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

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EXECUTIVE SUMMARY

This report is an updated version of the report D2.1 "Scenario descriptions and system requirements". It is focused on the SENDORA target scenario and has been refined from previous versions.

In SENDORA, the target scenario has been refined in an iterative process. The first version of the deliverable D2.1 described the process for the selection of the target scenario based on initial assumptions regarding technological parameters and technological performance and constraints. This scenario has been refined during the project based on new results from the business case evaluations and the technical studies conducted in 2009, and the technical reviews of the project. This version of the document is the final status of the SENDORA system specifications.

The selected target scenario for the SENDORA project is the "nomadic broadband in urban and suburban areas" scenario. In this scenario cognitive radio is used to provide a broadband service to users that are stationary when logged on the network. This scenario is expected to have a very good market potential since it can provide many of the same services as mobile broadband at a lower cost. Cognitive radio is also seen as the best solution for this application, since the system can use the frequency that best fits the radio propagation environment each user experiences. Alternative licensed technologies have to operate in given frequency bands and cannot adapt themselves to the propagation environment in the same way. The capacity of cognitive radio will also be better since the frequency resources available will be larger.

The innovative idea in SENDORA is to combine cognitive radio technology with sensor network technology. A sensor network will be used for monitoring the spectrum usage in an area and will significantly improve the system's ability to detect primary users compared to pure cognitive radio solutions. The sensor network will consist of an externally deployed sensor network and/or sensing capabilities embedded in user terminals. The external sensor network allows guaranteeing that primary users will be detected with a defined probability, regardless of the number of cognitive radios present in the area. Additionally, the embedded sensing in the terminals can enhance the system's performance by providing more local sensing information from the areas where the cognitive radio users are located and will improve sensing as the number of cognitive users grows.

The SENDORA system architecture consists of three parts: a sensing architecture, a communication architecture and a fusion centre. The sensing architecture and communication architecture are connected together logically by a fusion centre. The fusion centre receives the sensing data collected through the sensor network and estimates the spectrum usage situation in the area covered by the sensor network based on this information. The fusion centre also communicates with the communication network providing it with the information it needs to operate cognitively in an optimal way. Depending of the architecture chosen, the fusion centre might also act as the "brain" in the communication network controlling the global behaviour of the cognitive network and the sensor network.

The communication architecture consists of a centralized network of base stations through which the terminals can get Internet access, complemented by terminals communicating directly between each other forming local ad hoc networks.

The SENDORA system will be best suited to provide non real-time services like web browsing and video downloading. Real-time services like telephony and video streaming can be provided occasionally, but the operator will usually not be able to give strict quality guarantees for such services.

It is envisioned that the cognitive radio communication will use frequencies below 6 GHz. It is expected that cognitive radio will only be allowed in some frequency bands within this frequency range initially. Since it is important to have indoor coverage, it is important that the cognitive radios can operate at frequencies below 3 GHz.

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DOCUMENT VERSIONS

Version	Date	Description, modifications
1.0	28/03/2008	First version
2.0	06/2008	Intermediate version (internal to the consortium) improving the system requirements for the selected scenario
3.0	26/09/2008	Second official delivery. To make the report easier to use as a reference document, it contains only text associated with the selected “Nomadic broadband in urban and suburban areas” scenario.
3.1	14/05/2009	Revision of the version 3.0 document based on the comments from the year 1 periodic review evaluators.
4.0	12/01/2010	Third official delivery. Update of SENDORA architecture, specifications update, techno-economical study preliminary report.
5.0	30/06/2010	Fourth official delivery. Takes into account Period 2 reviewers’ comments.

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1 INTRODUCTION

This report is an updated version of the report D2.1 "Scenario descriptions and system requirements". The content of the current version consists mainly of updated and extended architecture and chosen scenario description, updated lists of system requirements and constraints and an appendix with the final working assumptions and parameter values used in the SENDORA project.

The updated information presented in this report is the result of an iterative process where the selected scenario and the corresponding requirements and constraints have been refined as more results from the technical and techno-economical studies have been obtained.

Initially, this document allowed reporting the process of selection of the target scenario for the project. The text describing the different candidate scenarios and the selection process in the original version (1.0) has been removed. In this way it is much easier to use the report as a reference to obtain information and avoid misinterpretations about the specifics of the SENDORA system, as only information related to the chosen scenario is included. For information about the candidate scenarios, the selection criteria and the selection process, the reader can refer to the original version (1.0) of the report available on SENDORA project web page (www.sendora.eu).

1.1 SENSOR NETWORK AIDED COGNITIVE RADIO OBJECTIVE

The motivation for developing a Sensor Network aided Cognitive Radio technology is to be able to exploit under-utilized radio spectrum resources.

Indeed, various measurements of spectrum utilization have shown that spectrum is under-utilized, in the sense that the typical duty cycle of spectrum usage at a fixed frequency and at a random geographical location is low. This means that there are many "holes" in the radio spectrum that could be exploited in an opportunistic manner. While this observation stands in some contrast to the general picture of spectrum shortage as can be inferred from official frequency allocation charts, the presence of spectrum holes is understandable given how inefficiently radio resources, and spectrum in particular, are in fact utilized in current systems. Cognitive radios should be able to exploit these spectrum holes by detecting them and using them in an opportunistic way.

Cognitive radio is therefore an emerging concept in wireless access, aimed at significantly improving the way radio spectrum is utilized. The principle of cognitive radio is temporal, spatial and geographic reuse of licensed spectrum. The basic idea is that an unlicensed user can be permitted to use licensed spectrum, provided that it does not interfere with any primary users. The research challenges include devising methods for how such coexistence can be implemented in practice. Indeed, the capability to detect spectrum holes, without interfering with the licensed network currently in use, is the major difficulty faced today by the cognitive radio, even more when fine granularity of allocation in time and frequency is targeted.

The Sensor Network aided Cognitive Radio technology represents a way to solve this issue thanks to the introduction of sensor networks for spectrum sensing and monitoring. This concept is a system approach that involves a set of advanced wireless communications techniques like spectrum sensing, interference management, cognitive radio reconfiguration management, cooperative communications, end-to-end protocol design, cross-layer optimisation and flexible radios design. All these enabling techniques together will form a compound system able to improve the spectrum use in a significant way.

Beyond the technical challenges that have to be addressed to enable efficient sensing and to minimize interferences to primary users, another important aspect which should be considered are the new business models that are expected to emerge from the capabilities provided by cognitive radios. This deliverable reports some initial results from the techno-economical study performed to evaluate the potential of the WSN aided cognitive radio technology developed in SENDORA. This study will be continued in 2010 and finally reported in the D2.2 deliverable.

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1.2 ARCHITECTURES

The innovative concept developed in SENDORA is the Sensor Network aided Cognitive Radio technology that utilizes wireless sensor networks to support the coexistence of licensed and unlicensed wireless users in a same area. The general scenario of the Sensor Network aided Cognitive Radio is depicted on Figure 1. In the proposed system, the network of cognitive users, called the secondary network, first communicates with the wireless sensor network. The wireless sensor network monitors the spectrum usage, and is thus aware of the holes that are currently available and can potentially be exploited by the secondary network. This information is provided back to the secondary network. The secondary users are then able to communicate without causing harmful interferences to the licensed network, called the primary network.

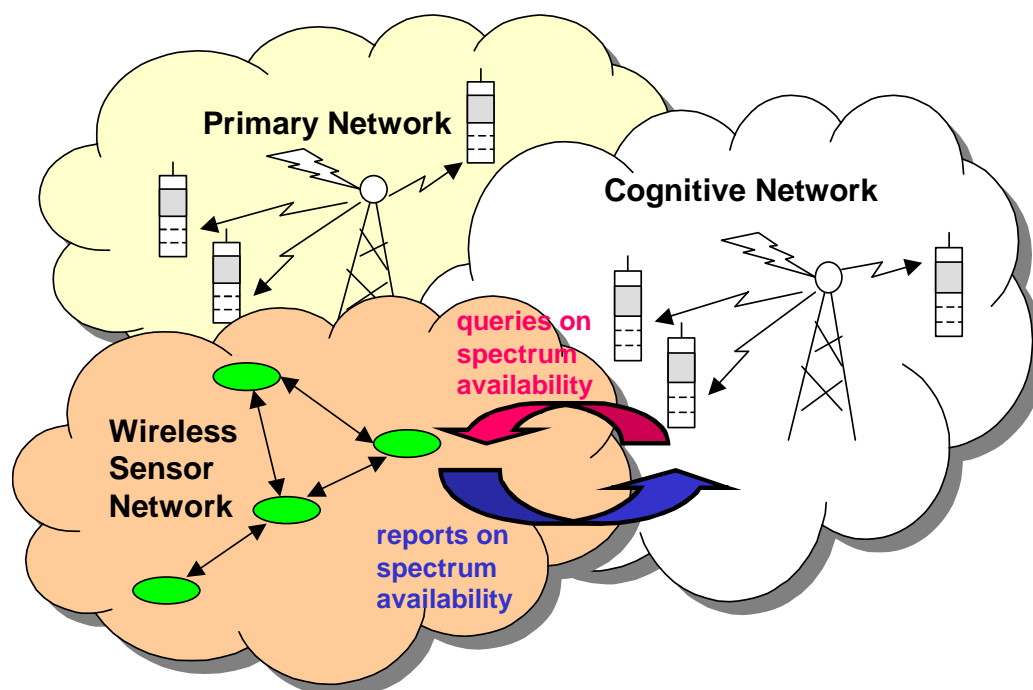


Figure 1 General scenario for Sensor Network aided Cognitive Radio

There are two main classes of architectures for the wireless sensor aided cognitive radio implementation. They can be denoted as "Independent sensor network aided cognitive radio architectures" and "Integrated sensor network aided cognitive radio architectures".

