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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 report is an updated version of the report D2.1 "Scenario descriptions and system requirements", first version (M3). It is focused on the SENDORA target scenario and has been therefore abridged and refined from its 1.0 version delivered in Month 3.

In SENDORA, the target scenario is refined in an iterative process. The first version of the report D 2.1 described the selection process for the target scenario first based on initial assumptions regarding techno-economical parameters and technological performance and constraints. This scenario is refined during the project based on new results from the business case evaluations and the technical studies conducted in SENDORA. In addition to the current update, there will be a last update later in the project (M24).

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 can not adapt 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 both an externally deployed sensor network and sensing capabilities embedded in user terminals. The external sensor network will allow guaranteeing that primary users will be detected with a defined probability, regardless of the number of cognitive radio present in the area. Additionally, the embedded sensing in the terminals will 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 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 act as the “brain” in the communication network controlling the behaviour of each individual terminal and sensor.

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 bitrates 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.

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. 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.

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 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.

CONTENTS

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.

1 INTRODUCTION

This report is an updated and abridged version of the report D2.1 "Scenario descriptions and system requirements" where the text describing the different candidate scenarios and the selection process in the original version have 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 is referred to the original version (1.0) of the report (available at the SENDORA project web site www.sendora.eu).

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 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 are refined as more results from the technical and techno-economical studies are obtained. In addition to the current update of the report, a last update is planned later in the project (M24).

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 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.

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.

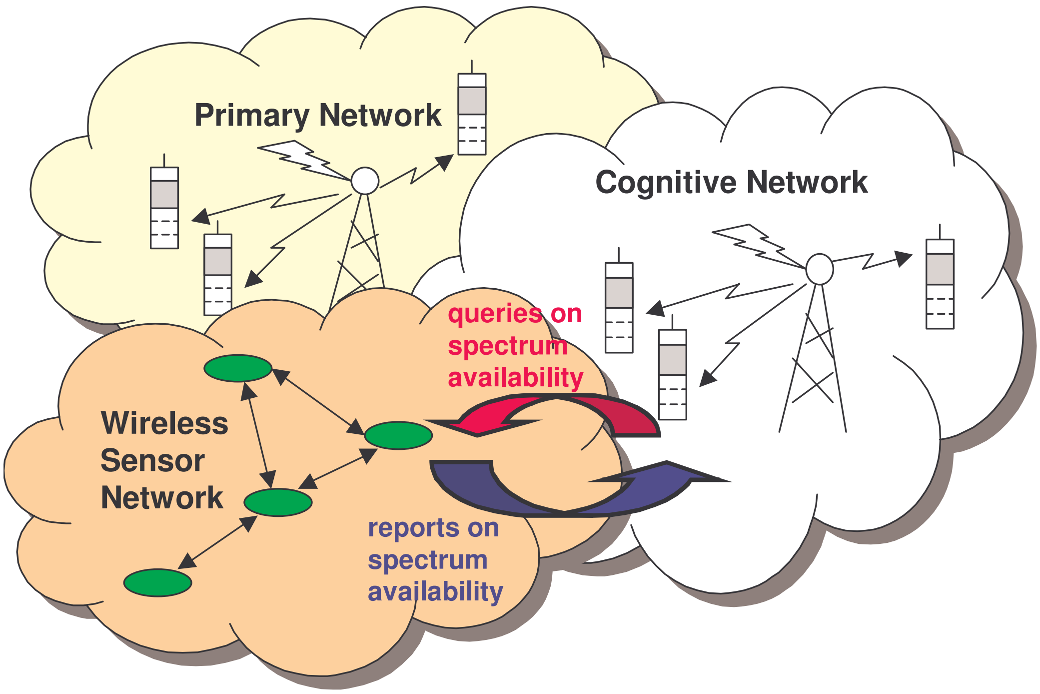

Figure 1 General scenario for Sensor Network aided Cognitive Radio

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 will monitor 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 is 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, sensors are also integrated into the cognitive radio terminals to improve the spectrum sensing as the number of users grows.

