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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 presents the background, assumptions and results of a study of three business case scenarios based on the SENDORA concept. The calculations in each business case are done from the perspective of a particular actor in the ecosystem.

SENDORA is an innovative concept and much research and development remains before commercial applications will appear. Therefore the input data to the SENDORA business cases are still uncertain and the results from the business case calculations can only give indications, not yet definite answer or strong conclusions. But the main value of the business case calculations has been to identify critical aspects for SENDORA profitability, so that future technical R&D work can focus on them.

Chapter 1 of this report describes the SENDORA concept and the role of the techno-economical studies and the interaction of these studies with the other activities in the SENDORA project. In addition economical terms and concept used in the business case analyses are defined.

Chapter 2 presents ecosystem considerations for the SENDORA system. This includes a presentation of the different roles that can be foreseen in the ecosystem for the sensor network aided cognitive radio in the chosen scenario and the motivation different actors have for being a part of this ecosystem. Finally, some examples of SENDORA ecosystems are given.

Chapter 3 presents the business case evaluations. A traditional cash flow analysis is used to get an indication of the profitability in each case. Due to large uncertainties in the input parameters, the cash flow analyses are enhanced with sensitivity analysis. The sensitivity analyses focus on aspects of the business cases which relates directly to the SENDORA concept.

The first business case considers a scenario where cognitive radio is used for spectrum sharing. The spectrum owners form a joint venture company, which is a cognitive radio operator that offers a nomadic broadband service using “unused” parts of the owners’ spectrum. The business case calculations are done from the perspective of the joint venture company.

The results of the cash flow analysis indicate that it might be possible to make profitable (long term) business by using the SENDORA concept in this business case scenario. The accumulated cash flow and the associated economical results are quite similar to many other telecommunication infrastructure projects. That means that it will be tough and a long-term business case, where the operator (joint venture) must be patient and have financial strength (long term financing) to wait a longer period for the return on investment.

The sensitivity analysis shows that the most critical SENDORA related aspects influencing the profitability are the required fixed sensor density and the fixed sensor operational costs. Sensitivity analysis with respect to the subscription fee shows that the business case is very sensitive to the subscription fee, and that a change of only a few percent from the assumed value has great impact on the economical results.

The second business case considers a broker that builds and operates a spectrum sensing network to detect vacant time/frequency slots in an area. This information is then given or sold to cognitive radio operators. The goal of this business case is to estimate what revenues this broker must get in order to cover its expenses. The revenues can be public money, fees from the cognitive radio operators or a combination of both. The required revenues were then used as an input parameter to the third business case.

The third business case considers a new entrant, without any existing infrastructure in the area, that wants to build and operate a cognitive radio network to provide a nomadic wireless broadband service. The new entrant gets, either for free or for a fee, information about vacant time/frequency slots from the broker considered in business case two. The analysis indicates that it might be difficult for the new entrant to get a positive business case unless he gets access to the spectrum for free. If the new entrant has to pay the broker what is needed for

covering the expenses, the business case gets strongly negative even when these expenses is shared with three other cognitive operators also using information from the broker.

It is too early to give a definite answer about the profitability of different SENDORA business cases. The main value of the business case calculations is the identification of the critical aspects for SENDORA profitability. The most critical aspects seem to be the costs for building and operating the fixed sensor network. The costs for building the fixed sensor network is strongly dependent on the regulatory requirements and should be taken into consideration when these are decided.

CONTENTS

DOCUMENT VERSIONS

Version	Date	Description, modifications
0.1	04/02/2010	First version, table of content and keywords
1.0	13/07/2010	Complete version including three business cases description, analysis, and conclusions on tech-no-economical study

1 INTRODUCTION

This report presents the background, assumptions and results for a study of three business case scenarios based on the SENDORA concept. The calculations in each business case are done from the perspective of a particular actor in the ecosystem.

1.1 SUMMARY OF THE SENDORA SYSTEM

SENDORA is a Sensor Network aided Cognitive Radio technology that utilizes wireless sensor networks to support the coexistence of licensed and unlicensed wireless users in an area. The general scenario of the Sensor Network aided Cognitive Radio is depicted in Figure 1. 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 spectrum 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 interference to the licensed network, called the primary network.