In the first case, the sensor network is deployed in an area by an operator and cognitive radio users entering the area can communicate with the sensor network to get information about spectrum usage and/or instructions of how they can use the spectrum.

In the integrated sensor network case there is no independent sensor network: instead, the sensors are integrated in the cognitive radio user terminals. They perform the sensing process and detect in a collaborative manner their own transmission opportunities. In this case, the cognitive network is also the wireless sensor network.

In SENDORA, these two architectures can also be combined into a hybrid architecture. In the hybrid architecture, an independent sensor network is deployed in an area to ensure sufficient knowledge of the spectrum use even when there are few cognitive users present. Then, sensing capabilities are also integrated into the cognitive radio terminals to improve the spectrum sensing with local information delivery as the number of users grows. This kind of architecture is probably the most promising one.

2 DEFINITIONS

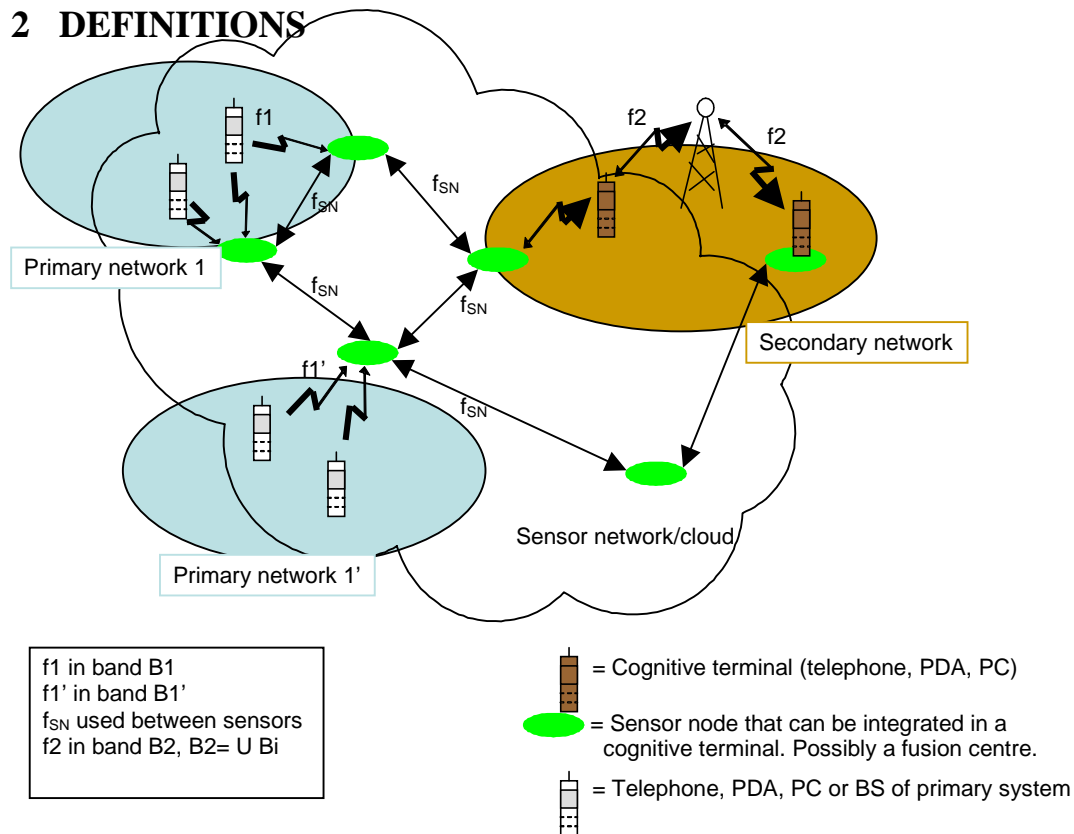


Figure 2 Spectrum usage in a generic sensor network aided cognitive radio system

Cognitive radio system

A radio system which is aware of its environment and internal state and can make decisions about its radio operating behaviour based on that information and predefined objectives. The environmental information may or may not include location information.

Cognitive radio base station

A base station that is used in a cognitive radio system. It may or may not have its own cognitive capabilities (sensing capabilities or cognitive actuation decision capabilities). If the base station does not have own cognitive capabilities, it will base its decisions on cognitive information from other parts of the network that have cognitive capabilities.

The cognitive network may be an ad hoc network and, in that case, there is no base station: all radio terminals are identical and direct communications between cognitive radio terminals can be set up.

Cognitive radio terminal

A radio terminal that is used in a cognitive radio system. It may or may not have its own cognitive capabilities. If the radio terminal does not have any cognitive capabilities, it will be instructed in how to behave by other parts of the cognitive radio system, e.g. a base station. If the radio terminal has decision capabilities but does not have any sensing capabilities, it will be provided such information by other parts of the cognitive radio system, e.g. a base station.

Fusion centre

A unit in which sensing data is collected and processed to deduce information about spectrum usage in the area covered by the sensors. A sensor network may have zero (in this case, the processing is distributed), one, or several fusion centres.

Wireless sensor network

A network of spectrum sensing sensors where the communication to and from the sensor nodes are wireless.

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Independent sensor network aided cognitive radio architectures

An independent sensor network aided cognitive radio architecture consists of a sensor network that is deployed in an area to provide a cognitive radio system entering in the area with information about spectrum usage in this area and/or instruct the cognitive radio system on how it shall behave. Physically, the sensors are independent terminals, external to the cognitive radio terminals.

Integrated sensor network aided cognitive radio architectures

An integrated sensor network aided cognitive radio architecture consists of cognitive radio system composed of terminals with integrated sensing capabilities. Terminals are both cognitive terminals and sensors, and all the terminals of cognitive radio system constitute a wireless sensor network.

Mobile scenarios

Scenarios where the cognitive radio terminals are allowed to move while communicating.

Nomadic scenarios

In nomadic scenarios the cognitive radio terminals are stationary when they are logged on to the network. The terminals can move when logged off and then log onto the network from a new location later.

Opportunistic Spectrum Access

Access opportunistically to the spectrum means to use spectrum resources, the license of which is owned by another network called "Primary Network" when this network does not use these resources. A cognitive radio system is needed to perform Opportunistic Spectrum Access since such operation require sensing capabilities. Different kinds of Opportunistic Spectrum Access can be foreseen: one can sense the primary network activity and transmit only when this primary network is not transmitting. Or one can transmit at the same time with the primary network if it guarantees that it uses the extra capacity let free by the primary network, without disturbing the primary network activity.

Primary network

A radio network that has been given the rights to use a certain frequency band on a primary basis. Other radio networks might be allowed to use this frequency band only when it is not used by the primary radio network.

Secondary network

A radio network that has been given the rights to use a certain frequency band on a secondary basis. The radio network can use this frequency band only when the primary radio network of this frequency band does not use it. Therefore a secondary network operates in a cognitive way to avoid creating interferences to the primary network, and is also called "cognitive network" in the following.

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3 GENERAL ECOSYSTEM CONSIDERATIONS

This chapter presents considerations about the roles of different actors in the ecosystems for cognitive radio and related sensor networks, related to the chosen scenario: Nomadic broadband in urban and suburban areas. The deliverable which deals with the ecosystem and business cases (D2.2) is due later in the project (month 30), but ecosystem considerations are an integral part in the scenario definitions and system requirements.

The word “ecosystem” in this context means **business modelling** including the roles of the actors, relations (e.g. partnership) between the actors, cost structures, revenues and money flows between the actors. **Business cases** can be used to quantify the value of different scenarios and options. The figure below shows the main elements in the (telecommunication) business case analysis.

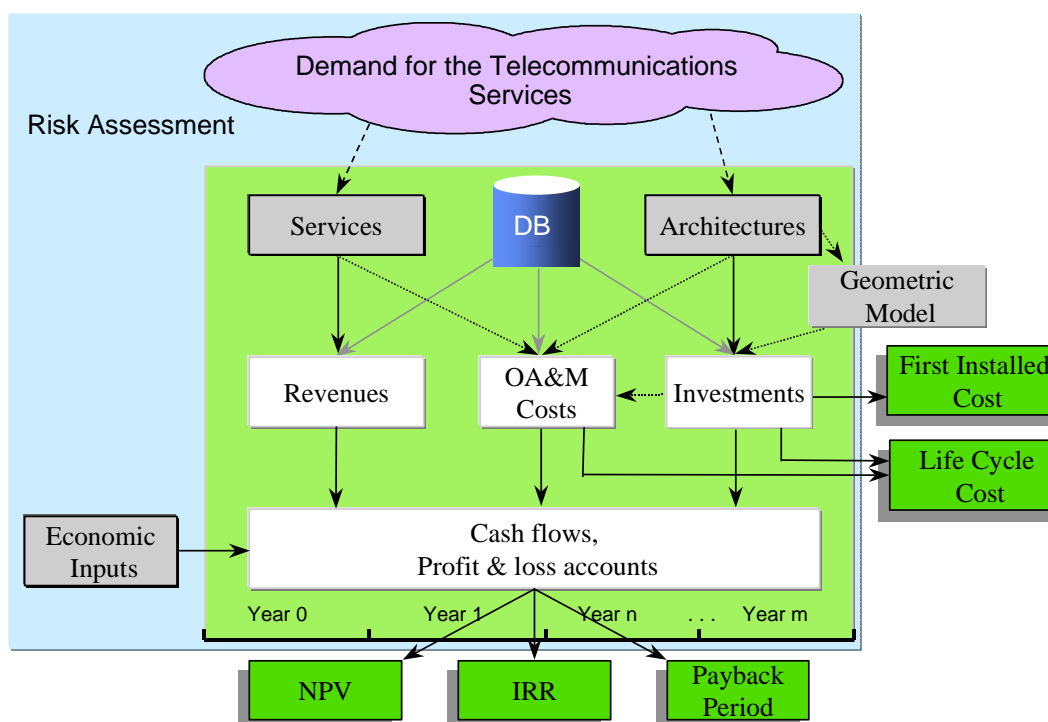


Figure 3 Business case methodology

Net Present Value (NPV), Internal Rate of Return (IRR) and the Payback Period are the most used economic profitability indicators.