2 DEFINITIONS

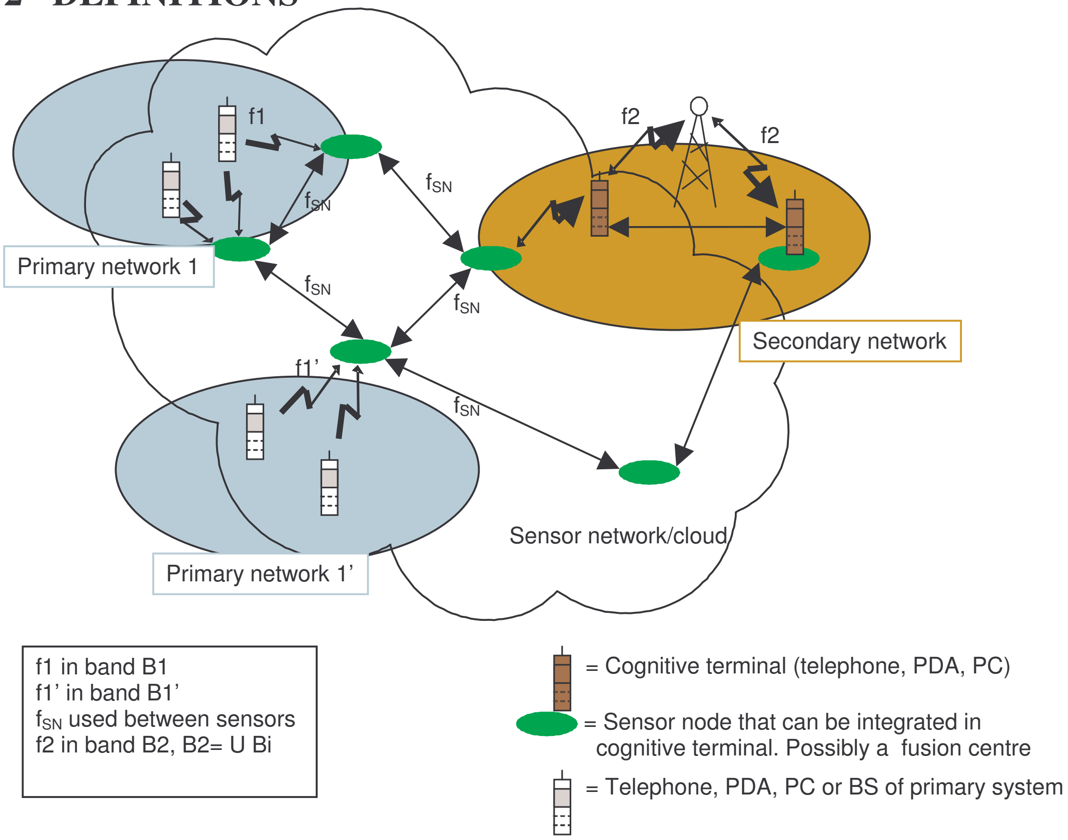

Figure 2 Spectrum usage in a generic sensor network aided cognitive radio system

<u>Cognitive radio system</u>
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.

<u>Cognitive radio base station</u>
A base station that is used in a cognitive radio system. It may or may not have its own cognitive capabilities. If the base station does not have cognitive capabilities of its own, 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, direct communications between cognitive radio terminals may be foreseen.

<u>Cognitive radio terminal</u>
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 do not have sensing capabilities, it will be instructed in how to behave by other parts of the cognitive radio system, e.g. a base station.

<u>Fusion centre</u>
A unit in which data from sensors are 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.

<u>Wireless sensor network</u>
A network of spectrum sensing sensors where the communication to and from the sensor nodes are wireless.

Independent sensor network aided cognitive radio architectures
Independent sensor network aided cognitive radio networks consists of a sensor network that is deployed in an area that can provide a cognitive radio entering the area information about spectrum usage in the area and/or instruct the cognitive radio on how it shall behave. The sensors are external to the cognitive radio terminals.