The sensor network aided approach will significantly improve the system's ability to detect primary users compared to other cognitive radio solutions. The sensor network will consist of a network of fixed sensors and/or sensing capabilities embedded in user terminals. The external sensor network makes it possible to guarantee that primary users will be detected with a specified 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 sensor network can also be used to measure the interference generated by the cognitive radio system. This can be used to accurately control the interference generated to ensure both protection of the primary system(s) and optimum use of the spectrum holes.

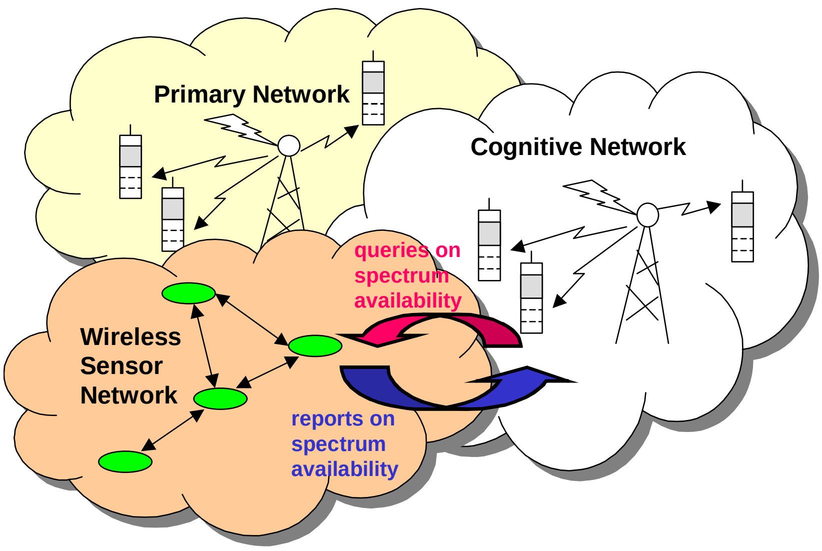

Figure 1 General SENDORA scenario

The SENDORA system architecture consists of three parts: the sensing architecture, the communication architecture and the fusion centre. The sensing architecture and communication architecture are connected together logically by the 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.

The target scenario for SENDORA systems is for providing a wireless broadband service in urban and suburban areas. The systems 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.

Figure 2 shows the SENDORA system architecture. The terminals 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.

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.