At least the following roles can be foreseen in the ecosystem for the sensor network aided cognitive radio in the chosen scenario:

- End user of the communication applications
- Owner of the licence for the radio spectrum
 - Existing mobile and fixed telecommunication operators
 - TV broadcasters
 - Public authorities (police, health care, aviation, etc)
 - Military organisations
- Cognitive radio operator that will utilize a radio spectrum licensed to others
 - As above
 - New operators
- Regulatory body
- Spectrum broker
 - Regulatory body

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- Owner of the licence for the radio spectrum
- Independent third party
- Owner of the sensor network
- Vendor of equipment
 - Cognitive radio elements
 - Sensor network elements
- System integrator

The requirement for a successful and functional new ecosystem is that the (main) actors have sufficient incentives to be part of that ecosystem. The most important incentive, at least for the commercial actors (private companies) is simple money i.e. the economical results for the company in the short and long term.

To start with, we have defined four different simplified alternatives for the sensor network aided cognitive radio ecosystem for the chosen scenario:

1. One actor uses cognitive radio and sensor network to improve or enhance running business
2. The owner of the radio spectrum sells cognitive spectrum resources to others
3. Spectrum broker is responsible for trade between spectrum owners and cognitive radio operators
4. Cognitive radio is deployed in unlicensed spectrum

One actor uses cognitive radio and sensor network to improve or enhance running business

The owner of the radio spectrum use cognitive radio for better utilization of its own spectrum to provide better service quality or to make new services possible in the same spectrum. For the nomadic broadband in urban and suburban areas, this could be an existing mobile operator that aims to provide nomadic broadband services in addition to its mobile voice and data services in the existing 2G/3G licensed spectrum.

In this alternative the owner of the radio spectrum will implement cognitive radio elements where needed and will also implement and own the related sensor network.

This alternative involves only one actor, so there is no need for agreements with others. If the license was originally limited to specific use or technology, there will probably be a need to renegotiate the license conditions with the regulator.

The business cases for this first ecosystem alternative are probably relative straightforward, i.e. the costs for implementing cognitive functionalities and the sensor network weighted with the economical advantages, like new customers and new revenues from the nomadic services and reduced churn for the mobile services.

The owner of the radio spectrum sells cognitive spectrum resources to others

The owner of the radio spectrum sells a cognitive access to its spectrum to others. The owner of the radio spectrum will implement and operate the sensor network and therefore will have control over interference etc. The cognitive radio operator will implement cognitive radio elements where needed in its own terminals and base stations.

This alternative includes two main actors (seller and buyer) and therefore requires agreements and trust between them. If the spectrum license was originally limited to specific use or technology, there will probably be a need to renegotiate the license conditions with the regulator. In case of conflicts between actors, there may be a need for independent instance to solve these conflicts.

A standardized interface between the cognitive network and the sensor network must be specified.

The business case for the owner of the radio spectrum includes costs for implementing and operating the sensor network weighted with the revenues from selling the spectrum and related sensor information to others.

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The business case for the cognitive radio operator includes the cost for implementing the cognitive functionalities and for buying the access to the spectrum and sensor information weighted with the revenues from the new customers and services.

Spectrum broker is responsible for trade between spectrum owners and cognitive radio operators

This alternative includes a spectrum broker, which is responsible for “trade” between the radio spectrum owners and the cognitive radio operators. The broker should be the regulatory body or another independent third party to insure fairness in the trade. The broker owns the sensor network and controls the sensor information.

This alternative needs maybe more bureaucracy including agreements and trust between several actors, so it will be more complicated to implement than the previous alternatives.

A standardized interface between the cognitive networks and the sensor network must be specified.

The business case for the broker includes the costs for implementing and operating the sensor network, and revenues from broker provisions.

Cognitive radio in unlicensed spectrum

In this alternative a specific frequency range is not owned by one licensed owner, but all actors can operate there on equal terms. This is similar to the license-exempt usage of spectrum that occurs in the 2.4 GHz band for WLAN systems. The only regulation of the use of this spectrum is related to power levels and interference. This alternative is in line with the idea that the future spectrum regulation should be more flexible with more unlicensed spectrum.

The uncoordinated use of spectrum and free competition between actors means that this alternative is best suited for “best effort” type of services.

All the actors that will use license-exempt bands can utilize cognitive functionalities for improving their services. It is an open question, how sensor networks can be utilized in this alternative. It will need co-ordination and trust between the actors. Also some kind of independent broker functions, like in the previous alternative, may be needed to fully utilize the possibilities given by cognitive radio and sensor networks in this alternative.

A standardized interface between the cognitive networks and the sensor network must be specified.

This last alternative is not the targeted one within SENDORA although the technology developed in the project may help to consider this case in the future.

Combination of the above alternatives

The four ecosystem alternatives presented above are simplified examples. In reality the situation will be more ambiguous and complicated:

- One company can have several roles at the same time, e.g. one company can be a owner in one frequency range and at the same time a cognitive radio operator in the other frequency range
- Two similar operators can trade their frequency resources on equal basis, e.g. competing mobile and nomadic operators can make agreement about trade based on cognitive radio/sensor network to avoid temporary overload.
- Inside the alternatives there is several options, e.g. is the sensor network self owned, outsourced or provided by a broker?
- There will be combinations between the four alternatives.

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4 THE CHOSEN SCENARIO: COGNITIVE RADIO BASED NOMADIC BROADBAND IN URBAN AND SUBURBAN AREAS

4.1 MOTIVATION

Mobile broadband is becoming a very important service for both operators and users and it will be very important for operators to be able to offer good and cost-effective wireless broadband services. The mobility feature will only be required for a small percentage of the users since the users will usually be stationary when using the mobile broadband services. This opens up the possibility to use a nomadic broadband network, which will be simpler and more cost-effective than mobile broadband networks, to complement actual mobile broadband networks.

To use a nomadic broadband network can be an attractive solution for both operators with and without their own mobile network. For an operator with a mobile broadband network, a cognitive nomadic broadband network can be used to off-load the mobile network by transferring parts of the traffic to the nomadic network. An operator with a mobile network without broadband capabilities (e.g. a 2G network) can use the nomadic network to offer wireless broadband to its customers.

A nomadic broadband service can also be an interesting service in its own. In this case the users either settle for a nomadic service or combine this service with mobile services (e.g. a 2G or 3G service).

Cognitive radio based nomadic broadband networks can be a very interesting opportunity for operators since they can offer both high bit rates and low costs. But since it is difficult to give strict quality of service guarantees with cognitive radio, the solution is better suited for non real-time services like broadband internet access than for real-time services like telephony and video streaming. Cognitive radio based nomadic broadband services should therefore mainly target non real-time services, with the possibility of offering real time services if the spectrum (and other) conditions allow it.

Cognitive radio has the advantage that different frequency bands can be used depending on the user needs and the situation the user is in. For example, in the case where the cognitive network uses base stations, if the cognitive user has line of sight to a base station and is equipped with a directional antenna the user can use high frequency bands to obtain a very high capacity link. The same user can use frequencies below 1 GHz to get Internet access when located in the basement of buildings or in rural areas. Generally, cognitive radio gives the opportunity to use part or parts of a large frequency band that best fits the user's communication needs. If several parts of the spectrum are used, the transmissions in the different frequency bands might be bonded to give a virtual high capacity channel. This characteristic of cognitive radio makes it possible to offer a type of service that it is not possible to offer with licensed radio systems which have strictly defined bandwidths and operation limited to a certain (narrow) frequency band.

4.2 SCENARIO CHARACTERISTICS

4.2.1 Deployment strategy

It is likely that an operator will start with deployment of hot-zones. A hot-zone is a small area where the capacity demand is high. It is larger than a Wi-Fi hot-spot, and cognitive radio deployments in hot-zones will be complementary to Wi-Fi hot-spot(s) in the same area.

Initial hot-zone deployments are expected to be the preferred solution for both 2G and 3G operators wanting to complement or off-load their licensed network and for green-field operators. Later the hot-zones will be extended to cover large parts of cities and eventually whole cities with suburbs. It is therefore important that the sensor network is extensible to larger areas and scalable to handle an increasing number of customers. Finally, the network can be extended to give blanket coverage over a large area.

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4.2.2 User terminals

Typical user terminals for nomadic usage are expected to be the laptops, Ultra-Mobile PCs, PDAs and smartphones. The antenna(s) can either be integrated (e.g. into the laptop lid) or be external. An external antenna can be everything from a unit that can be put on the table beside a laptop to larger antennas with better directivity. A large antenna can for example be used to obtain a high capacity backhaul link for a Wi-Fi access point that is temporarily put up when arranging a meeting at a location where no internet connection is available.

4.2.3 Geographical coverage

It is expected that an operator will typically start with local coverage in hot-spots or hot-zones covering areas ranging from a few hundred to a few kilometres in diameter. The coverage will later be extended to cover larger areas.

The cognitive radio network must give indoor coverage since the users will often be indoor when needing broadband services.

4.2.4 Services and capacities

The network will mainly provide non-real time services like web browsing and video downloading. Real-time services like telephony can be provided occasionally, but the operator will probably not be able to give strict quality guarantees for such services.

The bandwidth requirements will increase the coming years, and an increase of about 50% each year is not unrealistic [Cherry].

