing should be provided to ANC embedded in an SA use information request message.
5. As all the information on the spectrum availability resulting from the CIS and spectrum sensing function at the NA is gathered, the ANC should determine the operation channel(s) and indicate the NA through SA use response message to commence operation on the selected channel(s).
6. NA may hand over radio configuration information used for TVWS to the TEs located in the same area in order to control the interference to the primary services.

#### Primary service protection



Figure 28—Detailed procedure for primary service protection for shared spectrum access

1. Independent procedure of spectrum sensing may be performed periodically by TE and NA as the operation of the primary service changes over time. If the activity of the primary service is detected through the distributed sensing technique by both TE and NA, the ANC should be notified immediately.
2. If the ANC concludes that the operating channel is under interference and primary service needs to be protected, a channel switch notification message will be generated and sent from the ANC to the NA.
3. In this situation, the NA should update the status of the listed backup channels and notify the ANC with a channel switch confirm message. Meanwhile, the NA will start a timer to schedule the channel switch and notifies the TE about the action with a channel switch notification message.
4. If the backup channel is available when the timer expired, the NA will continue its operation on the backup channel and re-establish communication with the TE. Otherwise, the NA should terminate its operation on current channel and the access service will be shut down.

#### Renewal of spectrum access authorization



Figure 29—Detailed procedure for spectrum access authorization renewal

1. When NA is operating in the shared spectrum, its ANC needs to set up a timer to track the granted period of operation.
2. When the shared spectrum usage timer expired, the ANC will query the CIS with the updated location of NA to renew the use of shared spectrum.
3. If the operating channel is available, the CIS will grant the renewal request. Otherwise, it will reject the renewal request and trigger the re-initialization of the AN.
4. When the renewal request is granted, the ANC will reset the timer to the granted value and prolong the operation on current channel.

### Mapping to IEEE 802 technologies

While all IEEE 802 radio technologies contain specifications for operation in unlicensed, shared spectrum, only a few support operations in TVWS. IEEE 802.22 is fully aimed for TVWS operations, and IEEE 802.11af amended the IEEE 802.11 WLAN specification by a special mode fulfilling the requirements for licensed shared access in unused TV bands.

The procedures for access network setup and release are not covered through IEEE 802 specifications, but are realized in vendor-specific implementations.

## Access network discovery and selection