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DISSEMINATION LEVEL		
PU	Public	**X**
PCA	Public with confidential annex	
CO	Confidential, only for members of the consortium (including Commission Services)	

EXECUTIVE SUMMARY

This document identifies the required WSN (Wireless Sensors Network) aided cognitive radio modules for the implementation of the validation trials defined in D7.1 and specified in D7.2. For each module, it defines its interfaces and the exchanged messages though these interfaces based on the outputs defined in WP3, WP4, WP5 and WP6 and provided to WP7. Two scenarios are considered in SENDORA project as specified in D7.1 and D7.2. The first scenario focuses on a centralized architecture to enable a WSN aided cognitive radio. The second scenario describes a distributed architecture enabling Cognitive ad hoc Network. The current deliverable proposes and describes a set of modules and interfaces that will be handled by the Cognitive Radio Resource Management (CogRRM) entity of the global Cognitive radio Architecture proposed in D6.2. The document is mainly divided in three parts. The first part describes the modules that will allow the demonstration of WSN aided Cognitive radio. It contains also the description of the key parameters to be exchanged between different blocks to allow the validation and the operation of the global target system. The definition of these parameters was done jointly by the partners of SENDORA project in different WPs taking into account the requirements, performance and complexity of the candidate algorithms and the capabilities of the target platforms. In addition, specific parameters were defined for the SoC (System on Chip) based testbed developed at TKK. The second part is dedicated to describe in details the messages that will carry the parameters defined in the first part and which will be implemented in the final demonstrator developed jointly by Eurecom and Thales Communications. The third part describes the step by step implementation phases for the specified architectures including both scenarios. It details also the planning for the implementation of the SENDORA system.

Acronyms

Acronym	Meaning
AP	Access Point (wifi)
BTS or BS	Base Station
CH	Cluster Head
CS	Communication and Sensing capabilities (terminal)
FC	Fusion Centre
LLR	Log Likelihood Ratio
MAC	Medium Access Control (layer)
MON	Spectrum Monitoring message
PN	Primary Network
PU	Primary User
R	Relay
SCAN	Spectrum Scanning message
SN	Secondary Network
SU	Secondary User
SYNC	Synchronization message
WSN	Wireless Sensor Network

Contents

1. INTRODUCTION

1.1 D7.3 PURPOSE

In FP7 ICT SENDORA project, Work Package 7 is dedicated to System Integration and Demonstration activities. This document is the deliverable D7.3 and describes the outputs from the other technical WP to be integrated in demonstration activities.

The validation of SENDORA project objectives is performed through different complementary means, among which system demonstrations on hardware platforms. The corresponding demonstration scenarios and associated validation trials are defined in D7.1 "Validation Trial Definition". Then the validation of the project objectives will be completed through simulations and emulations, under realistic environment conditions. Simulation and emulation activities will be reported in D7.5 deliverable.

The objective of this deliverable is to identify the required modules for the implementation of the validation trials and demonstrations defined in D7.1 and D7.2 deliverables and define the related interfaces.

The implementation and integration of the interfaces and messages defined in this deliverable will be provided in D7.4 as mentioned in the annex of the project.

1.2 DOCUMENT VERSION SHEET

Version	Date	Description, modifications
1.0	02/10/2009	First version
1.1	21/12/2009	Update after Consortium internal review

2. SYSTEM DEMONSTRATION SCENARIOS

In D7.1, two real-time system demonstration scenarios and associated trials have been defined to prove the project overall concept, especially the concept of the WSN aided Cognitive Radio. These scenarios reminded below are the basis for the system demonstration activities in the project.

2.1 VALIDATION TRIAL FOR DEMONSTRATION SCENARIO #1

This system demonstration scenario shall demonstrate a secondary network providing the users with a cognitive nomadic broadband access using a sensor network aided Cognitive Radio technology based on an independent sensor network.

The secondary network shall receive transmission opportunities from the Fusion Centre and adapt its communications to take advantage of these opportunities. The objective is to take advantage of unused spectrum in an optimised way, in order to propose to the secondary users a broadband access on a best effort basis. The Fusion Centre is able to provide such information by computing sensing information provided by a dedicated sensor network. This sensor network is made of sensor nodes with detection and transmission capabilities.

The system demonstration scenario #1 is represented on the figure below:

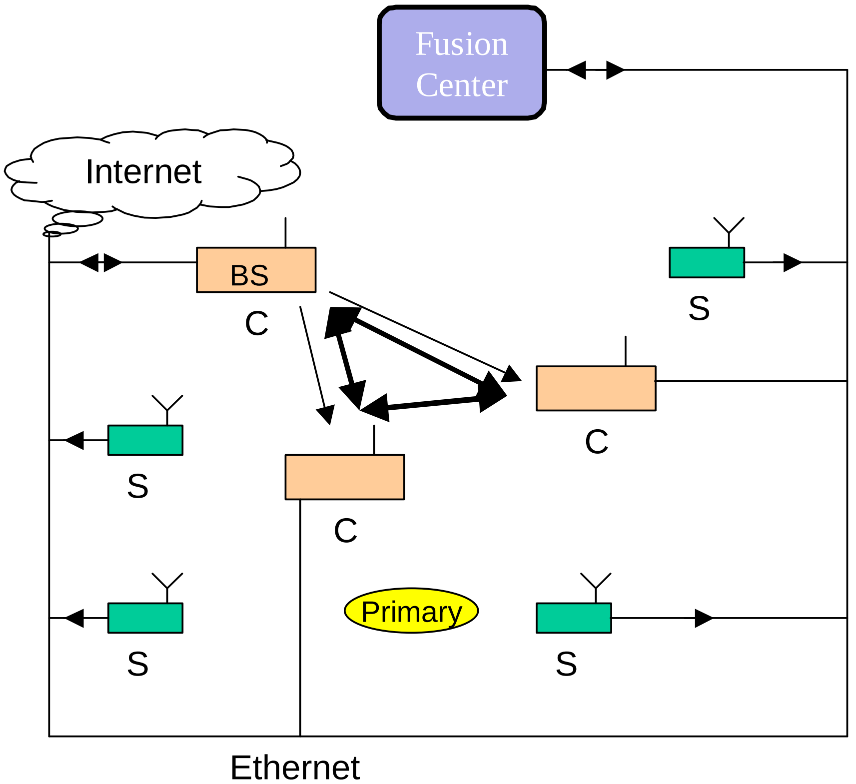

Figure 1 : System demonstration scenario #1

The primary system is a WiFi system and WiFi communications are considered as primary user communications. A sensor network is deployed in the area to detect the spectrum usage in the corresponding frequency band. The sensor nodes (S) have detection capability and communicate their detection results through a wired connection to a Fusion Centre entity that aggregates the information coming from the different sensors and proposes an interface with global spectrum monitoring. A secondary network (Base Station (BTS) + Secondary Users (SUs)), deployed in the area, takes advantage from this interface provided by the Fusion Centre entity to perform communications in an opportunistic manner. If primary user transmissions are detected by the Sensor Network in the corresponding band, the Fusion Centre shall receive the information and forward it to the Secondary Network. The Secondary nodes shall adapt their transmissions to avoid harmful interferences generated to the primary users.