The bit rates offered to customers should at least be the same as offered by other mobile technologies like WiMAX and LTE in order to be able to offer the services foreseen. With this in mind a reasonable requirement could be that in urban and suburban areas the capacity offered to the users should be at least 5 Mbit/s downlink and 1.3 Mbit/s uplink in 2010 and increase to about 11.3 Mbit/s downlink and 2.9 Mbit/s uplink in 2012.

There is also a trend that the capacity required will be more symmetric in the uplink and downlink. Hence, the capacity requirements might increase faster for the uplink than for the downlink.

4.2.5 Cognitive radio operating frequencies

The operating frequency range will initially be parts of the frequency range below 3 GHz increasing to 6 GHz or more later as the capacity requirements increase. The cost of sensors that can scan and user terminals that can operate over such a large frequency range will be high initially due to relatively modest production volumes and modest number of users. It is therefore expected that cognitive radios in the beginning will be designed to operate in one or more specific frequency bands rather than over the whole frequency range.

As the number of users grows there will be a larger demand for capacity and it will be necessary to extend the operating frequency range of the cognitive radios. This will be possible as the production volumes increase and the technology becomes more mature.

This approach will also match the situation of different regulatory constraints in some frequency bands. Since it is difficult for regulators to allow cognitive radio operation in frequency bands where the existing frequency licenses give the licensee exclusive rights to use the frequency band, cognitive radio will only be allowed after the existing licenses expire and the possibilities for cognitive radio operation can be included in the license conditions. Since the licenses expire at different times in different frequency bands, this kind of cognitive radio operation will initially only be allowed in certain parts of the frequency band below 6 GHz.

Some licensees might also allow cognitive radio operation in their frequency bands (if allowed by the regulator), e.g. to improve their own usage of the spectrum or to trade spectrum with other operators. Also in these cases the cognitive radio operation will be confined to certain frequency bands.

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4.2.6 Sensors placement, power and communication

The cognitive radio system will include a sensor network consisting of independent sensors nodes and/or sensing capabilities integrated into the user terminals. Independent sensor nodes can communicate either through a wired or wireless backhaul network. Integrated sensing will be communicated via radio.

Wireless sensors may communicate in an unlicensed band, in a (narrow) licensed band or use cognitive radio communication. Since it is important to pass information about detected primary users quickly and reliably, a licensed band would be best but it is uncertain whether such a band will be available. In any case, it shall be as narrow as possible, in order that regulation bodies accept to allocate such a band.

In densely populated areas, it will probably be possible to place fixed sensors so that they can be powered from the mains. The sensing functions integrated into user terminals will be powered from batteries.

One challenge associated with the fixed sensor network is that while these sensors are outdoor many of the users will be indoor. The fundamental effect of this is that the sensors have less predictive value for the interference and propagation environment experienced by secondary users. It is likely, for instance, that secondary users indoors will miss transmit opportunities due to not being able to identify a local (indoors) spectrum hole.

These effects are, however, significant only at higher frequencies where through-the-wall attenuation is high.

It appears that this problem may not be successfully solved unless an indoor sensing capability is present, possibly through the secondary terminal itself. This is especially true if also primary users are present indoors together with secondary users, and may be interfered by secondary transmissions.

4.2.7 Sensor sensitivity and spectrum release requirements

The regulatory requirements will determine how fast a primary user must be detected. The corresponding requirements will probably be different from one frequency band to another.

Even if the primary user detection time requirement is relatively relaxed, the requirements on the sensors can be very tough. In densely populated areas there will usually be a large number of cognitive radio users utilizing different parts of a large frequency band. The sensor network has to monitor the entire spectrum used by cognitive radio terminals to detect primary users within the required time limits.

4.2.8 Combination with licensed services

Due to the difficulties of providing real-time services with cognitive radio, it is a good idea to combine cognitive radio with one or more licensed radio technology in order to support all types of services.

Cognitive radio based nomadic usage can be a good complement for operators with 2G licenses. Their users can then be provided with a broadband service via cognitive radio. This service will only give a nomadic service, but the user will usually be stationary when needing broadband Internet access.

Cognitive radio based nomadic broadband networks could be combined with traditional broadband wireless services like UMTS/HSPA or WiMAX. In this case the user terminal could choose to switch to cognitive radio when the licensed system is not able to provide the service required, e.g. with respect to bit rate or coverage. The switch could also be initiated by the operator (assumed to own both the primary and cognitive radio networks) to off-load the licensed network by re-allocating users that do not need the distinctive functionalities of the licensed network (e.g. the mobility) to the cognitive system. Since the cost of acquiring new spectrum for licensed mobile broadband services is very high or even not possible at all, off-loading traffic by a cognitive radio network can be a very attractive alternative from an economical point of view.

Likewise, the user (or the operator) could switch from cognitive radio to the licensed technology when the cognitive radio system is not able to provide the user with the services he needs. Typically, this will be real-time services with strict QoS requirements.

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It is also possible to have a system where the users at any time are connected to both the cognitive radio system and the licensed mobile system, and in which each packet is routed to the network that is best suited at that time.

4.3 SYSTEM ARCHITECTURE

The *sensor network aided cognitive radio* system architecture that is considered to bring cognitive nomadic broadband access is illustrated in

Figure 5. Both the sensing architecture and the communication architecture are represented in this figure. The sensing architecture is based on a fixed deployed sensor network with additional sensing capabilities at user terminal level (hybrid architecture). The communication architecture takes advantage of this sensing architecture to communicate in a cognitive way.

The sensing architecture and communication architecture can be functionally connected together by a fusion centre as illustrated in Figure 4. The fusion centre collects sensing information from the sensor network and estimates the spectrum usage situation in the area covered by the sensor network based on this information. The fusion centre also communicates with the communication network providing it with the information it needs to operate cognitively in an optimal way. The corresponding interfaces will be defined in the project, in task WP44. The fusion centre might also act as the “brain” in the communication network controlling the behaviour of the secondary cognitive network, as well as the behaviour of the sensor network (referred to as the 'cognitive actuation' function and studied in the WP4 of the project).

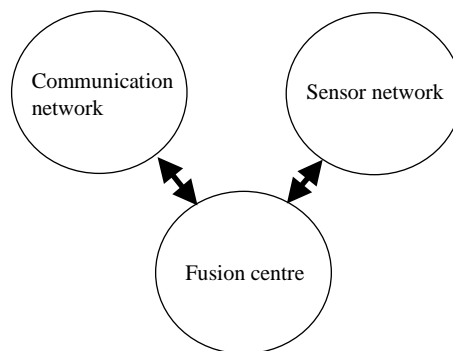


Figure 4 SENDORA general system architecture

4.3.1 Communication architecture

Figure 5, the terminals in the architecture are marked with C, A and S according to their functional capabilities and H if they are locally cluster heads:

Centralized access (C)	The terminal has the properties needed to communicate with the base stations
Ad hoc (A)	The terminal has the properties required to establish and be part of an ad hoc network.
Sensing (S)	The terminal has sensing capabilities.
Cluster Head (H)	The terminal is the Cluster Head of a local ad hoc network

The communication architecture consists of a centralized network of base stations through which the terminals can get Internet access, complemented by terminals communicating directly with each other forming local ad hoc networks.

A centralized solution is an efficient way of implementing Internet access with predictable service (coverage, throughput, delay, etc.). Centralizing the intelligence and the sophisticated hardware also makes the use of low cost terminals possible.

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Ad hoc communication between terminals located close to each other allows data to be transferred at higher bit rates and with less power than if the communication had to be transferred via base stations. Moreover, as terminals are close to each other, spectral opportunities will be higher in terms of capacity. In addition, thanks to ad hoc communication, the range and coverage of the secondary network can be extended by allowing terminals that are not able to access the centralized network directly to get access through nearby terminals with centralized access.

At any given time, some terminals will communicate with the centralized network and some will be part of local ad hoc networks forming what might be conceived as the *centralized part* and *ad hoc parts* of the network. It must however be noted that the centralized network and ad hoc network parts change all the time as terminals change from ad hoc communication to centralized communication or vice versa.

Some terminals have the capability to communicate with the centralized network and directly with other terminals at the same time. Such terminals can connect the local ad hoc networks to the centralized network, thereby providing the local ad hoc network with Internet access. This may be the role of the Cluster Head terminal.

The centralized part of the network will always make use of the fusion centre for sensing information collection and possibly for decision procedures, while the ad hoc part of the network may interact with the fusion centre as well but can also perform its own and independent distributed sensing and decision processes. In that case, the fusion centre shall nevertheless be informed of the decisions taken to be globally aware of the spectrum occupancy in the area.