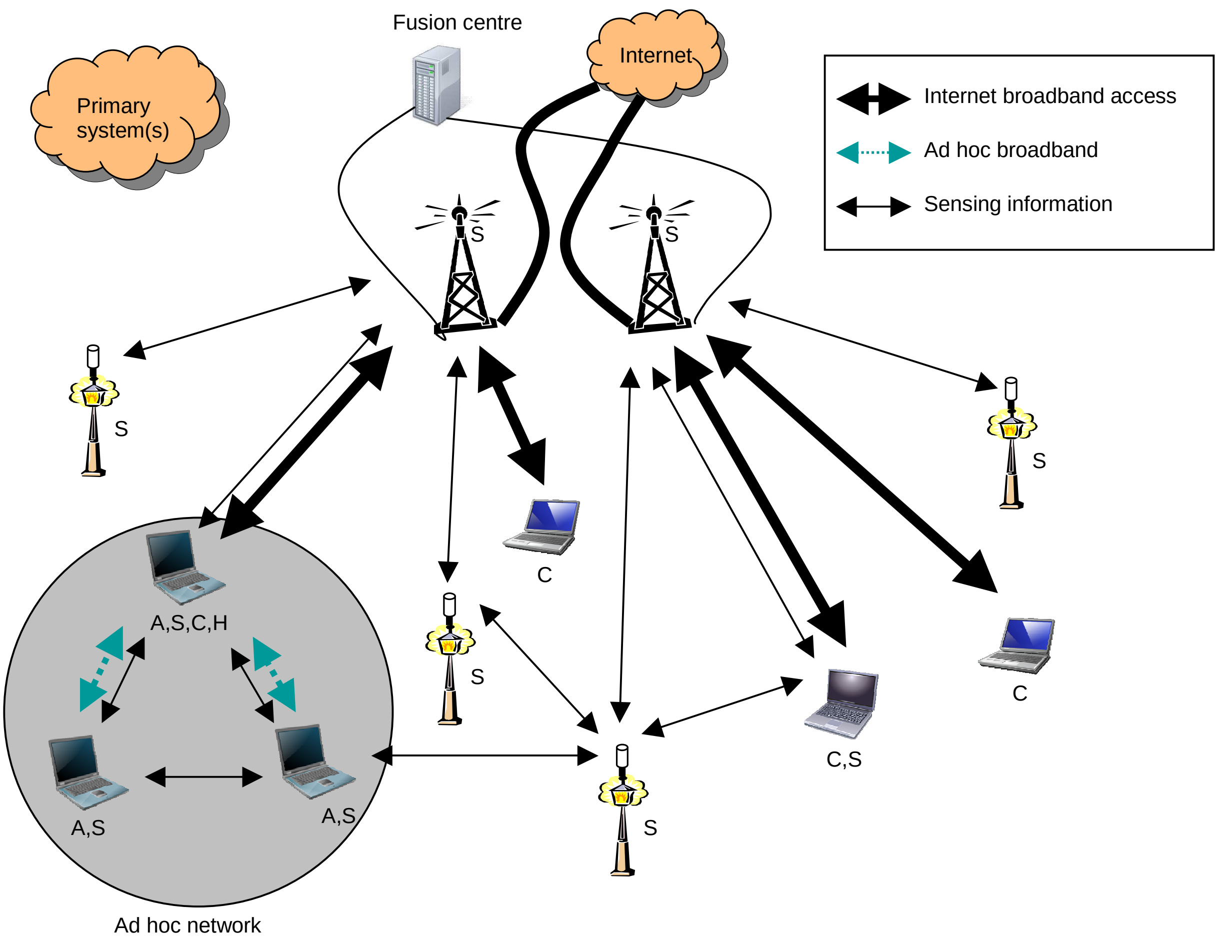

Figure 2 SENDORA system architecture.

1.2 IMPLEMENTATION OF THE TECHNO-ECONOMICAL STUDY IN SENDORA

The SENDORA project implementation follows a system design approach (depicted on Figure 3) that includes a techno-economical study in order to provide valuable outcomes on the interest and applicability of the designed system. While system simulations and demonstrations allow to prove the project concept, and while advanced studies are provided for each of the enabling techniques, techno-economical studies interact with these technical aspects by building business cases and by providing feedback to the technical studies by identifying the parts to take care about in priority.