A summary of the trial script defined for this scenario in D7.1 is provided below:

1) a WiFi network with two access points is deployed. The first Access Point is active on a given channel with primary users connected.
2) a sensor network is deployed in the area.
3) a fusion centre is launched.
4) the sensor nodes detect the primary system activity in its pool of scanned channels.
5) the sensor nodes forward the primary system activity they have detected to the fusion centre.
6) the fusion centre aggregates the sensing information and computes the free channels.
7) a centralized secondary network (including a base station) is deployed in the area covered by the sensor network.
8) the base station node consults the fusion centre dedicated interface to read a monitoring of the free channels.
9) the base station node decides what channels will be used for secondary communications and broadcasts the decisions of adaptation to the secondary nodes.
10) secondary nodes receive the required transmission adaptations and communicate using the free channels.
11) secondary nodes access to broadband services through the base station node connected (wired connexion) to the Internet and playing the role of gateway.
12) a communication is launched on the primary network (for example a video stream is transferred) through the second Access Point on a channel used by secondary nodes.
13) some of the disseminated sensor nodes detect the primary system activity in this channel and forward the information to the fusion centre.
14) the fusion centre is informed of the primary network activity on this channel and forwards the news (or the updated situation on free channels) on its interface to the secondary network base station.
15) the secondary network, that on a regular basis checks the corresponding interface, learns that the channel used by some of the secondary nodes is not yet free, decides of adaptations (to free the channel now used by the second Access Point) and forwards the decisions to the secondary nodes.
16) the communicating secondary nodes adapt their transmissions and communicate.

2.2 VALIDATION TRIAL FOR DEMONSTRATION SCENARIO #2

The second system demonstration scenario shall demonstrate a secondary network providing the users with a cognitive nomadic broadband access using a WSN aided Cognitive Radio technology.

In this scenario, the Secondary Network integrates the Wireless Sensor Network: secondary communicating nodes have sensing capabilities, they perform the spectrum sensing in a distributed manner, compute transmission opportunities and adapt their communications to take advantage of these opportunities without interfering harmfully with the primary technologies.

The system demonstration scenario #2 is represented on the figure below:

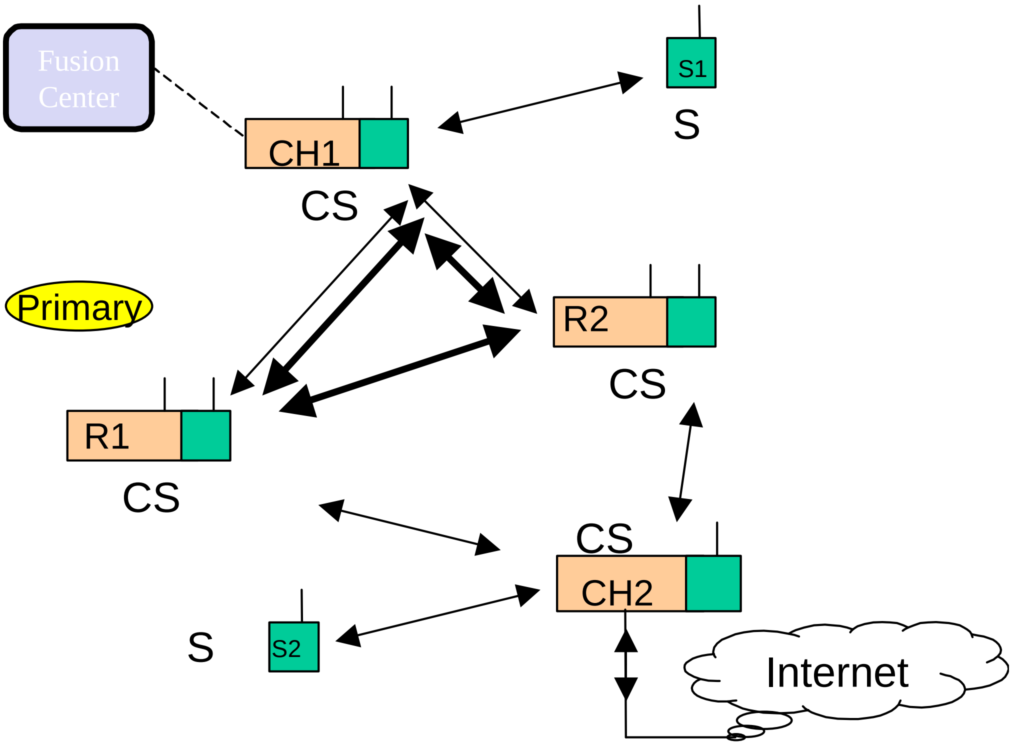

Figure 2 : System demonstration scenario #2

Like demonstration scenario #1, the primary system is a WiFi system and WiFi communications are considered as primary user communications. An ad hoc secondary network is deployed in the area. The secondary nodes have sensor capabilities to detect the spectrum usage and communicate their detection results between each other on a dedicated narrow band channel. There are 6 nodes in total, out of which 4 have communication and sensing capabilities (CS) and 2 nodes only have sensing capabilities (S). The WSN is organized in two clusters. Cluster 1 consists of cluster head 1 (CH1), sensor 1 (S1), and secondary nodes (R1 and R2). CH1 is supposed to be directly connected to a Fusion Centre (not implemented) over a wired connection, which should be mandatory in a real system to ensure a global spectrum management, as depicted in D2.1 "Scenarios and system requirements" document. The second cluster is formed by CH2, S2, R1 and R2. According to the result of this sensing phase, the secondary nodes perform cognitive communications in a channel that they have detected as free. The secondary nodes shall adapt their transmissions if they detect any primary user transmissions in the corresponding channel to avoid harmful interferences. Two cases are considered according to the role of the cluster heads. In the centralized channel allocation scenario all sensing results are collected by the cluster heads, and the cluster heads control the channel assignment upon a request from a secondary node. In the distributed scenario sensors broadcast the sensing results, and decide about possible free channels based on their own sensing result and the results broadcasted by nearby nodes. The cluster heads in this case only accept or reject the decision of the secondary nodes.

We provide below a summary of the trial script defined for this scenario in D7.1

1) a WiFi network with two access points is deployed. The first Access Point (AP) is active on a given channel with primary users connected. The AP2 is off.
2) an ad hoc secondary network is deployed in the area. It is composed of a few nodes organized in two clusters, each one with a cluster head. All nodes are identical, able to perform sensing and secondary communications. But the nodes of cluster 2 are only dedicated to sensing. The respective positions of the cluster heads do not allow a direct link and cooperative communications are required to allow their communication.

The following steps depend on the applied centralized or distributed channel allocation.

Centralized case

3) the cluster heads initiate sensing in the ad-hoc network, and the sensors report the channel availability measurements periodically to the cluster head of their cluster. The cluster head of the second cluster collects and forwards the measurements to the other cluster head using collaborative communication protocol initiated by the cluster head 1.
4) a secondary node initiates a connection by requesting an available channel from its cluster head.
5) the cluster head handles the monitoring of the available channel(s) (AP2 bands) used for secondary communication, in both clusters.
6) the secondary nodes perform broadband communications using the assigned channel, with a potential access to the Internet through the collaborative communication between CH1 and CH2 which acts as a gateway.
7) a communication is launched on the primary network (for example a video stream is transferred) through the second Access Point on a channel used by secondary nodes.
8) the secondary network detects the primary system activity through its sensing capability.
9) the cluster head of cluster 1 collects the new sensing information and instructs the secondary nodes to switch channel if necessary
10) the secondary nodes adapt their transmissions to switch to the free channel if any or stop the communication until it finds one.

Distributed case

3) the cluster heads initiate sensing in the ad-hoc network and the sensors broadcast their measurements periodically on the shared control channel .
4) from the own sensing results and the sensing results of the nearby sensors, the secondary nodes locally decide what free channel they will use for their communication and inform the first cluster head that coordinates allocations
5) the cluster head broadcasts an acknowledgement of the selected channel or asks to select another channel; through this broadcast message all secondary nodes in the transmission area become aware of the channels used by other secondary nodes
6) the communicating secondary nodes broadcast a request for monitoring of the channels to be used for the secondary communication.