Integrated sensor network aided cognitive radio architectures
Integrated sensor network aided cognitive radio architecture consists of two or more cognitive radio user terminals with integrated sensors, where the sensors constitute a wireless sensor network.

Fixed scenarios
In fixed scenarios the cognitive radios use permanently mounted outdoor antennas. The antennas are typically mounted on the walls or roofs of buildings.

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

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

Primary radio 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 radio 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 it is not used by the primary radio network of this frequency band.

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 28), but ecosystem considerations are an integral part in the scenario definitions and system requirements. Therefore this update of deliverable D2.1 and the final D2.1 in month 24 will include preliminary ecosystem evaluations.

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.

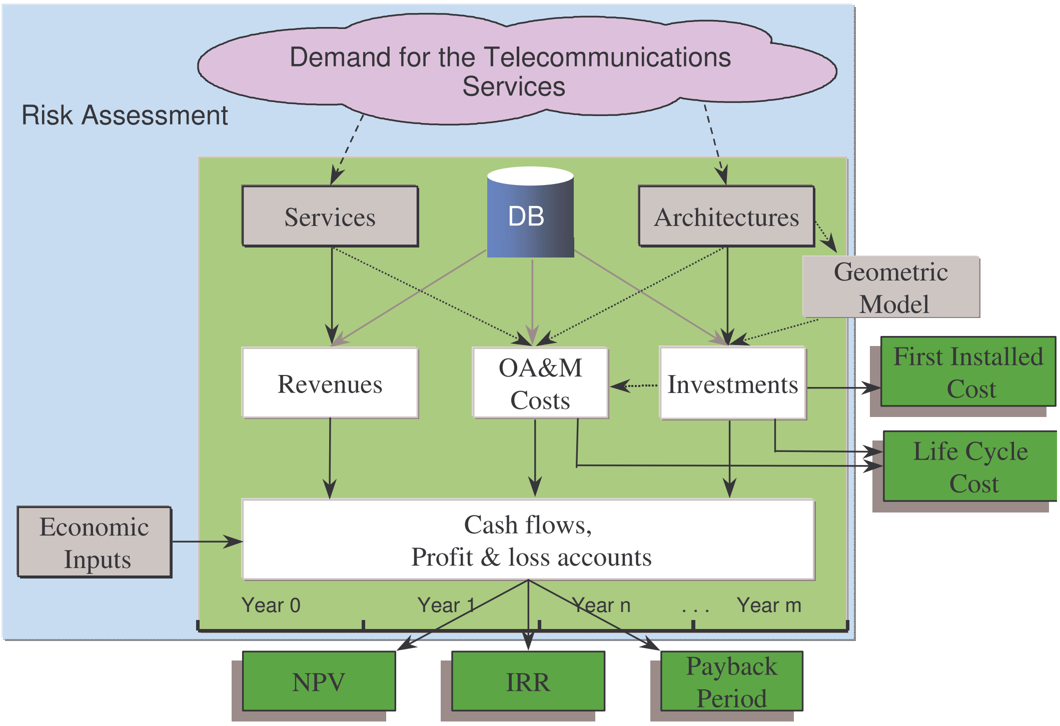

Figure 3 Business case methodology

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

This version of D2.1 does not include quantitative business case results.

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
    - 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 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 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.

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.

4 GENERAL REGULATORY CONSIDERATIONS

Historically spectrum has been, and still is, regulated rigorously. There seems, however, to be a trend towards a more liberalized policy. New frequency licences are to a greater extent allocated based on auctions and some countries have opened for secondary trading of spectrum. Technological flexibility is also emphasized to a greater extent. For instance, recently the European Commission proposed to repeal the GSM directive. If the Commissions proposal is approved by the European Parliament and Council, operators can in the future use e.g. UMTS technology in the 900 MHz band. One additional future trend in spectrum management is release of analogue TV broadcasting frequencies. Some countries have started this process. For instance, in January 2008 USA launched the auction of spectrum resources in the 700 MHz band.