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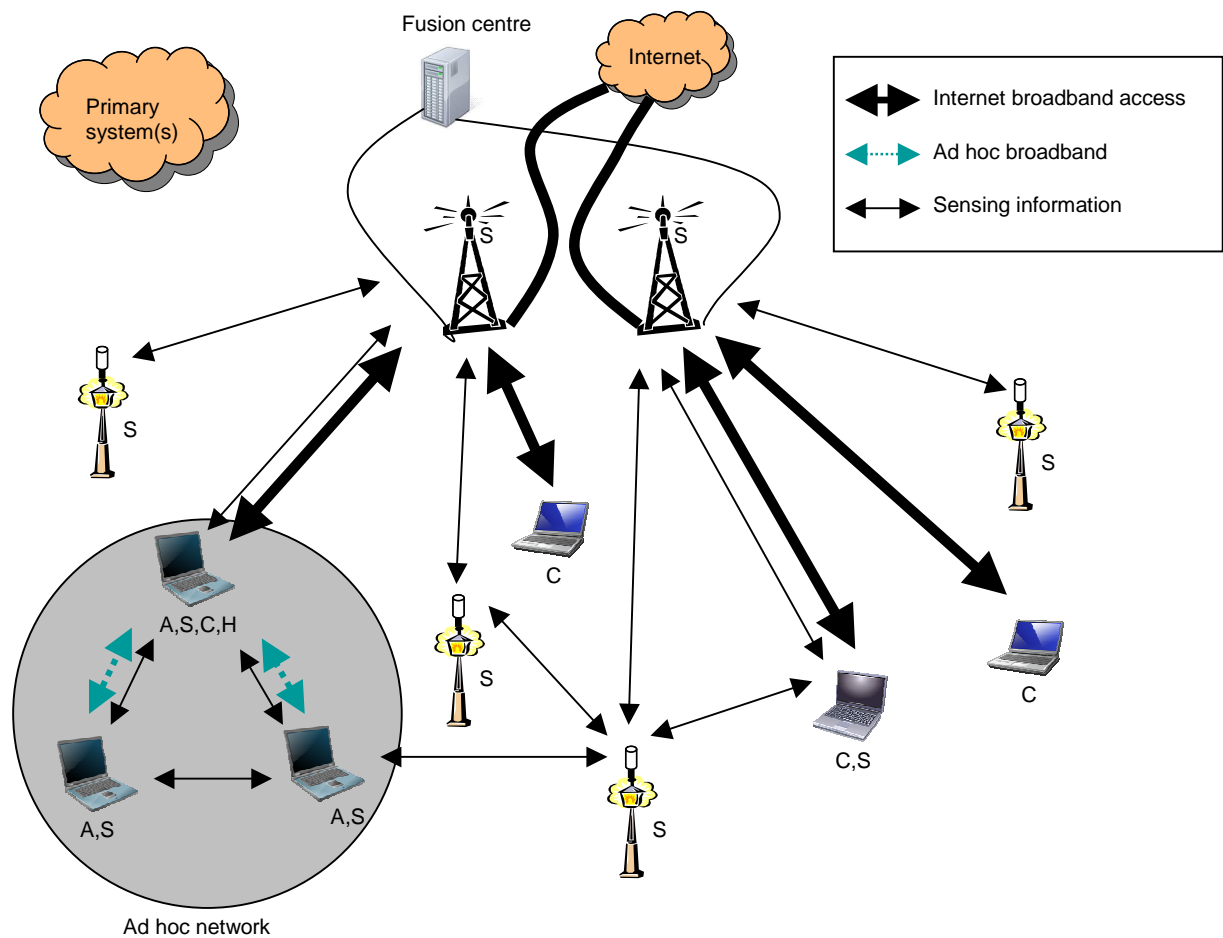


Figure 5 Cognitive radio based nomadic broadband system architecture.

4.3.2 Sensing architecture

The sensing architecture consists of a fixed network of sensors complemented with sensing capabilities integrated in some of the terminals.

The reason for having a fixed network of sensors is that it is difficult to base the operation of a cognitive radio network solely on information from sensing integrated in the user terminals. The number and positions of the terminals will indeed be random variables and sometimes the sensor network formed by the terminals will not be able to detect primary users with the required confidence. By deploying a fixed and dedicated network of sensors where the number and location of the sensors are carefully chosen, a certain primary user detection confidence can be guaranteed.

A fixed deployed sensor network also has the advantage that the sensors can communicate with each other and eventually with one or several fusion centre(s) through a wired backbone network and that the sensors can be powered from the mains.

On the other hand, sensing integrated into the terminals will be co-located with the cognitive radios and hence be capable of providing accurate local information. By using this information in addition to information from a fixed deployed sensor network, the cognitive radio network can be controlled in a much better way. Primary users in close proximity to the user, which are the ones that will experience the most serious interference from the cognitive radio terminal, will be detected much faster by the integrated sensor than by the deployed external sensor network.

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The integrated sensing can also be much simpler than the deployed sensors, for example only monitoring the frequency band that is actually used by its associated cognitive radio terminal.

The fixed sensor network can probably be smaller (e.g. fewer sensors) if it is combined with integrated sensing in the terminals than if the spectrum sensing had to be solely based on the deployed sensor network. This gives reduced costs for the operator and a certain sharing of the sensor network costs between the operator and the users.

Based on the discussion above, different types of sensor nodes can be foreseen:

- Class 1: Nodes with high processing power, powered from the mains and connected to a wired backhaul network.
- Class 2: Same as class 1 but not connected to a wired backhaul network, i.e. they must use radio for sensing information communication.
- Class 3: Nodes with low processing power, battery powered and use radio for sensing information communication. Sensor nodes integrated into user terminals will usually belong to this class.

Information from the sensors in the fixed sensor network and from sensing integrated in terminals connected to the centralized network is collected in one or more fusion centres. The fusion centre(s) use(s) this information to deduce the spectrum usage and send(s) this information to the base stations. Then the base stations use this information when allocating transmission opportunities to the terminals. Alternatively, the fusion centre(s) can allocate the transmission opportunities to the terminals itself.

4.3.3 Fusion centre

The fusion centre functionally connects the sensor network and the communication network.

The fusion centre acts as an aggregation point (partial aggregation may also be performed locally by the sensors of the sensor network while collecting sensing information towards the fusion centre) for the data from the sensors in the sensor network. Based on the sensor data received, the fusion centre estimates the spectrum usage in the geographical area covered by the sensor network.

The sensors can either send sensing information to the fusion centre unsolicited or the fusion centre can poll the sensor network for sensing information. In the latter case a sensor will send a message to the fusion centre when it connects to the sensor network with information about its sensing capabilities and, if it is known, its position. The fusion centre will then respond with a message telling the sensor whether to sense or not and possibly instruct the sensor on how to sense e.g. which frequency range to sense, which primary system(s) to look for, the sensing policy etc. During operation the fusion centre can give new instructions to the individual sensors. In this way the fusion centre gets the sensor data it needs in order to utilize the sensor network optimally at all times.

The sensors integrated in terminals operating in ad hoc mode can ask the fusion centre(s) for information about the spectrum usage in the area they are located. They can also operate without interactions with the fusion centre in a distributed manner, but the fusion centre must always be informed about the ad hoc network's spectrum usage.

With respect to the communication network, the fusion centre can act as a source of information about the spectrum usage in the area and/or as an entity performing some level of control of the communication network. If the fusion centre only acts as an information source, the base stations allocate transmission opportunities to the terminals based on spectrum usage information they get from the fusion centre. The level of control that a fusion centre can have on the communication network range from simple control like instructing the communication network to use specific frequency ranges to detailed control of specific parts of the communication network like controlling behaviour of individual terminals.

The 'cognitive actuation' function will decide the frequency and bandwidth to be used by cognitive radio terminals but will also decide, in a refined architecture, some other parameters (like for example the Modulation and Coding Scheme (MCS), the retransmission scheme, etc.) to optimise the spectrum use. The corresponding decisions may be taken at different levels of the system architecture (at Fusion Centre level, Base Stations level, Ad hoc Cluster Heads level or cognitive terminals level). For instance, it can be more optimal to select

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frequencies at a high level of hierarchy (typically at Fusion Centre level) while it can be more optimal to select MCS at a link level (typically at Base Stations level). Therefore, the 'cognitive actuation' function implementation may be distributed on the system architecture.

A cognitive radio network might have more than one fusion centre which will communicate with each other and share information about the spectrum situation in their areas and the network's own usage of spectrum resources. In the following, we define the generic interface of a fusion centre:

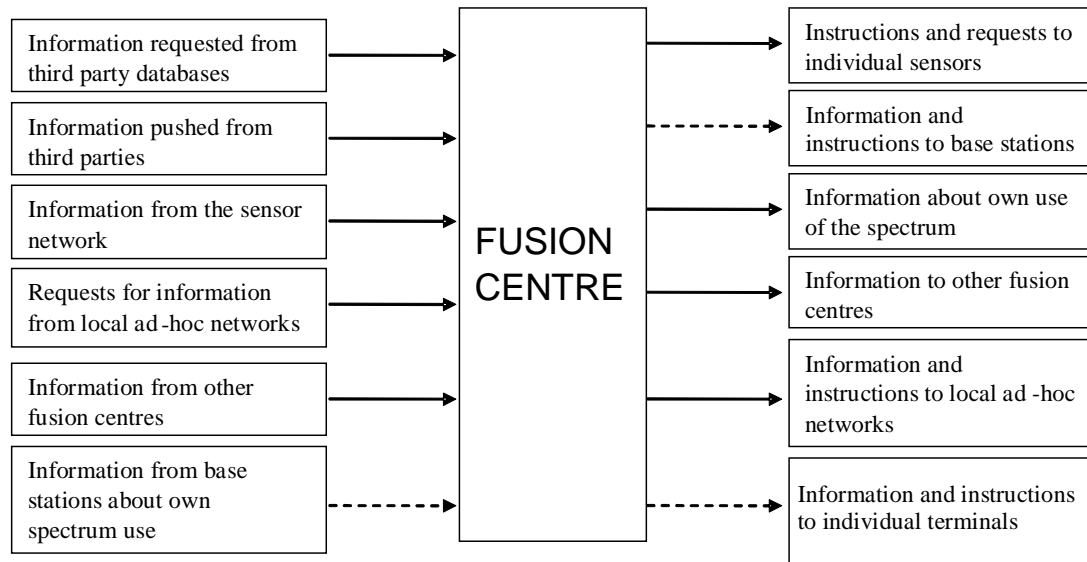


Figure 6 Fusion centre inputs and outputs

Fusion centre inputs

- **Information requested from third party databases**
Some examples are:
 - Information from the regulator's databases about frequencies where cognitive radio operation is allowed and which primary system can operate in different frequency bands
 - Information about spectrum usage from primary system operators databases
 - Information about available spectrum from spectrum broker databases
 - Information from other cognitive radio operators' databases about their spectrum usage
- **Information pushed from third parties**
Some examples are:
 - Information sent from the regulator containing updated information about regulatory issues or instructing a specific behaviour of the cognitive system
 - Information from a primary system operator informing about time/frequency slots that is made available for cognitive spectrum usage
 - Information from a spectrum broker about which frequencies can be used for cognitive radio operation during a certain time interval
 - Information from other cognitive radio operators about their presence in the area and their spectrum usage
- **Information from the sensor network**
Sensor information from the fixed sensor networks and from sensing integrated in the terminals.
- **Requests for information from local ad hoc networks**
Local ad hoc networks can request information about the spectrum usage situation in the area they are located.