7) the secondary nodes perform broadband communications using the acknowledged channel, with a potential access to the Internet through the collaborative communication between CH1 and CH2 which acts as a gateway

8) a communication is launched on the primary network (for example a video stream is transferred) through the second Access Point on a channel used by secondary nodes.

9) the secondary network detects the primary system activity through its sensing capability and selects a new free channel for communication following the acknowledgement protocol described above.

10) the secondary nodes adapt their transmissions to switch to the free channel if any or stop the communication until it finds one.

3. MODULES DEFINITION

After having reminded the two demonstration scenarios selected by D7.1 to validate the sensor network aided cognitive radio concept, this section assesses the required modules for their implementation. For each module, we provide a short definition useful for the understanding of sections 4 and 5 devoted to interfaces definition and specification respectively. More details/specifications about these modules will be reported in a coming deliverable D7.4 “Report on WSN aided cognitive radio platform”

A summary of the required modules is given by the following figure:

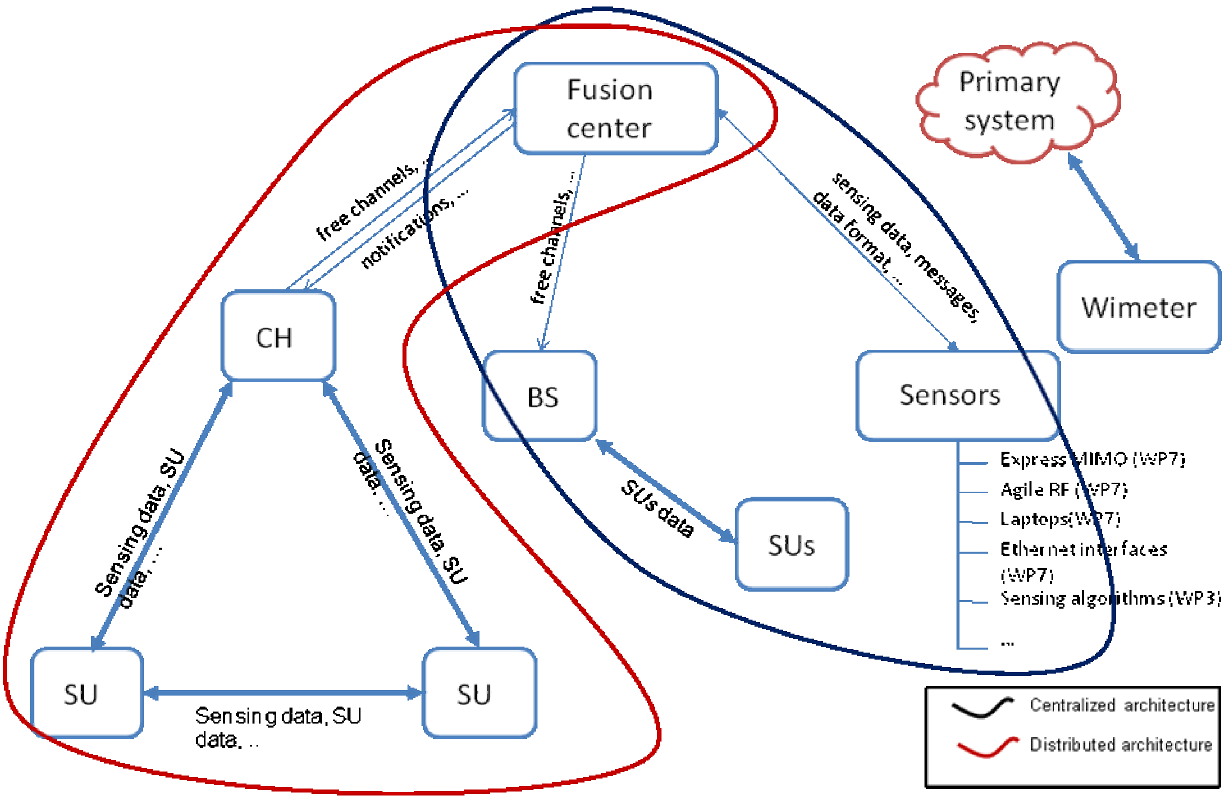

Figure 3: A schematic overview of the required modules for the implementation

3.1 SECONDARY NETWORK MODULE

3.1.1 General description of the module functionalities:

According to deliverable 7.2 “Demonstration Specification” the functional specification for the secondary user module is different for the two trials.

In **scenario# 1**, the secondary user module is a centralized architecture with one base station and at least two nodes. The base station node consults the fusion centre dedicated interface to read a monitoring of the free channels in an area. It makes the decision on which radio resource to be allocated to a SU and notifies the fusion centre about the frequency and power level that it allocates to SUs so that the fusion centre can initiate the monitoring of that frequency band by the sensor network. Nodes only need to support communication.

The communication between nodes shall be based on a flexible OFDMA waveform which will be adapted to include silent periods and thus allow to WSN to operate sensing. Further, a signalling channel for the transmission of information related to the cognitive operation, such as silent period duration, is required.

From the list of trials listed in section 2, we extract the following actions which concern the secondary network module:

- the base station node consults the fusion centre dedicated interface to read a monitoring of the free channels and the information about silent intervals period. (Interface SN-FC)
- the base station node decides what channels will be used for secondary communications and broadcasts the decisions of adaptation to the secondary nodes. (SN internal interfaces)
- secondary nodes access to broadband services through the base station node connected (wired connexion) to the Internet and playing the role of gateway (Interface SN-Internet)
- the secondary network, that on a regular basis checks the corresponding interface, learns that the channel used by some of the secondary nodes is is now occupied by the primary system and decides of adaptations (SN internal interfaces).

In **scenario #2,** the secondary user module is an ad-hoc mesh network with one of the nodes as cluster head (CH). In addition to the requirements of trial #1, the nodes of the secondary user module shall also support sensing. The secondary user module shall also serve as a wireless sensor network to convey this information to the cluster head (CH) via the specified narrow band. The measurement information could be aggregated in the CH or in each node (centralized or distributed channel allocation). Based on the aggregated information, the CH/node makes a decision about the available frequencies. The coordination between sensor nodes is controlled by the CH.

In a realistic system, the CH would indeed notify the fusion centre about the set of frequencies detected as free in its environment and potentially candidate to be used by the users attached to this CH. The fusion centre would send then a message to the CH to authorize it (or not) to occupy these bands. The fusion centre is not implemented in the demonstrator.

In this scenario, we select from the trials listed in section 2, the following actions which concern the interfaces related to the distributed case.

Centralized case:

- a secondary node initiates a connection by requesting an available channel from its cluster head.
- the cluster head handles the monitoring of the available channels(s) (AP2 bands) used for secondary communication, in both clusters.
- the secondary nodes perform broadband communications using the assigned channel, with a potential access to the Internet through the collaborative communication between CH1 and CH2 which acts as a gateway.
- the secondary nodes adapt their transmissions to switch to the free channel if any or stop the communication until it finds one.

Distributed case:

- from the own sensing results and the sensing results of the nearby sensors, the secondary nodes locally decide what free channel they will use for their communication and inform the first cluster head that coordinates allocations
- the cluster head broadcasts an acknowledgement of the selected channel or asks to select another channel; through this broadcast message all secondary nodes in the transmission area become aware of the channels used by other secondary nodes
- the communicating secondary nodes broadcast a request for monitoring of the channels to be used for the secondary communication.
- the secondary nodes perform broadband communications using the acknowledged channel, with a potential access to the Internet through the collaborative communication between CH1 and CH2 which acts as a gateway
- the secondary network detects the primary system activity through its sensing capability and selects a new free channel for communication following the acknowledgement protocol described above.
- the secondary nodes adapt their transmissions to switch to the free channel if any or stop the communication until it finds one.