The main motivation for liberalization is to achieve an improved utilization of spectrum resources. This seems to be supportive for the SENDORA idea about more effective use of frequencies by sensor network aided cognitive radio. The regulators will probably be, at least, in principle, positive. However, cognitive radio is a new item, also for regulators, leaving many issues open. At the present time it is too early to have definite statements, how the frequency regulators will react to detailed questions. Some of the regulatory issues, which must be clarified later in the SENDORA project, include:

- Conditions and expiry dates for existing licences, e.g. mobile frequency licences (probably large country and operator variations)
- Possibilities to change licence conditions underway to allow secondary trading
- Release of analogue TV broadcasting frequencies (country variations)
- Possibilities for frequency ranges reserved only for common use with cognitive radio

The project intends to establish contact with regulatory bodies to demonstrate the potential of sensor network aided cognitive radio and especially discuss how regulation may be adapted to improve the global radio spectrum use by taking advantage of the capabilities provided by SENDORA technology. Specifically, regulators will be invited to attend demonstrations and workshops conducted by SENDORA.

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

5.1.1 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 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 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 potentially be a very interesting opportunity for operators since it can offer both high bitrates 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 he 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 he is equipped with a directional antenna he 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 he is in the basement of buildings or in rural areas. Generally, cognitive radio gives the opportunity to use that 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 can be bonded to give a virtual high capacity channel.

This characteristic of cognitive radio makes it possible to offer a type of service that is not possible to offer with licensed radio systems which have strictly defined bandwidths and operation limited to a certain (narrow) frequency band.

5.1.2 Scenario characteristics

5.1.2.1 Deployment strategy

It is likely that an operator will start with deployment of hot spots or hot zones. This will be the case for both 2G and 3G operators wanting to complement or off-load their licensed network and for green-field operators. Later the hot spots/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.

5.1.2.2 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.

5.1.2.3 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.

5.1.2.4 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].

In order to qualify as a broadband service, the bitrates offered to customers should not be much less than the bitrates that are offered to users with mobile broadband today. 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 1 Mbit/s downlink and 250 kbit/s uplink in 2008 and increase to about 5 Mbit/s downlink and 1.3 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.

5.1.2.5 Cognitive radio operating frequencies

In densely populated areas the cognitive radio should be able to make use of frequencies below 6 GHz.
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 to allow cognitive radio operation in frequency bands where the existing frequency licenses gives 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, cognitive radio operation will initially only be allowed in certain parts of the frequency band below 6 GHz.

5.1.2.6 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 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.

5.1.2.7 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.

5.1.2.8 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 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.

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 that each packet is routed to the network that is best suited at that time.

5.1.2.9 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 on this figure. The sensing architecture is based on a fixed deployed sensor network with additional sensing capabilities at user terminal level. The communication architecture takes advantage of this sensing architecture to communicate in a cognitive way.

The sensing architecture and communication architecture are connected together by a fusion centre as illustrated in Figure 4 . 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 corresponding interfaces will be defined in the project. The fusion centre might also act as the “brain” in the communication network controlling the behaviour of each individual terminal (often referred to as the 'cognitive actuation' function).

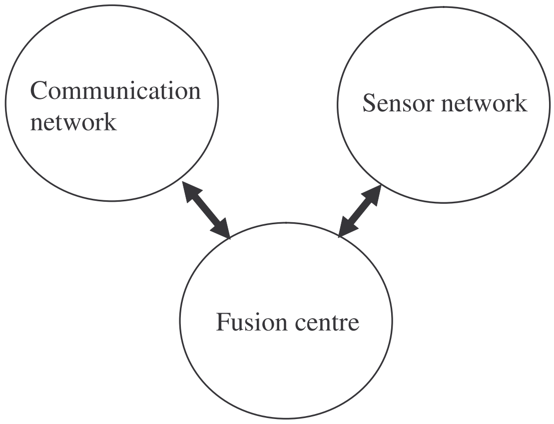

Figure 4 SENDORA general system architecture

COMMUNICATION ARCHITECTURE

In 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/or 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.