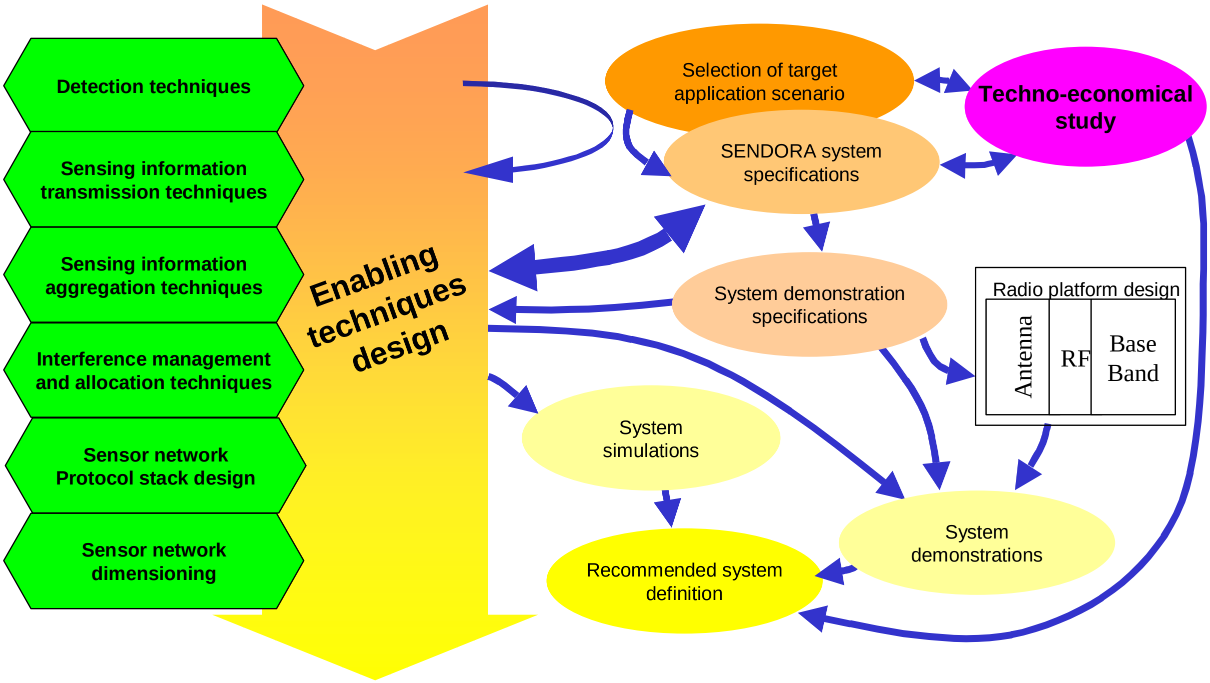

Figure 3: SENDORA implementation scheme

SENDORA partners presented techno-economical study results during a SENDORA special session at Crowncom 2010 conference on Cognitive Radio related topics and received many positive feedbacks, which can be understood by the fact that many studies are currently on-going on cognitive radio and dynamic spectrum allocation topics, but they are rarely linked to a techno-economical study but rather focused only on technical aspects. Moreover, cognitive radio has been a key word for a few years now, it is time now to converge to more concrete cases and practical issues, this is an objective when dealing with such techno-economical studies.

This report presents the methods, assumptions and results of the SENDORA business case studies. This study was launched in 2009 and preliminary results were provided in D2.1. This document reports the refinement of the proposed business case as well as the proposal of new business cases. The SENDORA approach provides a means to identify communications opportunities (that would not be used without such a system), and this extra capacity can be used through different strategies by the operator. Moreover, the WSN-aided Cognitive Radio approach is based on a WSN for spectrum measurement that would probably be of interest for other applications and therefore be shared with other actors.

1.3 BUSINESS CASE ANALYSIS AND ECOSYSTEM EVALUATIONS

SENDORA is an innovative concept and much research and development remains before commercial applications will appear. Therefore the input data to the SENDORA business cases is uncertain and the results from the business case calculations can only give indications, not yet definite answer or strong conclusions. The main value of SENDORA business case calculations is to identify the critical aspects for SENDORA profitability, so that the technical R&D work can focus on them.

The traditional cash flow analysis will be used to get an indication of the profitability. The cash flow means income (revenues) subtracted by cost (investments and operational costs) for a given time period. Due to large uncertainties the cash flow analysis must be enhanced with sensitivity analysis. Sensitivity analysis is done by changing the value of one (critical) input parameter and showing how the economical results are changing.

Several economical concepts are used in the business case analyses in this document. These are summarised below:

ARPU (Average Revenue Per User)

CAPEX (Capital expenditures)
Expenditures associated with the implementation or extension of fixed assets. There is a residual value associated to these expenses. **Investment** is often used as an identical term to CAPEX.

OPEX (Operational expenditures)
OPEX is defined as expenditures necessary for running the business or the equipment, indispensable to keep the services active and running. Once made, these expenses have no residual value.

EBITDA (Earnings before interests, taxes, depreciation and amortization)
EBITDA = Revenues – OPEX. This measure is often used to estimate the operational efficiency..

NPV (Net present value)
NPV is the sum of a series of cash flows (revenues subtracted by costs), when discounted to the present value:

$$NPV = \sum_{t=1}^{n} \frac{A_t}{(1+p)^t}$$

where p is the annual discount rate, A_t the payment in year t and n the lifetime of the project. NPV is the most important criteria when defining the profitability of the project.

Discount rate
Discount rate is the rate used for discounting amounts to other points in time as in the calculation of NPV. It reflects the inflation and the fact that the estimated amounts in the future carry significant uncertainty. Typical values of discount rate are around 10%.

IRR (Internal rate of return)
IRR is the discount rate, that gives NPV = 0. The higher the IRR is, the better the project is. Assuming all other factors are equal among various projects, the project with the highest IRR would probably be considered the best.

Payback period
Payback period is the amounts of years that it takes to have the accumulated revenues equal the accumulated costs (CAPEX and OPEX).

These concepts are not necessarily always unambiguous: there can be slight variations and different interpretations. More information about economical terms can be found e.g. in [1].