3.1.2 General description of the module parameters:

Scenario #1, WSN Centralized Cognitive Network

In scenario #1, in addition to the parameters defined in openair interface [2][3] for nodes communication, the following parameters are defined.

Frequency allocation task:

BTS required parameters (from FC):

- List of available frequencies
- BTS identifier

BTS provided parameters (to FC):

- Allocated frequencies
- BTS identifier

SN control task

BTS required parameters (from SU):

- QoS parameters
- SU id

BTS provided parameters (to SU):

- SYNC parameters
- Frequency allocation
- MAC parameters

Scenario #2, Cognitive Ad hoc Network: centralized channel allocation

In scenario #2, centralized decision, in addition to the communication protocol defined for openairinterface ad hoc network, the following parameters are needed to incorporate interference management/resource allocation (see parameters list defined above for scenario #1), and frequency selection (see parameters defined for FC module). Note that the functionality is assumed to be implemented in the CH of each cluster, and, thus, co-locate with the sensing control functionality of the WSN.

<u>Frequency allocation task:</u>

SN(CH) required parameters:

- List of available frequencies

SN(CH) provided parameters:

- Allocated frequencies

<u>SN control task</u>

SN(CH) required parameters (from transmitting SU):

- SU id

SN(CH) provided parameters (to transmitting SU)

- SYNC parameters
- Frequency allocation
- MAC parameters.

Scenario #2, Cognitive Ad Hoc Network: distributed channel allocation

In this scenario the SUs decide about the channel allocation themselves. Frequency allocation and SN control required the following parameters:

<u>Frequency allocation task</u>

CH required parameters:

- occupied frequencies parameters (from transmitting SU)
- SU id (from SUs)
- CH identifier

CH provided parameters (to transmitting SU):

- frequency allocation confirmation

- SUs Id

3.2 WIRELESS SENSOR NETWORK MODULE

3.2.1 General description of the module functionalities:

The WSN shall have the following functionalities:

- Spectrum sensing at each node
- Cooperative communication between nodes to convey sensed information to CH or fusion centre in scenario 2.
- Protocol design to enable sensing and cooperative communication

Cooperative communication task:

Cooperative-communication techniques are applied in the demonstration scenario #2 as defined in D71 and D72.
In summary, we have two clusters with cluster heads CH 1 and CH 2. The nodes in cluster 2 perform spectrum sensing; sensing data of the connected nodes are collected by CH 2 and forwarded to CH 1 which is connected to a fusion center. CH 1 consults the fusion center, allocates frequencies for cognitive communications, and returns this information to CH 2.
The nodes in cluster 2 start broadband communications utilizing the resources allocated by CH 1.
In this scenario it is assumed that CH 1 lies outside the communication range of CH 2 (and vice versa). Cooperative communications are used to transmit the sensing data from CH 2 to CH 1 utilizing the relays R 1 and R 2 as shown in Figure 4.

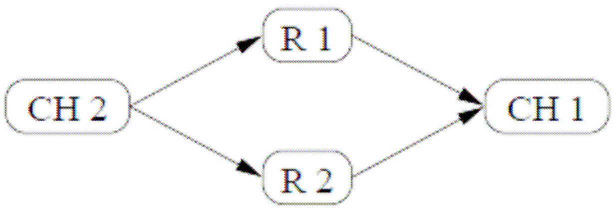

Figure 4: Cooperative communications in scenario #2 of the validation trial definition (simplified).

Cooperative communications will be carried out in two phases, as shown in Figure 5. In a first phase, CH 2 broadcasts the sensing data to the relays R 1 and R 2. In the second phase the relays cooperate in forwarding the sensing data to CH 1.

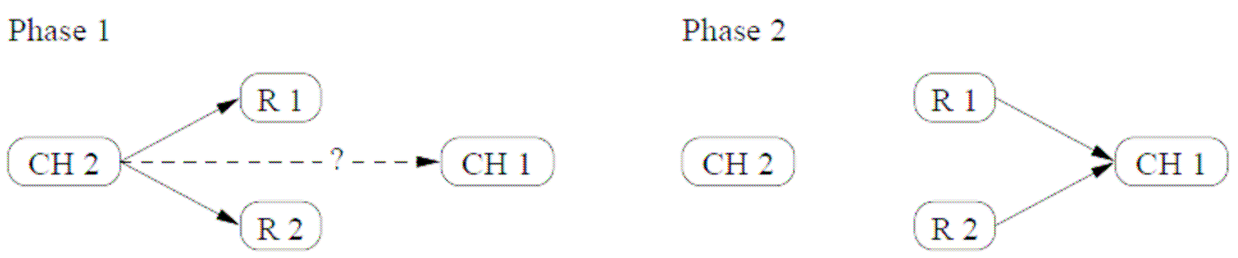

Figure 5: Cooperative communication protocol in two phases

In this scenario, we assume that the relays do not have any individual sensing data which have to be forwarded. The sensing data of the relays are already included in the sensing data from CH 2.

Information fusion and WSN control

Scenario #1

The measurement activity of the sensors, periodicity and scanned frequencies, is controlled by the fusion centre. The sensors send sensing information to the fusion centre unsolicited (proactive sensing). In the case of proactive sensing, sensor nodes of the Sensor Network send spectrum availability information periodically and the fusion centre maintains a map of free channels. The set of sensors are deactivated once the secondary communication service is turned off.

Scenario #2, centralized decision

The functionality of the fusion centre is now in each cluster located at the cluster head (CH). Each CH then, in addition to controlling the sensing in its own cluster, requests sensing actions (SCAN and MON) from remote clusters and processes the results.

Scenario #2, distributed decision

The sensors broadcast the sensing results on the shared control channel and collect the sensing results from the nearby sensors. The CH accepts or declines the channel selection decision of the secondary nodes. The CH then, confirms the list of allowed free channels in a broadcast message to all SUs in the cluster area.

3.2.2 General description of module parameters:

Sensing:

Algorithm input parameters
(for a single module)

- Sensing bandwidth, number of sub bands
- Maximum sensing time
- Period of sensing interval
- Sampling rate

- Decision threshold based on detector performance specification Pfa Pd , if yes/no answer is required
- Time delay Td for the autocorrelation. (in multiples of sampling period)

Inputs required for the local sensor module:

- Centre frequency and resolution of the frequency scan. Resolution of the frequency can be default, for example, 200 KHz in which case this information need not be transferred.
- Kind of primary users targeted (Wi-Fi, UMTS, DTT, LTE) and related parameters. For example, cyclic prefix duration for LTE, and DTT; scrambling codes for UMTS; uplink or downlink for LTE, etc.
- Sensing method to be used from the pool of sensing algorithms. Depending on Primary user to be detected and algorithm to be used, the parameters will change.

Algorithm output parameters

- Autocorrelation coefficient to be compared to threshold value or to be used in co-operative sensing (alternatively yes/no answer if the received signal).
- LLRs
- Interference/Power level
- Sub space dimension

Outputs of local sensor module implemented at TKK:

- Log Likelihood Ratio (LLR): Required at the fusion centre (or cluster head) for cooperative spectrum sensing. Distribution of the primary user waveform or related parameters under the two hypotheses may be needed for this.

- SNR value: Required for sequential detection at the fusion centre.
- Noise variance: Required for energy detection at the fusion centre.
- Power level/ SINR: Required for generating spatial spectrum usage map at the fusion centre. Also needed for limiting interference to the primary user.
- Location of the sensor: Required for generating spatial spectrum usage map at the fusion centre. The sensors with GPS should easily generate this information. The ones without GPS will have to send some related statistics (may be SNR) so that fusion centre can interpolate its location with help of other sensors.
- Time stamp of the sensor results so that fusion centre can verify the validity of the results.
- Battery level of a battery operated sensor: This will help fusion centre to allocate the sensing tasks efficiently.