Ad hoc communication between terminals located close to each other allows data to be transferred at higher bitrates and with less power than if the communication had to be transferred via base stations. 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.

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.

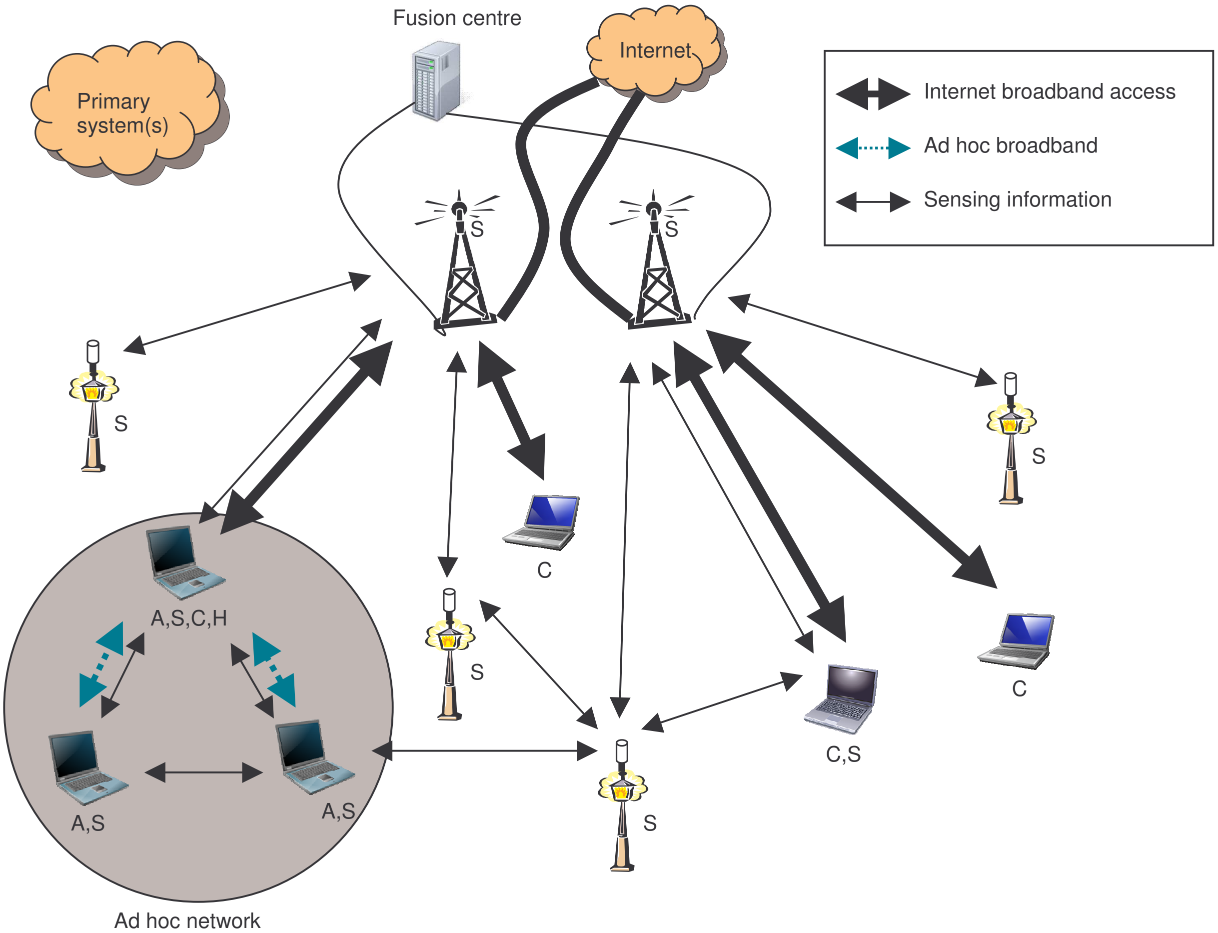

Figure 5 Cognitive radio based nomadic broadband system architecture.