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- **Information from other fusion centres**
This includes both sensing information and information about their own spectrum usage.
- **Information from base stations about own spectrum use**
This input will only exist if the allocation of the transmission opportunities is performed by the base stations and not by the fusion centre itself.

Fusion centre outputs

- **Instructions and requests to sensors**
The fusion centre can send instructions to the individual sensors (both fixed and integrated in terminals) in the sensor network about which frequency they shall sense, which primary system they shall look for, the sensing strategy etc. In this way the fusion centre can optimize the use of the available sensor network.
- **Information and instructions to base stations**
The fusion centre sends information about the spectrum usage to the base stations in the cognitive radio communication network. It can also send instructions to the base stations and in this way perform some level of control of the behaviour of the communication network.
- **Information about own usage of the spectrum**
This information can be sent to different parties, e.g. to the operator who owns the spectrum (as a basis for later payment), to other cognitive radio operators or to a spectrum broker.
- **Information to other fusion centres**
A cognitive radio network can have several fusion centres which may share sensing information and information about the system's own spectrum usage.
- **Information and instructions to local ad hoc networks**
The fusion centre can send information to local ad hoc networks about the spectrum usage in the area they are located. It might also send instructions to the ad hoc network about how it should behave, e.g. which frequency range to use. The scheduling of the traffic within the ad hoc network is however done locally within the ad hoc network, for example by the cluster head node in a clustered ad hoc network.
- **Information and instructions to individual terminals**
The fusion centre sends information about the spectrum usage to individual terminals in the cognitive radio communication network. It can also send instructions to individual terminals and in this way perform some level of control of the behaviour of the terminals.

4.3.4 Cluster head

In the local ad-hoc networks, one of the terminals is appointed as the Cluster Head (CH). The cluster head has a similar role in the local ad hoc network as the fusion centre has in the SENDORA network as a whole. Information from the sensing taking place in the local ad hoc network terminals (i.e. in the terminals with sensing capability) is collected by the CH. The CH uses this information to decide on how the available spectrum should be allocated to terminals in the local ad hoc network and instructs the ad hoc network terminals on which frequency/time slots they can use.

It should be noted that the CH is not an autonomous unit in the SENDORA network, but rather handles a functional part of the Fusion Centre (FC). The FC must either allocate a set of available frequencies to the CH which the CH can then allocate to individual terminals locally, or the CH must ask the FC for acceptance to use a particular set of frequencies locally. The FC can also instruct the CH to behave in a particular way, e.g. to stop all local transmissions in a particular frequency band when a primary user using this band is detected somewhere else in the network.

Figure 7 shows the functional architecture of a local ad hoc network.

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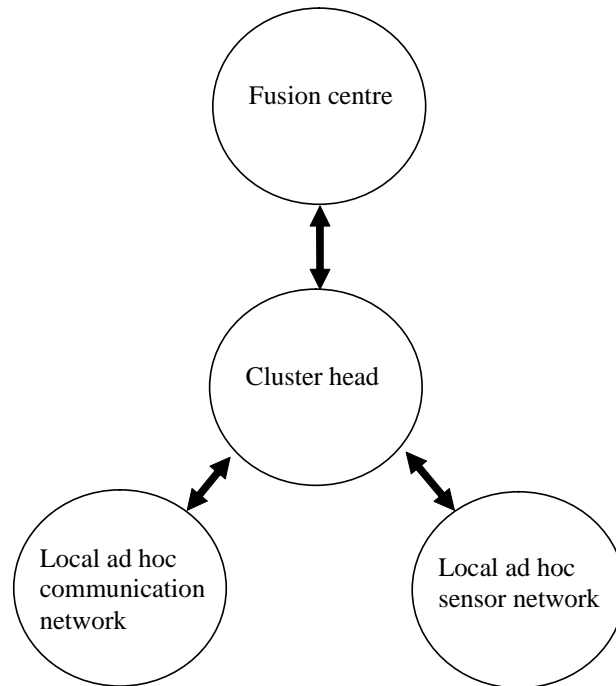


Figure 7 Local ad hoc network architecture

The CH that plays the role of interface between the local ad hoc network and the centralised network (and which may also be the gateway for broadband access provision to the ad hoc network) is one of the terminals of the local ad hoc network. If this terminal is switched off or has low batteries, then another terminal shall be elected. This CH election is classical in ad hoc topologies. Then the new CH handles the roles of the previous CH terminal.

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5 SYSTEM REQUIREMENTS AND CONSTRAINTS

This section gives the requirements and constraints which are crucial for the design of the SENDORA sensor network aided cognitive radio system.

In addition to the requirements and constraints given in this section, there are also several parameter values and assumptions that the different WPs need but which are not crucial for the system concept. These working parameter values and assumptions need to be coordinated across the SENDORA project, and are given in the appendix.

The selected scenario is cognitive radio based nomadic broadband in urban and suburban areas with a hybrid architecture. Hybrid architecture means that there will both be deployed an external independent sensor network and sensing integrated in the user terminals.

REQUIREMENTS AND CONSTRAINTS RELATED TO THE COGNITIVE COMMUNICATION NETWORK

As described in Section 4.3, at any time the network can be divided into a centralized access part and local ad hoc network parts. The requirements below may be different for the two parts of the network. If that is the case, it will be explicitly stated.

1. Usage model

Nomadic, i.e. the terminals are stationary when they are communicating with the network but the users can move between sessions.

2. Network topology

The network will at any time consist of two parts:

- a. a centralized access network with dedicated base stations. In this case all wireless broadband communication is directly between the terminal and the base station. The base station has a connection both to the fusion centre and the Internet. These connections are typically wired.
- b. local ad hoc networks where all cognitive terminals are equivalent and organize themselves in a network. One (or several) cognitive terminal(s) can also be connected to the centralized access network and play the role of gateway for the other terminals to communicate with the centralized network part (e.g. for Internet access)

The topologies for the two parts of the network are specified in 4.3.

3. Terminal types

The terminal types will be laptops, Ultra-Mobile PCs, PDAs and smartphones. The main focus in SENDORA is on laptops and ultra-mobile PCs. Furthermore, three functionalities are identified for the terminals:

- Cognitive centralized communication (requirements described in this section)
- Cognitive ad hoc communication (requirements described in this section)
- Sensing (requirements described in next section)

A terminal may have one or more of these functionalities as described in Section 4.3.

4. Capacity for each user

The capacity experienced must be sufficient to be conceived as broadband by the users. The capacity requirements are expected to increase by about 50% each year.

- a. For the centralized part of the network, the requirement for 2010 is an average bitrate of 5 Mbit/s for downloading and 1.3 Mbit/s for uploading of data. It is also expected that there will be greater symmetry between uplink and downlink capacities in the future.
- b. For the ad hoc parts of the network, a few Mbit/s is assumed in both directions, i.e. receiving and transmitting.

The capacities offered to each user will depend on the amount of spectrum available and can be significantly higher than the minimum figures given above if sufficient spectrum is available. Indeed, the capacity of the cognitive network depends not only on the network load like in a classical network, but also on the primary network activity.

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5. Services and QoS

The main services will be Internet access and other services without real-time constraints. Real-time services might be offered on a best effort basis. The system may offer some kind of QoS guarantees to the users, e.g. minimum average bitrate measured over a relatively long period.

6. Operating frequency range

The operating frequency range will initially be parts of the frequency range below 3 GHz increasing to 6 GHz or more later as the capacity requirements increase. In most cases it is expected that only parts of this spectrum range will be allowed for cognitive radio usage in a given country or area. In addition, there will probably be different constraints related to cognitive operation in different frequency bands.

7. Coverage

Outdoor and indoor coverage is required.

- a. For the centralized part of the network, it is likely that an operator will start with deployment of hot spots or hot zones. Then the hot spots/zones will be extended to cover large parts of cities or finally whole cities with suburbs later. It is therefore important that the sensor network is extensible to larger areas and scalable to handle an increasing number of customers. Finally, the network can be extended into rural areas to give blanket coverage or at least coverage along the main roads and in villages.
- b. In the ad hoc parts of the network, the coverage shall be lower (maximum a few hundred meters) as the ad hoc network will provide connectivity to a more restricted area of the system.

8. Available power

Most terminals will be battery operated. The cognitive radio should not empty the battery faster than conventional technologies like Wi-Fi. It should however be taken into account that battery technology can improve significantly in the coming years.

9. Dynamic power control

The cognitive user terminals must have dynamic power control.

10. User terminal and base station range

- a. The centralized part of the network should be designed for a typical base station separation of 1 km.
- b. The ad hoc parts of the network should be designed with a typical maximum distance between the nodes of a few hundred meters.

11. Resource allocation

The transmission opportunities are allocated based on sensing information from the sensor network and other information (e.g. from the primary network or from other database). The cognitive radio terminals might be instructed to use a particular set of transmission parameters (e.g. modulation, FEC scheme, transmission power, etc.).

In the centralized part of the network the transmission opportunities are allocated by the base stations or by the fusion centre. In the ad hoc parts of the network more distributed resource allocation algorithms will be considered.