2 SENDORA ECOSYSTEM

2.1 INTRODUCTION

This chapter presents ecosystem considerations for the SENDORA system, meaning the cognitive radio and related sensor networks. The chosen SENDORA scenario: "Nomadic broadband in urban and suburban areas" is the basis for these considerations.

The word "ecosystem" in this context means business modelling including the roles of the actors, relations (like partnership) between the actors, cost and revenue structures and money flows between the actors. Specific business cases can then be used to quantify the value of different ecosystem options.

The SENDORA is an innovative concept with a long term focus, and therefore the related ecosystem is unproven in real market conditions. There will be several actors (see section 2.3), that may not always have the same interests and expectations to the SENDORA concept. 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 and sometimes the only incentive, at least for the commercial actors (private companies) is simple the money i.e. the economical results for the company in the short and long term.

The SENDORA ecosystem will include mostly actors, which have economical profit as their main motivation, but it can also include actors like regulators, which can have other motives, like welfare of the society as a whole, fairness, wish to increase competition in the telecommunication, etc.

To create a functional SENDORA ecosystem will be a challenging task with many uncertain aspects.

2.2 SENDORA ECOSYSTEM ROLES

SENDORA ecosystem will include both traditional roles in the communication business and some new roles specific only for the SENDORA ecosystem. At least the following roles can be foreseen in the ecosystem for the sensor network aided cognitive radio in the chosen scenario:

1. End user of the communication applications
2. Owner of the licence for the radio spectrum
    - Existing mobile and/or fixed telecommunication operators
    - TV broadcasters
    - Public authorities (police, health care, aviation, etc)
    - Military organisations
3. Cognitive radio operator that will utilize a radio spectrum licensed to others
    - As in point 2 above
    - New operators
4. Regulatory body
5. Spectrum broker
    - Regulatory body
    - Owner of the licence for the radio spectrum
    - Independent third party
6. Owner of the sensor network
7. Hardware and software vendor
    - Cognitive radio elements
    - Sensor network elements
8. System integrator

There is a clear difference between "roles" and "actors" in the ecosystem. One specific real actor (company) can have several roles in the SENDORA ecosystem. Example is an existing mobile operator, which can simultaneously be a spectrum owner, cognitive radio operator, owner of the sensor network and even spectrum broker.

2.3 SENDORA ECOSYSTEM ACTORS

The different actors in the future SENDORA ecosystem will have varied motivations why they will be part of this ecosystem. Below follows preliminary discussion, what could be the motivations of different actors ?

2.3.1 End users of (telecommunication) services

In principle, the normal end user (person) does not care about technology. What matters to him/her is the price and quality of the services provided. The cognitive radio or SENDORA system is mostly invisible to the user and has only indirect influence to the user. It can make possible better and more affordable services through technology advancements and increased competition between service providers.

One special user group in the SENDORA ecosystem could be technologically advanced users, that could remove the need for a network operator by having own ad-hoc networks with the SENDORA concept to provide nomadic broadband for a limited user group. This requires advanced technical skills and also coordination (regarding terminals, software etc) between the users.

2.3.2 Existing (mobile) operators

Mobile operators can have many roles (spectrum owner, cognitive radio operator, broker, owner of the sensor network) in the SENDORA ecosystem. They can have defensive motives (e.g. to hinder that cognitive operation disturbs their primary operation, to protect their valuable assets in spectrum licences), but they can also have offensive motives (e.g. earning money on SENDORA spectrum trading, improving their own operation by SENDORA system, being themselves cognitive radio operators in new areas).

2.3.3 TV broadcasters

TV broadcasters are important spectrum owners, and they will avoid that the new systems disturb their TV distribution. As for other spectrum owners, SENDORA spectrum trading is an earning opportunity for the TV broadcasters.

2.3.4 Public authorities

Public authorities (police, fire brigades, health care, aviation, military) are on the other hand spectrum owners, but they could also be cognitive radio operators. For them one important application could be a high quality ad-hoc networks during large accidents or military actions

2.3.5 New operators

Cognitive radio operation is one possibility for new operators to enter the market. In the mobile business until now the ownership of the spectrum license has been crucial and expensive part of the business model. The potential new operators are clearly interested in getting a reasonable priced access to spectrum by the SENDORA system.