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 terminal sensors will be random variables and sometimes the terminal sensor network will not be able to detect primary users with the required confidence. By deploying a fixed network of sensors where the number and location of the sensors are chosen so that 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.

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 communication.
- Class 3: Nodes with low processing power, battery powered and use radio for communication. 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 this information to deduce the spectrum usage information data and sends 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.

FUSION CENTRE

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

The fusion centre acts as an aggregation point 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 individual sensors for sensor 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 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.

With respect to the communication network, the fusion centre can either act as a source for information about the spectrum usage in the area or as the “brain” in the communication network controlling each terminal in the network.
In the first case the base stations allocates transmission opportunities to the terminals based on spectrum usage information the get from the fusion centre. In the latter case, the fusion centre itself allocates the transmission opportunities for each terminal and either sends this information directly to the terminals or to the base stations which then generate the appropriate MAC messages.

The 'cognitive actuation' function will decide the frequency to be used by cognitive radios but may also decide, in a refined architecture, some other parameters (like the Modulation and Coding Scheme (MCS)) 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 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.

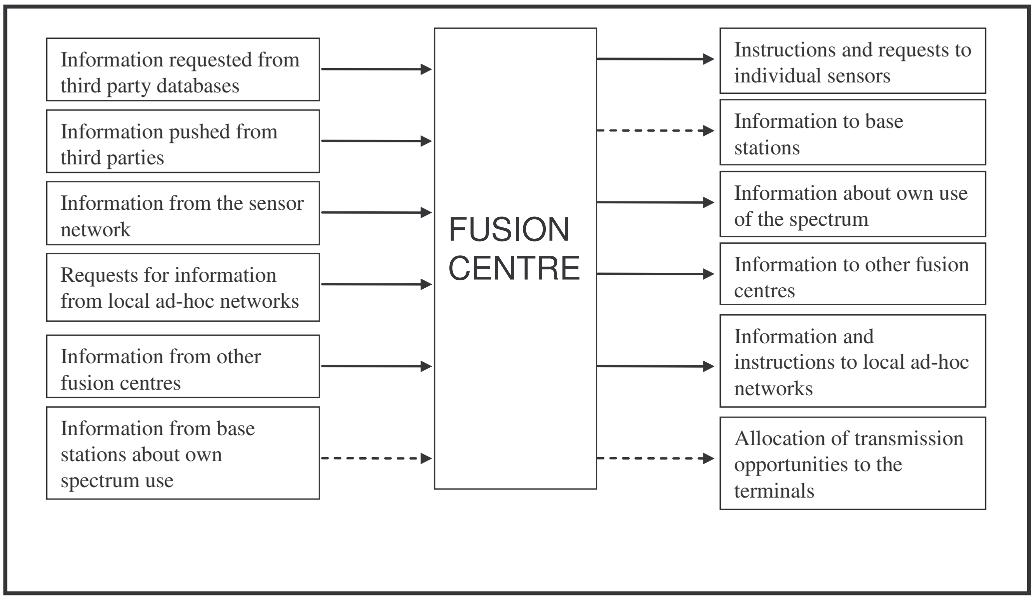

Figure 6 Fusion centre inputs and outputs

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 that 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 that 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.

- **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 are done by the base stations and not by the fusion centre itself.

Fusion centre outputs:

- **Instructions and requests to sensors**
  The fusion centre will 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 to base stations**
  If the base stations allocate transmission opportunities to the terminals, the fusion centre can send information about the spectrum usage to the base station. (If the fusion centre allocates the transmission opportunities, it can either send information about this directly to the terminals or it can send it to the base stations which then generate the proper MAC messages).