Co-operative decision algorithm inputs parameters at FC or CH or sensing node (in distributed sensing)

- Number of decision statistics to be used for co-operative detection
- Decision threshold based on required false alarm rate (alternatively false alarm rate)
- Time delay for which the autocorrelations should be computed
- Computed estimates of decision statistic such as autocorrelation value with defined delay of individual modules, LLRs, etc…

Inputs to the fusion centre for sensing (apart from the outputs of local sensor module):

- False alarm constraint to design the cooperative detection scheme at the fusion centre.
- Other performance parameters like minimum probability of detection and maximum sensing time.
- Information related to primary user waveforms.
- Sensing policy.
- Apriori probabilities of the primary users being present and absent.
- Number of secondary users cooperating.

NOTE: It is suggested to have some redundancy (vacant slots) in all messages related to sensing for unseen future issues as a precautionary measure.

Co-operative sensing algorithm outputs

- Yes/no estimate about the presence of a system identified by Td .

Cooperative communication:

COOPERATION MODE, e.g.,

- no cooperation
- amplify-and-forward cooperation using a particular cooperation scheme
- decode-and-forward cooperation using a particular cooperation scheme

The COOPERATION MODE depends on:

- nodes which are selected as relays (R1 and R2 in our case)
  - ➢ parameter: AVAILABLE_RELAYS
- SNR on the links between CH2 and the relays R1 and R2
  - ➢ parameter: AVERAGE_SNR
- required data rate
  - ➢ parameter: RATE_REQUIREMENT
- deadline for the transmission
  - ➢ parameter: MAXIMUM_TRANSMISSION_TIME

The RATE_REQUIREMENT and MAXIMUM_TRANSMISSION_TIME depend on the application (sensing) which is managed by CH1 in this scenario.

Information fusion and WSN control

Scenario #1

WSN required parameters (from FC)

- SYNC parameters
- SCAN parameters
- MON parameters

WSN provided parameters (to FC)

- sensor id
- sensing result parameters

Scenario #2, centralized decision case

Cluster head: Spectrum sensing control task

Algorithm input parameters:

- List of SN occupied bands – in MON state
- sensing result parameters
- For each remote CH:
    - List of SN occupied bands in remote cluster – in MON state
    - sensing result parameters from remote CH sensors

Algorithm output parameters

- SYNC parameters
- Sensor MON parameters
- Sensor SCAN parameters
- WSN SCAN sequence
- WSN SCAN parameters

Cluster head:

- Spectrum availability decision task

Algorithm input parameters

- sensing result parameters
- sensing result parameters from remote CH sensors

Algorithm output parameters

- List of available frequencies
- MAC parameters (to transmitting SU)

Scenario #2, distributed decision case

Cluster head: Spectrum sensing control task

CH provided parameters to sensing SUs

- SYNC parameters
- SCAN parameters

Cluster head: Spectrum availability confirmation and broadcast task:

- *source and destination SU id*
- *session id*
- occupied frequency parameters.

Transmitting SU: spectrum availability decision task

SU provided parameters to other SUs

- SU id
- MON parameters

SU required parameters from other SUs

- SU id
- sensing results parameters

All SU: spectrum sensing task

SU provided parameters to other SUs

- SU id
- sensing result parameters

SU required parameters

- SYNC and SCAN parameters from CH
- MON parameters from the transmitting SU

3.3 FUSION CENTRE MODULE

3.3.1 General description of module functionalities:

The fusion centre (FC) connects the sensor network and the BTS of the secondary communication network. It acts as an aggregation point for the data from the sensors in the sensor network. The FC configures the sensors to monitor specified frequencies to either detect unused bands, or detect PU activity on bands used by SN. Based on the measurement of the PU activity, the fusion centre keeps a list of available frequencies. Whenever the sensors detects PU activity on a band, the fusion centre is be notified immediately about the change in power levels at the concerned frequencies. The fusion centre can combine the measurements of multiple sensors to increase the detection reliability.

The fusion centre offers a dedicated interface to the communication network through its base station to read a monitoring of the free channels in an area. It is also notified by the base station about the frequency and power level that the BTS allocates to SUs so that the fusion centre can initiate the monitoring by the sensor network of frequency bands occupied by SN.

In scenario#1:

From the list of trials listed in section 2, we extract the following actions which concern the interfaces between FC and other modules:

- a sensor network is deployed in the area (Interface WSN-FC)
- the FC configures sensors to scan frequencies to find free band
- the sensor nodes forward the primary system activity they have detected to the fusion centre (Interface WSN-FC)
- the base station node consults the fusion centre dedicated interface to read a monitoring of the free channels (Interface SN-FC)
- The Base station informs the FC about the allocated bands (Interface SN-FC)
- The FC configures sensors to monitors allocated bands for PU activity
- disseminated sensor nodes detect the primary system activity in this channel and forward the information to the fusion centre (Interface WSN-FC)
- the fusion centre is informed of the primary network activity on this channel and forwards the news (or the updated situation on free channels) on its interface to the secondary network base station (Interface SN-FC)
- the secondary network, that on a regular basis checks the corresponding interface, learns that the channel used by some of the secondary nodes is not yet free (SN-FC interface)

In scenario #2 the fusion centre is not implemented.

3.3.2 General description of module parameters:

The parameters related to this module are the ones defined in the other modules as inputs provided from the FC or as outputs intended to FC.

<u>Spectrum sensing control task</u>

Algorithm input parameters

- List of SN occupied bands – in MON state
- SCAN result from sensor
- MON result from sensor

Algorithm output parameters

- Sensor MON configuration
- Sensor SCAN configuration
- WSN SCAN sequence
- WSN SCAN parameters

<u>Spectrum availability decision task</u>

Algorithm input parameters

- SCAN results from sensors
- MON results from sensors

Algorithm output parameters

- List of available frequencies

3.4 PRIMARY USER MODULE

3.4.1 General description of module functionalities:

The primary system is a WiFi system and WiFi communications are considered as primary user communications. The WIFI system is composed of two access points and some terminals. Access points are using the 802.11g protocol which provides a maximum net bit rate of in theory 54 Mbit/s with OFDM modulation using the 2.4 GHz frequency band. In EU, there are 13 channels spaced 5 MHz apart (from 2 412 MHz until 2 472 MHz). As the protocol requires 25 MHz of channel separation, adjacent channels overlap and will interfere with each other. That’s the reason why, channel 1, 5, 9 and 13 have to be privileged. We can consider that each Access point can manage around 15 mobile nodes.

3.4.2 General description of module parameters:

Since Access Points should propose the same network to Mobile Nodes, they will thereby broadcast the same Service Set ID (SSID).

3.5 WIMETER MODULE

3.5.1 General description of module functionalities:

Wimeter [1] is a sniffing-based tool that implements a novel technique for available bandwidth estimation in WLANs and its assistance to QoS provisioning. It captures and analyses on real-time the frames going to or coming from a pre-configured access point. The analysis of captured frames consists on determining the portion of time when the channel is free and then to estimate the available bandwidth in function of the packet size of expected frames to be transmitted and the link-layer rate of the sender and the receiver stations.

3.5.2 General description of module parameters:

- Active access point SSID (input)
- Available bandwidth (output)

4. INTERFACES DEFINITION

4.1 WSN CENTRALIZE COGNITIVE NETWORK

This case corresponds to scenario #1. The information exchange between the secondary units and the sensor network is defined by WP4 in deliverable D4.2. The scope addressed in D7.3 is demonstration-focused only while in D4.2, more complex message exchanges are foreseen, for instance to allow a dynamic control of power allocation for each SU of the SN.