REQUIREMENTS AND CONSTRAINTS RELATED TO THE SENSOR NETWORK

1. Mobility

The sensors in the external sensor network will be fixed and their placement will usually be the result of careful planning by the entity that deploys the sensor network. The sensing in the user terminals may communicate with external sensors or base stations even when the terminal moves. But there are no handover functionalities involved; the sensing information is just communicated to other sensors or base stations that are able to pick up the corresponding transmissions of the terminals as they pass by.

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2. **Topology for sensor network communication**

WP6 in cooperation with WP5 is currently proposing and studying topologies for the sensor network communication.

3. **Power for the sensors**

The external sensor network can be assumed to be powered from the mains, while the terminals with integrated sensing will be powered from batteries.

4. **Geographical layout and planning of the external sensor network**

The geographic layout must at least encompass the area covered by the cognitive nomadic broadband network. WP6 has produced outcomes regarding the sensor network dimensioning that allows the optimal placement of the external sensors.

The coverage of the sensor network shall be large enough to cover the area of cognitive operation. In particular, it shall be extensible and scalable as well.

5. **Frequencies for communication between the sensors**

In order to guarantee the availability of the sensing information and decisions, it will be assumed that the wireless sensors can use a narrow licensed band for communication. No specific bandwidth will be assumed for this communication, but it is important that this sensor network communication must be spectrum efficient.

In addition it will be assumed that the sensor network can use cognitive radio communication for capacity extension to transmit signalling information.

6. **Minimum probability of detection**

The probability for a sensor to detect a primary user within its coverage area is at least 0.95 for a channel without shadowing between the sensor and the primary user.

The detectors are designed such that the test statistic remains the same and the threshold can change depending on the constraints on error probabilities. Different sensors cooperate so that the missed detection and false alarm probabilities are minimized.

The aim is to maximize the probability of detection while constraining the false alarm probability. Therefore the probability of detection of 95% is a minimum value and not fixed. To qualify for sensing, the minimum SNR of the sensor should be the SNR corresponding to the probability of detection of 95%. If the SNR is more than the qualifying SNR, the probability of detection at the sensor will be more than 95%.

Diversity gain in cooperative detection is highly important. Cooperative detection helps in simplifying the individual sensors. Therefore even though the probability of detection is 95% per sensor, the system probability of detection value for 2, 3, and 4 sensors cooperating is 99.75%, 99.87% and 99.99% respectively.

7. **Scalability of the fusion centre**

The fusion centre must scale with the number of customers served, so that the coverage area of the network can be extended e.g. from a hot-zone to a whole city in a cost efficient manner.

CONSTRAINTS RELATED TO THE PRIMARY NETWORK

1. **Primary technologies**

The cognitive radio based nomadic broadband network will operate over a large frequency band which encompasses several frequency bands, each associated with a specific primary technology. The frequency bands and their associated primary technology might vary from country to country, or even from area to area. In SENDORA, the primary technologies that will be targeted are Wi-Fi, UMTS (including HSPA), LTE and DTT.

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CAPACITY OF THE DEMONSTRATION PLATFORM

This section provides some general characteristics of the demonstration platform, especially of its RF part. The objective of the demonstration is to prove the sensor network aided cognitive radio concept and in particular the feasibility of the targeted scenario. The hardware constraints of the RF part shall therefore be taken into account for the design of the enabling techniques to be integrated in the demonstrator.

The main objective of the RF platform is to show that a highly reconfigurable RF transceiver is possible with existing available components. Hence, the targeted prototype is very ambitious in term of frequency bands, since the objective is to address from 200 MHz to 7.5 GHz, with a maximum bandwidth of 20 MHz. Hence, we will be able to receive and transmit almost all the existing commercial Radio Access Technologies. Concerning the transmitted power, the target is comparable to existing GSM terminals (+21 dBm). On the receiver side, the objective is to have a noise figure from 8 to 12 dB, depending on the frequency band. Since SENDORA is also considering Multiple Antenna Processing, the RF equipment will include up to 4 antennas and 4 RF chains. Finally, the key features of the targeted prototype are the following:

- It will integrate advanced re-sampling functionalities
- It will allow to communicate at the same time in different bands and different waveforms
- The board by default is Time Division Duplex based. It means that we use the same frequency band for Rx and Tx on one chain, and that a switch is used at the front end. In other words, one can only either transmit or receive. In order to implement a Frequency Division Duplex system, one has to use 2 chains, one for the uplink, and one for the downlink.

The overall RF board is composed of 3 parts:

- TX ANALOG PART
- LO DRIVES PART
- RX ANALOG PART

Each part has a control interface that comes from the digital mother board. More over, TX and RX parts have an I/Q signal interface to the mother board, for AD/DA conversion. OL part feed the 2 other parts in term of Local Oscillators for modulation/demodulation and frequency conversion.

A. Local oscillators

Since we address a very wide frequency band, the local oscillator generation is a key feature of the RF transceiver. The LO generation is based on a wide band frequency synthesizer (1.9 to 4.1 GHz) and a frequency doubler. Hence the LO range is from 3.8 GHz to 8.2 GHz. The drawback of this solution is that the frequency step is quite large, but it can be compensated digitally on the base band signals.

B. Transmitter section

The base band signal (zero IF) is in I/Q format, and fed to a quasi direct modulator. The chosen component allows one to generate a signal directly from base band to a frequency range from 4 to 8 GHz. The modulated signal is then filtered and amplified. Afterwards, a switch is used to separate low and high frequencies, if the signal shall be transmitted between 4 to 7.5 GHz

C. Receiver section

This part is certainly the most complex one, due to the very wide addressed frequency band (from 400 MHz to 7.5 GHz). As explained in section V, the LNA is a critical part, since the performance of existing wide band LNAs are not yet adequate (relatively high noise figure, non constant gain vs. frequency). Hence, the overall frequency band is divided (by a switch) into 2 sub-bands, one from 400 MHz to 2 GHz, and another one from 2 GHz to 7.5 GHz. After the LNA stage, the signal is filtered and the frequency bands are again splitted in 2 sub bands. It gives us 4 sub-bands:

- 400 MHz to 1.2 GHz
- 1.2 GHz to 2 GHz
- 2 GHz to 4 GHz
- 4 GHz to 7.5 GHz.

This approach is used to decrease the amount off outer band interference (one has to keep in mind that basically all existing RATs are received at the antenna level, sometimes with huge level of signal). After this part, the architecture uses basically the same principle as for the transmitter section. We up convert the signal into a

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frequency range of 4 to 7.5 GHz and the signal is converted into base band thanks to an I/Q MMIC mixer. The base band signal is finally filtered and amplified.

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6 SUMMARY AND CONCLUSIONS

This report is the final version of the report D2.1 "Scenario descriptions and system requirements" focused on the SENDORA target scenario. In the original version of the report the main goal was to define the target scenario that will be the basis for the system that will be developed in the SENDORA project.

Another goal for this final version of the report was that it should be easy to use it as a reference for information about the chosen scenario, its architecture and the system requirements and constraints.

The content of the current version consists mainly of final descriptions of the chosen scenario and of the associated architecture and chosen scenario description, updated lists of system requirements and constraints and an appendix with a snapshot of the working assumptions and parameter values used in the SENDORA project at the time of writing.

The updated information presented in this report is the result of an iterative process where the selected scenario and the corresponding requirements and constraints have been refined as more results from the technical and techno-economical studies were obtained.

The report also includes initial results of the techno-economical study. This study is still on-going and will be reported in details in deliverable D2.2.

The innovative idea in SENDORA is to combine cognitive radio technology with sensor network technology. A sensor network will be used for monitoring the spectrum usage in an area and will significantly improve the system's ability to detect primary users compared to pure cognitive radio solutions.

The sensor network will consist of both an externally deployed sensor network and sensing capability in user terminals. The external sensor network will make it possible to guarantee that primary users will be detected with a certain high probability while the sensing in the terminals will enhance the system's performance by providing more detailed sensing information from the areas where the cognitive radio users are located.

The SENDORA system architecture consists of three parts: a sensing architecture, a communication architecture and a fusion centre. The sensing architecture and communication architecture are connected together by a fusion centre. The fusion centre collects sensor data from the sensor network and estimates the spectrum usage situation in the area covered by the sensor network based on this information. The fusion centre also communicates with the communication network providing it with the information it needs to operate cognitively in an optimal way. The fusion centre might also perform some level of control on the communication network, e.g. giving instructions on frequency ranges the communication network can use or even controlling behaviour of each individual terminal.

The communication architecture consists of a centralized network of base stations through which the terminals can get Internet access, complemented by terminals communicating directly with each other forming local ad hoc networks. A centralized solution is an efficient way of implementing Internet access with predictable service (coverage, throughput, delay, etc.). Centralizing the intelligence and the sophisticated hardware also makes the use of low cost terminals possible.

Ad hoc communication between terminals located close to each other allows data to be transferred at higher bit rates and with less power than if the communication had to be transferred via base stations. This reduces the interference generated by the cognitive radios and increases the system capacity. In addition, the range and coverage of the network can be extended by allowing terminals that are not able to access the centralized network directly to get access through nearby terminals with centralized access.

The SENDORA system will be best suited to provide non real-time services like web browsing and video downloading. Real-time services like telephony and video streaming can be provided occasionally, but the operator will not be able to give strict quality guarantees for such services.

It is assumed that the SENDORA system will utilize frequencies below 6 GHz, but that cognitive radio will only be allowed in some frequency bands within this frequency range initially. Since it is important to have indoor coverage, it is important that the cognitive radios can operate at frequencies below 3 GHz.

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Based on the selected target scenario, requirements and constraints have been specified for the cognitive radios, the sensor network and the primary technologies to be considered.