- **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 and to a spectrum broker.

- **Information to other fusion centres**
  A cognitive radio network can have several fusion centres which may share sensor 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 nodes in a clustered ad hoc network..

- **Allocation of transmission opportunities to the terminals**
  If the fusion centre allocates the transmission opportunities, it can either send information about this directly to the terminals or it can send it to the base stations which then generate the proper MAC messages

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 cluster head. The CH uses this information to decide on how the available spectrum should be divided between the 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 general architecture of a local ad hoc network.

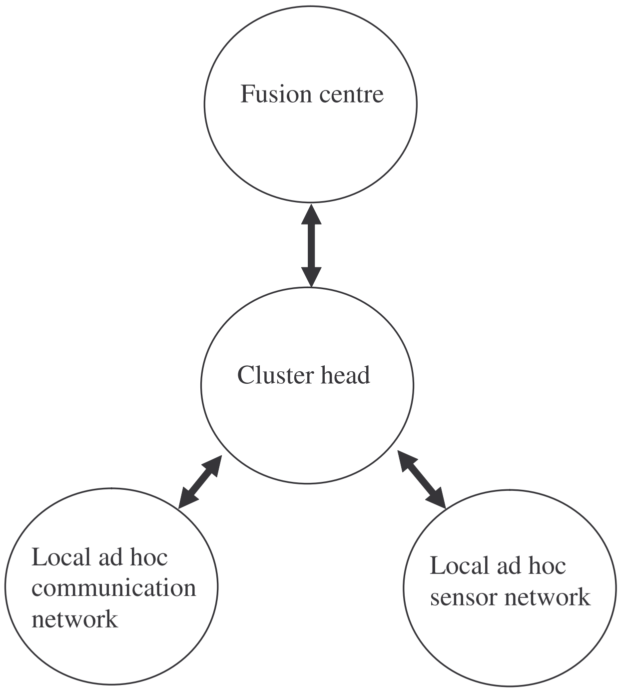

Figure 7 Local ad hoc network architecture

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.

6 SYSTEM REQUIREMENTS AND CONSTRAINTS

This section gives the requirements and constraints which are crucial for the concept 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 5.1.2.9, 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 5.1.2.9.

3. **Terminal types**
   The terminals 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 5.1.2.9.

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 2008 is 1 Mbit/s for downloading and 250 kbit/s for uploading of data. These numbers corresponds to what is typically offered as mobile broadband services by operators today. 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.

5. **Services and QoS**
   The main services will be Internet access and other service 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 the whole or 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. **Medium Access Control (MAC)**
The transmission opportunities are allocated based on sensing information from the sensor network and other information (e.g. from the primary network or a 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 MACs 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.

2. **Topology for sensor network communication**
WP6 in cooperation with W5 will decide on the best topology or topologies for the sensor network

communication later in the project.

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 will develop a method for planning the placement of the external sensors based on inputs from WP3 and WP5.
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. with a bitrate of 10 kbit/s for communication.
In addition it will be assumed that the sensor network can use cognitive radio communication. No specific bandwidth will be assumed for this communication, but it is important that this sensor network communication must be spectrum efficient.

6. **Minimum probability of detection**
The probability for the sensor network to detect a primary user within its coverage area is at least 0.95.

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.

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 spitted 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 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.

7 SUMMARY AND CONCLUSIONS

This report is an updated 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. In the current version, the main goal is to extend and clarify the description of the target scenario and refine the system requirements and constraints based on results obtained within the project.

Another goal for the current 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. To achieve this the text describing all the candidate scenarios, the selection criteria, the evaluations and the justification for the final scenario selection has not been included in this version of the report. For information about these issues, the reader is referred to the original version (1.0).

The content of the current version consists mainly of updated and extended 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 are refined as more results from the technical and techno-economical studies are obtained. In addition to the current update of the report, one additional update is planned later.