The information flow graphs below were already drafted in D7.2 in the description of the demonstration scenario. , including both proactive and reactive sensing scenarios. In Figure 6 we provide the information flow graphs specific for the demonstration trial.

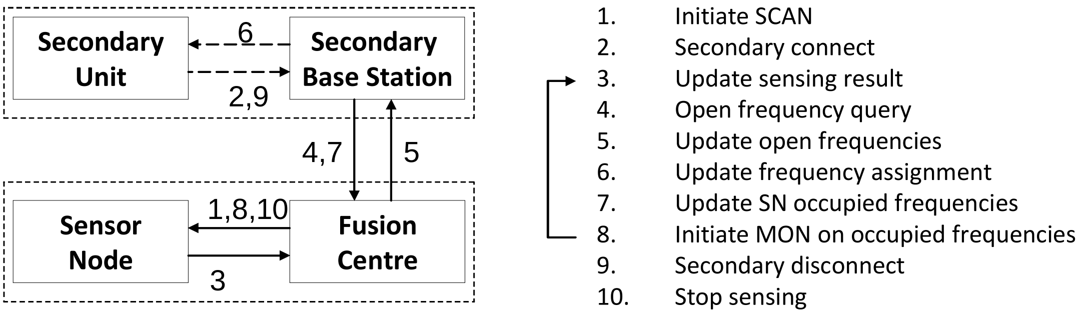

Figure 6: Information flow in scenario #1.

4.1.1 Interface Sensor Module – Fusion Centre

This interface is bidirectional and used by the Fusion Centre as well as the WSN to communicate. The Fusion Centre uses this interface to control the measurement activity of the sensors, periodicity and scanned frequencies. The sensors of the WSN use this interface to report their sensing data (measurements) to the fusion centre for the frequencies they are requested to scan or monitor.

4.1.1.1 Messages list

Exchanged messages within this interface follow a specific communication protocol that will be addressed in WP4 and WP6. This protocol shall implement the following messages. Both for proactive and reactive sensing solutions, the following message has to be implemented:

1. Initiate SCAN message from the FC to the WSN, to instruct for starting continuous scanning on all frequencies considered for cognitive operation. The message issued when the WSN is set up and includes the following parameters: *sensor id, SYNC parameters, SCAN parameters*.

3. Update sensing result periodic message from the WSN to the FC including parameters: *sensor id, sensing result parameters*.

8. Initiate MON on occupied frequencies periodic message from the FC to WSN to instruct for monitoring the frequencies used by the SN, in the SN silent period, including *sensor id, MON parameters*.

10. Stop sensing message from the FC to the WSN when the sensing service is to be closed, parameter is *sensor id*.

Out of these messages message 10 needs to be acknowledged. Messages 1 and 8 are acknowledged by message 3.

4.1.2 Interface Secondary Network – Fusion Centre

In target demonstration trials, the base station uses this interface with the fusion centre for the following purposes:

- To read a monitoring of the free channels in an area
- To notify the fusion centre about the frequency that allocates to SUs. In this way the FC keeps track of the channels used by a specific secondary network, and initiates the monitoring of the used channels.

4.1.2.1 Messages list

Exchanged messages within this interface follow a specific communication protocol that will be addressed in WP4. These messages are not affected by the reactive or proactive ways of spectrum sensing. The protocol shall implement the following messages:

4. Open frequency query periodic message from the BTS to the FC to receive the list of available frequencies, with parameters such as *BTS id*

7. Update open frequencies periodic message from the FC to the BTS with the list of frequencies that the SN is allowed to use in the following time period, with parameters *BTS id, SYNC parameters, open frequencies parameters.*

5. Update SN occupied frequencies periodic message from the BTS to the FC, to identify the channels selected for cognitive operation with parameters: *BTS id, occupied frequency parameters.*

4.1.3 Secondary Network Interface

This interface is used by the secondary nodes and the secondary base station to submit frequency requests and allocate frequencies to use.

This interface shall be implemented in the communication protocol of the secondary network. It will be based on OpenAirInterface protocols [2][3], adapted for the need of the project. Parts of this protocol stack adaptation are depicted in D6.2 (section 5) where the protocol stack for WSN aided cognitive radio architecture is designed and addressed in a genera manner. The modules and interfaces of WSN aided architecture are defined and specified in this deliverable and will be detailed in D7.4.

The protocol stack adaptation for the management of the dedicated messages will be reported in D7.4.

4.1.3.1 Messages list

The protocol shall implement the following messages, independently from the reactive or proactive way of sensing:

2. Secondary connect message from the SU to the BTS with parameters *SU id, QoS parameters* if any.

6. Update frequency assignment periodic message from the BTS to the SU with parameters *SU id and MAC parameters.*

9. Secondary disconnect message from the BTS to the SU with parameters *SU id*.

Messages 2 and 9 may need to be acknowledged. Also, alternative message from BTS to SU can be implemented to force disconnection.

4.1.4 Secondary Network-Internet Interface

This interface is a classical wired connection via IP to internet and will use openairinterface protocols and will demonstrate the application defined in WP2.

4.2 COGNITIVE AD HOC NETWORK

This case corresponds to scenario #2. The information exchange between the secondary units and the cluster heads is defined by WP4 in deliverable D4.2. The scope addressed in D7.3 is demonstration-focused only while in D4.2, more complex message exchanges are foreseen, for instance to allow a dynamic control of power allocation for each SU of the SN.

The information flow graphs below were already drafted in D7.2 in the description of the demonstration scenario, including both proactive and reactive sensing scenarios. With Figure 7 we provide the information flow graphs specific for the demonstration trial, including both centralized and distributed channel allocation decision in scenario #2.

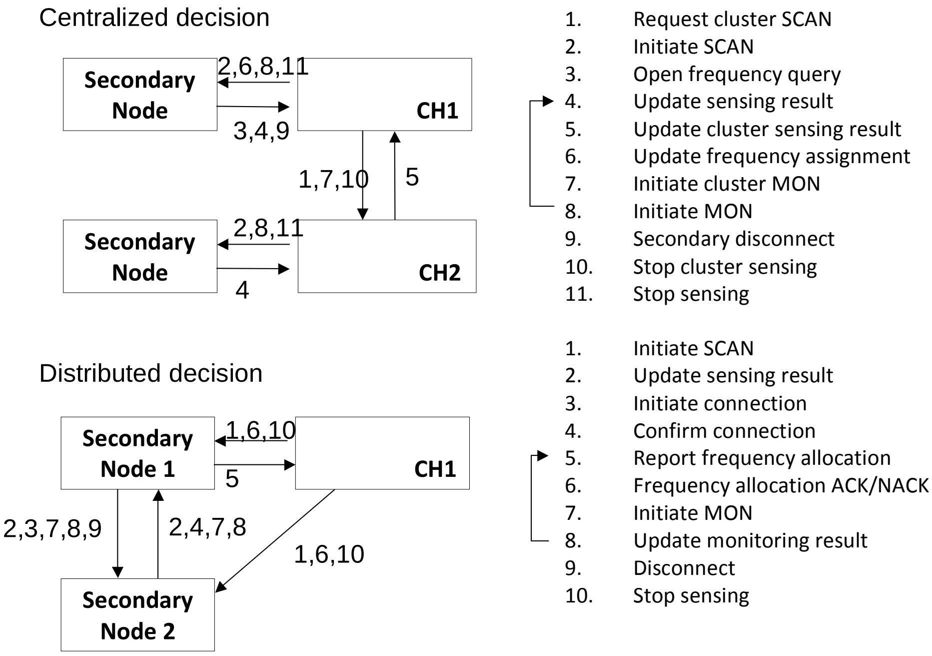

Figure 7: Information flow in scenario #2

4.2.1 Interface Cluster-head – Fusion Centre

The interface between the ad hoc network and the Fusion Centre allows to consolidate the frequency allocations at a higher level (the one of the Fusion Centre) and avoids sub-optimal allocations in the different parts of the SENDORA system (specified in D2.1). This is required for an operator that wants to control the allocations in a given area.