Finally, the report contains an appendix listing assumptions and parameter values that are used in the SENDORA project but which are not crucial for the system concept. The purpose of these tables is to ensure that the same parameters and assumptions are used by all partners and working groups in the project. This makes it easier to compare and combine results achieved by different partners and working groups. This version of the document presents the final status of these tables.

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7 REFERENCES

- [Cherry] Steven Cherry, "Edholm's law of bandwidth", IEEE Spectrum July 2004, pp. 58-60.
- [Baum] D.S. Baum, J. Hansen, G. Del Galdo, M. Milojevic, J.Salo and P. Kyösti, "*An interim channel model for beyond-3G systems – Extending the 3GPP spatial channel model (SCM)*", in Proc. of IEEE VTC 2005 Spring, Stockholm 2005, pp. 3132-3136.

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APPENDIX 1: WORKING ASSUMPTIONS AND PARAMETER VALUES

Note: the tables in this appendix contain assumptions and parameter values that are used in the SENDORA project but which are not crucial for the system concept. The purpose of these tables is to ensure that the same parameters and assumptions are used by all partners and working groups in the project. This makes it easier to compare and combine results achieved by different partners and working groups.

Assumptions and parameters that are crucial to the system concept are given in chapter 5 “System requirements and constraints”.

Table 1: SENSOR NETWORK RELATED PARAMETERS						
Parameter name	Description	Value	Justification/motivation	Proposer (WP)	WPs using the parameter	Comments
Pd	An individual sensor’s minimum probability for detecting a primary user under non-shadowing conditions	0.95	Initial assumption.	WP2	WP3	Finally, the value for Pd has to be set to satisfy the required minimum probability of detection for the sensor network as a whole (ref. D2.1 v4.0 chapter 5).
Pf	An individual sensor’s maximum probability of false alarm	0.05	Initial assumption.	WP2	WP3	
Primary system channel model	The channel model with corresponding propagation parameters for each primary system	SCME (3GPP Spatial Channel Model Extended)[Baum]	In deliverable D5.4	WP3	WP3, WP4, WP5	Well documented Matlab codes are available on the 3GPP web site. This channel model will be considered in the scope of D5.4
fres	Resolution of frequency scan	200 kHz	Initial assumption	WP3	WP3	
Tuse	Time for which a secondary user can use the primary resource, once it gets it	Will be specified for each type of primary system later in the study		WP3	WP3, WP4	
Pprim	A priori probabilities of the primary users being present	Will be specified for each type of primary system later in the study		WP3	WP3, WP4	

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Table 2: SENSOR NETWORK RELATED ASSUMPTIONS

Assumption name	Assumption	Justification/ motivation	Proposer (WP)	WPs using the assumption	Comments
Sensing policy	Emphasis is on highly reliable detection of primary users, less on detecting secondary users. Initially, the preference is to identify the channels which are less used. Only one secondary system is considered, the coexistence of secondary systems is not considered.	The objective is to use the spectrum in an opportunistic manner	WP2	WP3, WP4	There are a lot of challenges in connection with detection of and co-existence with other cognitive radio systems in the same area. SENDORA will not be able to study these issues, and will focus only on coexistence with primary users.
A priori knowledge	The primary systems that operate in a certain frequency range in a given area can be assumed to be known by the fusion centre.	Initial assumption	WP2	WP3, WP4	
Sensor statistics	Initially it is assumed that the sensor statistics that are sent to the fusion centre are log-likelihood ratios (LLRs).		WP3	WP3, WP5	
WSN waveform	The waveform of the sensor network to convey the sensed information can be an OFDM, CDMA or spread spectrum based waveform		WP2	WP5, WP6, WP7	The project will assess which waveform is the best. The demonstrator will use an OFDM waveform.
Licensed frequency band	It is assumed that the sensor network operator has been allocated (i.e. been given a license for) a 10 kHz wide frequency band.	Need to guarantee the transmission of signaling messages related to the cognitive process	WP2	WP4, WP5	This do not preclude that the sensor network communicates at much higher bit rates using cognitive radio in other frequency bands. The narrow frequency band is required for the setup of the WSN and to guarantee the release of the spectrum when a primary communication is detected.
Sensor radios	The sensors will not transmit and receive data at the same time			WP3, WP4	
Interface to the communication network	Specification of a standard interface between the communication network and the sensor network must be established (even more when different actors are involved, e.g. if the sensor network is owned by a spectrum broker).		WP2	WP4, WP6	Interface defined in WP4. Interface that may be potentially brought to standardization.

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Table 2: SENSOR NETWORK RELATED ASSUMPTIONS

Assumption name	Assumption	Justification/ motivation	Proposer (WP)	WPs using the assumption	Comments
Sensor antennas	It will be assumed that the sensor nodes may use multiple antennas. Sensors integrated in terminals will use maximum 4 antennas while the fixed sensor nodes might use more than 4 antennas.	Assumption for the definition of sensing strategies		WP3, WP4, WP5	
Capacity and QoS for sensor communication	The required capacity for communication of sensor information depends on the amount of information that has to be transferred and QoS requirements (e.g. latency) for different types of sensor information. WP3 and WP4 jointly assess the required sensor communication capacity and QoS requirements.			WP5, WP6	
Sensor node processing power	The processing power of a battery operated sensor node will be assumed to be at least the same as the processing power of a mobile phone today.			WP3, WP4, WP5, WP6	
Sensor node communication capabilities	If the sensor nodes use cognitive radio for communication it is assumed that they cannot transmit and receive at the same time.			WP3, WP4	
Link between global sensing and local sensing	Figure 5 shows a potential link between the global sensing and the local sensing.		WP2	WP3, WP4	
Exit strategy	A node stops its transmission in the bandwidth if a primary user has been detected locally in order to release the spectrum quickly, and then it informs the Fusion Centre through the sensor network.		WP3 WP2	WP4	

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Table 3: PRIMARY SYSTEM RELATED PARAMETERS AND ASSUMPTIONS

Parameter name	Description	Value	Justification/ motivation	Proposer (WP)	WPs using the parameter	Comments
Primary systems	The primary systems that the sensor network must be able to detect	Wi-Fi, UMTS/HSPA, LTE and DTT		WP2	WP3, WP4	
Interference constraints	The interference constraints for each primary system	See sub-table 3-1	See sub-table 3-1	WP2	WP3, WP4	
Interaction with cognitive radio system	Interaction between the cognitive radio network and primary technology networks	There might be information exchange between the cognitive radio network and the primary technology network, e.g. information about the location of primary technology users.			WP4	

Sub-table 3-1: Primary system related parameters – Interference constraints

Parameter	Wi-Fi	UMTS/HSPA	LTE	DTT
Maximum response time	100 ms	10 ms/2 ms (TTI length)	0.5 ms (one resource block)	2 s (same as 802.22 requirements)
Detection threshold	-82 dBm over 5 MHz	-117.3 dBm over 5 MHz (10% of thermal noise)	-121.2 dBm over 200 kHz (same as thermal noise)	-116 dBm over 6 MHz (same as 802.22 requirements)
Acceptable level of interference	< -76 dBm over 20 MHz (from Wi-Fi standard)	< -117.3 dBm over 5 MHz	< -121.2 dBm over 200 kHz	< -116 dBm over 6 MHz
Maximum outage probability	0.001	1.39e-6 (10 TTIs every hour)	1.39e-6 (10 TTIs every hour)	3.5e-4 (30 sec per 24 h)
Maximum transmitted power	20 dBm (ISM requirements)	43 dBm	43 dBm	43 dBm
Signal bandwidth	5 MHz (one channel)	5 MHz (one carrier)	180 kHz (one resource block)	6 MHz (one TV channel)

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Table 4: COMMUNICATION NETWORK RELATED PARAMETERS

Parameter name	Description	Value	Justification/motivation	Proposer (WP)	WPs using the parameter	Comments
Nusers	Number of users that must be served simultaneously	10	<p>a. For the centralized part of the network at least 10 simultaneous users should be supported for initial deployments. Later the system must be able to support a significantly higher number of simultaneous users per base station.</p> <p>b. In the ad hoc parts of the network, 10 simultaneous users should be supported.</p>	WP2	WP4, WP5, WP6	The maximum number of cognitive users that must be served will depend on the required outage probability that will guarantee the QoS of the primary system. WP3 and WP4 studies provide some indications about this.
Channel model	The channel model for the communication network	The propagation environment is urban and suburban non line-of-sight (i.e. with reflections mainly from buildings), both indoor and outdoor. The following channel models will be used: Cost-Hata (path-loss), log-normal (shadowing), Rayleigh (fast fading).	See deliverable D4.1	WP2	WP4	This channel model will be considered in the scope of D4.1

Table 5: COMMUNICATION NETWORK RELATED ASSUMPTIONS

Assumption name	Assumption	Justification/motivation	Proposer (WP)	WPs using the assumption	Comments
Location information	It will be assumed that 50% of the user terminals have an integrated GPS (or Galileo) receiver. Note however that GPS information will not be available indoor.		WP2	WP4	
Communication network waveform	The waveform of the cognitive network to convey the user communications can be an OFDM based waveform	Coherence with demo	WP2	WP5, WP6, WP7	
Interface to the sensor network	Specification of a standard interface between the communication network and the sensor network must be established.			WP4, WP6	This interface is considered in the scope of WP44 task

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Table 5: COMMUNICATION NETWORK RELATED ASSUMPTIONS

Assumption name	Assumption	Justification/motivation	Proposer (WP)	WPs using the assumption	Comments
Accountability and enforcement	It is assumed that the SENDORA network has mechanisms that ensure proper accountability and enforcement in relation to interference infringements. However, the development and specification of such functionalities are outside the scope of the SENDORA project.		WP2		