The report includes a general ecosystem consideration with business modelling including the roles of the actors, relations (e.g. partnership) between the actors, cost structures, revenues and money flows between the actors. The roles that can be foreseen in the ecosystem for the sensor network aided cognitive radio system have been identified and four different alternatives for the ecosystem have been described.

General regulatory considerations are presented. Historically spectrum has been, and still is, regulated rigorously. There seems, however, to be a trend towards a more liberalized policy. The main motivation for liberalization is to improve the utilization of the spectrum resources. The SENDORA concept of more effective use of frequencies by sensor network aided cognitive radio is in accordance with this. The regulators will probably be, at least, in principle, positive. However, cognitive radio is a new item, also for regulators, leaving many issues open. At the present time it is too early to have definite statements on how the frequency regulators will react to detailed questions.

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 act as the "brain" in the communication network controlling the 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 bitrates 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.

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 later. Entries in the tables are changed and new entries are added regularly as new results are achieved in the project.

8 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.

APPENDIX 1: WORKING ASSUMPTIONS AND PARAMETER VALUES

NB! 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.
Entries in the tables are changed and new entries are added as new results are achieved in the project. Hence, the tables given here only represent a snapshot at the time of writing.
Assumptions and parameters that are crucial to the system concept are given in chapter 6 "System requirements and constraints".

Table 1: SENSOR NETWORK RELATED PARAMETERS

Parameter name	Description	Value	Justification/motivation	Proposer (WP)	WPs using the parameter	History	Comments
Pd	An individual sensor's minimum probability for detecting a primary user	0.95	Initial assumption.	WP2	WP3	20.06.08: Initial value (WP2)	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 v3.0 chapter 6).
Pf	An individual sensor's maximum probability of false alarm	0.05	Initial assumption.	WP2	WP3	20.06.08: Initial value (WP2)	Expects more realistic values later in the project
Primary system channel model	The channel model with corresponding propagation parameters for each primary system	SCME (3GPP Spatial Channel Model Extended)[Baum]		WP3	WP3, WP4, WP5	26.06.08: Initial value (WP3)	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	26.06.08: Initial value (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	Apriori probabilities of the primary users being present	Will be specified for each type of primary system later in the study		WP3	WP3, WP4		

[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.

Table 2: SENSOR NETWORK RELATED ASSUMPTIONS

Assumption name	Assumption	Justification/motivation	Proposer (WP)	WPs using the assumption	History	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	20.06.08: Initial assumptions (WP2)	There are a lot of challenges in connection with detection of and co-existence with other cognitive radio systems in the same area. Since SENDORA will probably not be able to study these issues, it is better to focus only on 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	20.06.08: Initial assumptions (WP2)	
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	20.06.08: Initial assumptions (WP2)	The project will assess which waveform that 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.		WP2	WP4, WP5	20.06.08: Initial assumptions (WP2)	This do not preclude that the sensor network communicates at much higher bitrates 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 sensor 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 that may be potentially brought to standardization
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.			WP3, 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 will jointly assess the required sensor communication capacity and QoS requirements later in the project.			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. This link will not be considered in the study.		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.		WP3 WP2	WP4		

Table 3: PRIMARY SYSTEM RELATED PARAMETERS AND ASSUMPTIONS

Parameter name	Description	Value	Justification/motivation	Proposer (WP)	WPs using the parameter	History	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	20.06.08: Initial value (WP2)	
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)

Table 4: COMMUNICATION NETWORK RELATED PARAMETERS							
Parameter name	Description	Value	Justification/motivation	Proposer (WP)	WPs using the parameter	History	Comments
Nusers	Number of users that must be served simultaneously by a base station	10	**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. **b.** In the ad hoc parts of the network, 10 simultaneous users should be supported.	WP2	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. Studies planned in WP3 and WP4 will 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).		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	History	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 a OFDM based waveform	Coherence with demo	WP2	WP5, WP6, WP7	20.06.08: Initial assumptions (WP2)	
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 will be considered in the scope of WP44 task