To implement this interface, in each ad hoc network, one CH would be interfaced with the FC.

As explained in D7.2, this interface will not be implemented in the demonstration, as it does not bring anything to the concept validation, since only one ad hoc network is considered. Therefore the FC related messages are not depicted in the information flow figure.

4.2.2 Ad-hoc Network Interfaces

This Section describes the interfaces of the secondary ad hoc network for trial #2. In this trial, the secondary network also takes the role of the wireless sensor network. Two options are possible:

1) The ad hoc terminals collect sensing data and send it to the cluster head (CH) via the specified narrow band. The CH takes a local decision with respect to the presence of the primary system in its environment and forwards it back to the ad hoc terminals. The sensing procedure is initiated by the CH which asks periodically for sensing data from the attached ad hoc terminals. We call this scenario as the *centralized decision case*.

2) A fully distributed scheme with sensing-decision/frequency-allocation taken at the ad hoc terminals is also addressed in this trial. In this case the CHs initiate the proactive sensing, but then the ad-hoc secondary terminals connects to the other secondary and possibly sensing nodes in their interference area, collect the sensed information periodically, and make a suggestion for frequency allocation. The CH acknowledges the allocation or requests the secondary terminal to make a new decision. We call this scenario as the *distributed decision case*.

Cooperative schemes in this trial are used to allow to neighbouring CHs to assist the CH of interest (CH1 in the defined trials) in its sensing decision if needed. Neighbouring CHs (CH2 in the defined trials) could play also the role of gateway and allow to CH1 and its attached nodes to access to internet.

4.2.2.1 Messages list

Centralized decision case

<u>CH-Ad hoc terminal interface:</u>

The following messages are defined:

Sensing mode:

2. Initiate SCAN message from the CH to the sensing SU, to instruct for starting continuous scanning on all frequencies considered for cognitive operation. The message is issued when the ad-hoc network is set up and contains the following parameters: *SU id*, *SYNC parameters, SCAN parameters*.

3. Open frequency query message from the SU to the CH when an SU wish to perform cognitive transmission, and contains the following parameters: *SU id, QoS parameters, if any.*

4. Update sensing result periodic message from the sensing SU to the CH with parameters *SU id, sensing result parameters*.

6. Update frequency assignment periodic message from the CH to the transmitting SU with parameters *SU id* and *MAC parameters*.

8. Initiate MON periodic message from the CH to the sensing SU with parameters *SU id* and *MON parameters*.

9. Secondary disconnect message from the transmitting SU to the CH when it wishes to stop cognitive operation, with parameter *SU id*.

11. Stop sensing message from the CH to the sensing SU at the end of the cognitive service in the ad-hoc network, with parameter *SU id*.

Messages 9 and 11 may be acknowledged. Also, a message alternative to 9 can be implemented to force disconnection.

<u>Ad Hoc-Ad hoc terminal interface:</u>

This interface defines the communication protocol between ad hoc nodes. It will be based on OpenAirInterface protocols [2,3] adapted for SENDORA purpose.

<u>CH1-CH2 interface:</u>

CH1 and CH2 link is depicted in Figure 2. CH2 can assist CH1 by providing some measurements data collected in its environment. It will serve also as a gateway to the internet. This interface will include the following messages:

1. Request cluster SCAN message from CH1 to CH2, to initiate sensing in cluster 2 and agree on the way of transmission between the CHs. Parameters include: *CH1 id, CH2 id, COOPERATION MODE parameters, SYNCH parameters, SCAN parameters.*

5. Update cluster sensing result periodic message from CH2 to CH1 including the sensing results of the sensors in cluster 2, including *CH2 id, CH1 id, the vector of {sensor id, sensing result parameters}.*

7. Initiate cluster MON periodic message from CH1 to CH2 to initiate the sensing of frequencies used be the SUs in CH1, with parameters *CH1 id CH2 id, MON parameters.*

10. Stop cluster sensing message from CH1 to CH2 at the end of the cognitive service in the ad-hoc network, with parameters *CH1 id, CH2 id*.

Message 1 may be acknowledged, or even may need a handshake protocol to agree in COOPERATION MODE parameters. The cooperation mode is selected based on the information provided by the nodes (e.g., channel conditions, available relay nodes) and based on the requirements from the application (required rate and maximum transmission time).

Message 10 may be acknowledged, and alternative message from CH2 to CH1 can be implemented that allows CH2 to finish cooperation if needed.

Distributed decision case

In this case the CH has two roles: it initiates sensing after network set-up and confirms the frequency allocation of the SUs, to provide some coordination among secondary transmissions.

Each sensor broadcasts the sensing results periodically. SU that wishes to communicate with another SU identifies, with the same periodicity and based on the collected sensing results, possible available channels, puts them in order of preference, and asks for confirmation from the CH. The CH acknowledges the free channel with higher preference value broadcasting the information about the selected channel and SUs that will use it. Once a frequency is allocated, the SUs broadcast messages to request the monitoring of the used channels.

<u>CH-Ad hoc terminal interface:</u>

The following messages are defined:

Sensing mode:

1. Initiate SCAN message from the CH to the sensing SU, to instruct for starting continuous scanning on all frequencies considered for cognitive operation. The message is issued when the ad-hoc network is set up and contains the following parameters: *SU id*, *SYNC parameters, SCAN parameters*.

5. Report frequency allocation periodic message from the connection initiating SU to the CH, with parameters *source and destination SU id, session id, occupied frequencies parameters.*

6. Frequency allocation ACK/NACK periodic broadcast message to confirm message 5 and inform all SUs in the area, with parameters *CH id, source and destination SU id, session id, occupied frequency parameters.*

9. Stop sensing message from the CH to the sensing SU at the end of the cognitive service in the ad-hoc network, with parameter *SU id*.

Messages 1 and 11 may be acknowledged.

Cognitive Communication mode:

- **Active node**

  node id, location, attached CHs list (to identify probable relays)…

- **Active node and active node/update/disconnect**

  node id, location, attached CHs list (to identify probable relays)…

- **Node Disconnect**

  Node id, location,…

Ad hoc-Ad hoc terminal interface:

Sensing mode: In this mode, the nodes broadcast their measurements (for example using TDMA) to their environments using the narrow band dedicated to signalling, and agree on the channels to use.

2. Initiate connection message from the source SU to the destination SU when an SU wish to perform cognitive transmission, and contains the following parameters: *source and destination SU id, session id, QoS parameters, if any.*

3. Confirm connection message from the destination SU to the source SU with parameters *source and destination SU id, session id.*

4. Update sensing result periodic broadcast message from the sensing SU with parameters *SU id, sensing result parameters*.

8. Initiate MON periodic broadcast message from the transmitting SUs with parameters *session id, MON parameters*.

9. Disconnect broadcast message from the transmitting SU when it wishes to stop cognitive operation, with parameter source and destination *SU id, session id.*

Message 10 may be acknowledged. Also, a message alternative to 8 can be implemented to force disconnection.

Cognitive Communication mode:

This interface defines the communication protocol between ad hoc nodes. It will be based on OpenAirInterface protocols [2][3] and operates using the free allocated band.

CH1-CH2 interface :

Sensing mode: does not require any messages on this interface.

4.2.3 Ad hoc Network -Internet Interface

For this interface, we will use Openairinterface ad hoc protocols.