2.3.6 Regulatory body

Regulatory bodies have interest to all technologies that can improve the utilisation of the radio spectrum. The spectrum relevant for telecommunication purposes is a limited and therefore expensive resource. The opportunistic use of radio spectrum is not yet scheduled in Europe (it has been allowed in TV white spaces by FCC in the US), but it may be needed soon to open some bands to cognitive operation considering the future need for bandwidth. Today's approach consists in dividing the spectrum into small pieces, each for a specific purpose and the applications use their spectrum to a limited extent, which leads to the unwanted situation of under-utilization of this scarce resource. Regulation authorities recognise that this approach is reaching its limits.

One of the key issues for the regulation is how to control interference among systems. In the SENDORA ecosystem, the regulation may be provided interference measurement means thanks to the WSN approach. The regulator could own itself the WSN capacity.

2.3.7 Vendor

Vendors are also a key actor in the ecosystem. Base stations and terminals require some new capabilities to allow cognitive radio operation, and especially WSN-aided cognitive radio operation. In particular, hardware platforms shall be flexible enough to support communications in several frequency bands (corresponding constraints and solutions will be addressed in D4.4), they will be based on a Software Radio approach. In the ecosystem, the complete platform sent by the integrator shall allow him to sell a sufficient quantity of stations/terminals with enough margins.

2.4 EXAMPLES OF SENDORA ECOSYSTEMS

SENDORA ecosystems can have different grade of complexity. The simplest SENDORA "ecosystem" is the case where one actor (e.g. a mobile operator with a variety of spectrum resources) will use cognitive radio for better utilization of its own spectrum to provide new services. An extension of this is the "spectrum sharing" case (see section 3.2), where spectrum owners form a joint venture that gets rights to use the "unused" spectrum of all those spectrum owners in a cognitive way. Minimal coordination and interaction with other actors is needed for these ecosystems.

The more complete SENDORA ecosystem can include spectrum trading between the spectrum owners and the new cognitive operators. This trading can be replaced by regulatory decisions to regulate the access to the spectrum. One possible important new role in this kind of ecosystem will be the broker role, often a regulatory body or an independent third party, that will ensure fairness in the interactions. This kind of ecosystem is more complicated to create, because it may require coordination, trust and interaction between several actors, which even may have conflicting motivations for participating. Detailed rules governing the cognitive radio operations have to be developed. The broker (see section 3.3) and new entrant (see section 3.4) cases are the first attempts to analyze these aspects.

3 BUSINESS CASE EVALUATIONS

3.1 INTRODUCTION

Three business cases are studied. In each case the business case calculations are done from the perspective of a specific actor in the ecosystem. However, it is important to remember that that in order for a business case scenario to be viable, all commercial actors in the ecosystem must have a positive business case.

The first business case considers a scenario where cognitive radio is used for spectrum sharing. The spectrum owners form a joint venture company, which is a cognitive radio operator that offers a nomadic broadband service using "unused" parts of the owners' spectrum. The business case calculations are done from the perspective of the joint venture company.

The second business case considers a broker that builds and operates a spectrum sensing network to detect vacant time/frequency slots in an area. This information is then given or sold to cognitive radio operators in the area. The goal of this business case is to estimate what revenues this broker must get in order to cover its expenses. The revenues can be public money, fees from the cognitive radio operators or a combination of these.

The third business case considers a new entrant, without any existing infrastructure in the area, that wants to build and operate a cognitive radio network to provide a nomadic wireless broadband service. The new entrant will get, either for free or for a fee, information about vacant time/frequency slots from the broker considered in business case two. The business case calculations are done from the perspective of the new entrant.

3.2 BUSINESS CASE 1: SPECTRUM SHARING

3.2.1 Business case scenario description and motivation

The main idea behind this business case is that several spectrum owners establish a **joint venture** and this joint venture gets the rights to use the "unused" spectrum resources of all those spectrum owners in a cognitive way based on the SENDORA concept.

The joint venture will build a fixed sensor network and will provide a **cognitive nomadic broadband service** in the "unused" spectrum. The business case is calculated from the point of view of this joint venture i.e. the mother companies establish the joint venture and hope to get the invested money back by receiving dividends from the joint venture. The success criterion could be for example that the pay-back period (time, when accumulated cash flow turns positive) is less than five years.