One CH shall be connected to the Internet in order to provide the broadband application service targeted by SENDORA system.

5. INTEGRATION STEPS

5.1 WP7 WORK PLAN

Currently, SENDORA WP3, WP4 and WP5 are developing the enabling techniques modules to address respectively the spectrum sensing, the cognitive actuation and the cooperative communications in the WSN of the SENDORA WSN aided CR system. In these WPs, various approaches are developed, and one of these WP objectives is to compare the candidate modules and select the most appropriate one to be included in the demonstration framework. The comparison is taking into account several criteria, the main one being the performance of the module for the demonstration scenarios that we target (the ones defined in D7.1 and D7.2 deliverables), but we consider as well the feasibility of the integration of the module, its complexity in terms of HW/SW resources to run it, etc. Finally, the description of the content of the blocks to be integrated in the demonstration and the integration tasks will be specified in D7.4 deliverable scheduled by M24.

In parallel (as scheduled in the general planning for demonstration implementation proposed in D7.2 - section 6 and reminded below on Figure 8 WP7 has worked jointly with these WPs to define the demonstration framework to prepare the integration of these modules. This work is the one reported in the sections above and has allowed to define the interfaces (and associated messages) between the modules that form the compound SENDORA system.

According to the planning below, the hardware radio platform (radio front-end board and digital base-band board) is still under validation and will be available for the modules integration. It relies on EURE platform that is currently adapted for the purpose of the project.

5.2 STEP-BY-STEP IMPLEMENTATION

The implementation of the two demonstration scenarios will be performed on a step-by-step basis. The targeted validation trials to set up are the ones defined in D7.1 and D7.2. 3 steps are defined to achieve the system integration:

Step 1

The first step consists in developing the demonstration framework able to embed the WPs modules once developed. In other words, this step consists in implementing the D7.3 interfaces to ensure that the adapted radio platform will support the exchanges of the messages defined above. This shall be done for both system demonstration scenarios.

This step will be performed by adapting the OpenAirInterface stack according to the required adaptations specified in deliverable D6.2 – section 5.

This step will lead to an initial demonstration framework where basic knowledge modules will be integrated to enable a first complete system design. But the crucial outcome of this steps remains the skeleton able to embed the SENDORA dedicated modules.

In this step, the OpenAirInterface emulation capabilities (also depicted in deliverable D6.2 – section 5) will be used. This means that secondary communications will be performed through emulated PHY layer. One emulation cluster will be dedicated to this implementation work at EURE and one at TCF, and the demonstration framework implementation will be performed jointly.

End of step 1 is estimated in March 2010.

Step 2

Based on the D7.4 outcomes, the step 2 will consist in integrating the different modules coming from WPs following the selection process in WP3, WP4 and WP5 of the most adapted techniques for demonstration purpose.

WP3 will provide the most adapted sensing modules, WP4 will provide resource allocation modules and WP5 will provide an adapted cooperative communication technique (for scenario #2 only).

Step 2 will be also performed using the OpenAirInterface emulation capabilities.

End of step 2 is estimated in June 2010.

Step 3

Step 3 is the final integration step.

In step 3, the secondary cognitive communications will be performed over-the-air instead of using the emulation capabilities of the demonstration environment. Both validation trials will be set up at Eurecom premises.

End of step 3 is estimated in October 2010.

Following step 3 (corresponding to the end of the system integration process), system validations and performance measurement will be led to prove the concept in both demonstration scenarios, to check the spectrum usage improvement and to prove that the interference generated to the primary system is controlled.

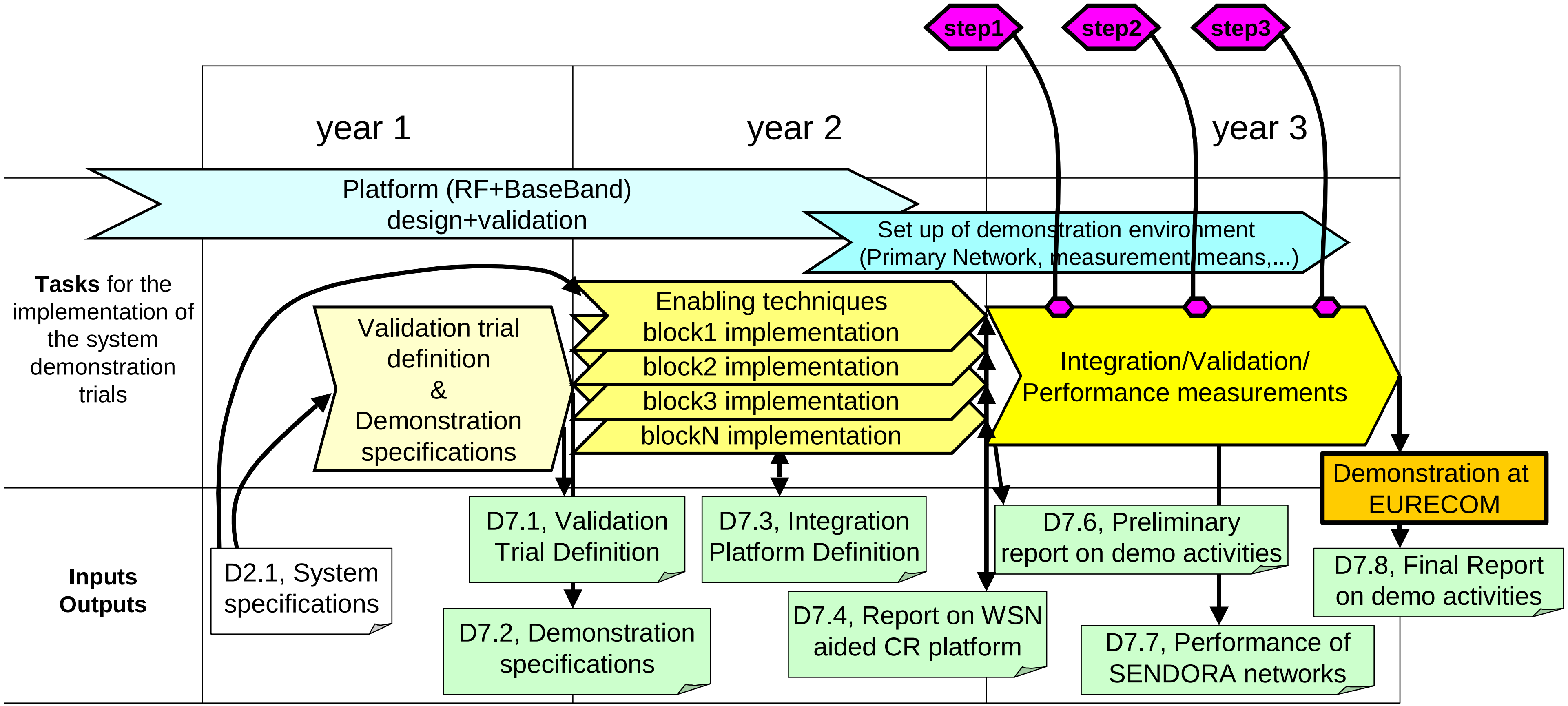

Figure 8: Planning for the implementation of SENDORA system validation trials including implementation steps

REFERENCES

[1] F. Filali, Wimeter: a novel technique for available bandwidth estimation for WLANs and its assistance to QoS provisioning, Eurecom research report, RR-06-165, June 2006.

[2] H. Anouar, C. Bonnet, F. Kaltenberger and R. Knopp, " OpenAirMesh - an experimental platform for cooperative mesh networks" 1st COST2100 Workshop on MIMO and Cooperative Communications, June 3-4, 2008, Trondheim, Norway

[3] openairinterface.org