The spectrum owners can be of different types, for example companies having bought spectrum just as an investment, cellular operators and broadcast operators. However, it is assumed that at least one of the spectrum owners is a cellular operator having an infrastructure, including backhaul and base station, in the area. Then the joint venture can reuse this infrastructure by leasing cognitive radio access functionality and backhaul capacity from the cellular operator.

Due to the close connection between the joint venture and the owners of the spectrum used, it can be expected that the maximum levels of interference accepted by the spectrum owners can be somewhat relaxed compared to the case where the spectrum owners do not get any economical benefits for the secondary use of their spectrum.

The joint venture represents a practical way of dividing the incomes and expenses of the cognitive radio network between the spectrum owners. The composition of the joint venture is very important and should ensure both that the cognitive radio network get access to sufficient spectrum resources and that there are little need to build new infrastructure (e.g. base station sites).

From a strategic point of view spectrum sharing is not much used today. However, it can be seen as a natural extension of infrastructure sharing, which used to be limited to sharing of non-electronic infrastructure (e.g.

antenna mast) but has now been extended to sharing of electronic infrastructure. Sharing important network elements like base stations was almost unthinkable from a strategic point of view only a few years ago but is now becoming increasingly popular.

From a regulatory point of view, this business case is probably one of the easiest to implement since the joint venture operator uses only the owning companies' spectrum. Hence, the main regulation of acceptable interference can be done among the joint venture owners and little coordination is required with external spectrum owners. If technology neutral regulations applies to for the frequencies used by the joint venture operator, there should be no or little need for coordination and for getting permissions from the regulator.

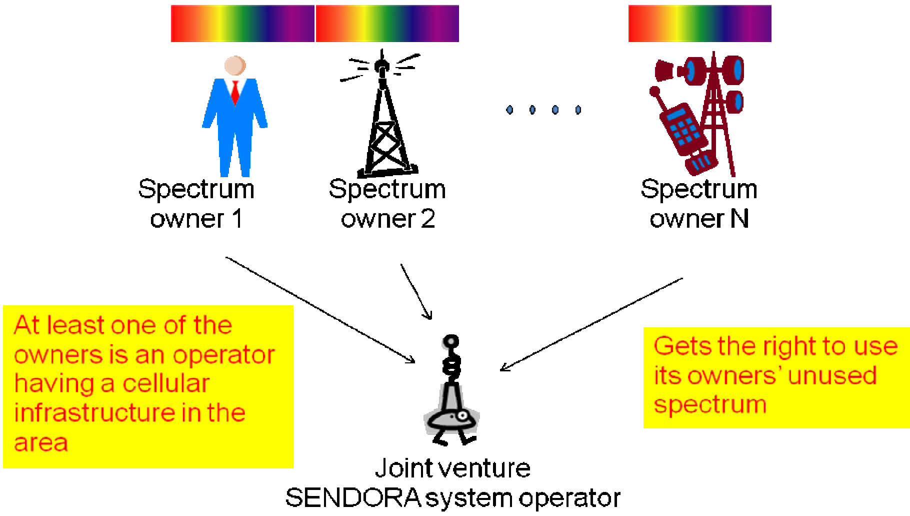

Figure 4 A number of spectrum owners form a joint venture operator that gets the rights to use the "unused" spectrum resources of all those spectrum owners in a cognitive way based on the SENDORA concept

3.2.2 Input assumptions

3.2.2.1 General assumptions

The business case is calculated for a hypothetical western European city with 1 million inhabitants and with an area of 200 km^2. The city has a downtown area which covers 50 km^2. All calculations will be made for this city, but can with some effort be scaled up and down for larger and smaller cities.

The studied city is assumed to have a well developed telecommunication market. This means a high penetration of both mobile (voice, data and broadband) and fixed telecommunication services and also TV services. A working competition environment with several network owners and service providers is assumed.

The commercial realization of SENDORA technologies lies some years ahead. To allow for this, the study period is assumed to be from 2015 to 2020. This adds some more challenges to the study, since the technological developments and other development related to the telecom industry in the years from now (2010) to 2015 must be anticipated.

A traditional cash flow analysis will be used to get an indication of the profitability. The discount rate used in the calculations is 10%. Due to large uncertainties the cash flow analysis must be enhanced with sensitivity analysis.

The basis for this business case calculation is the SENDORA target scenario description given in deliverable D2.1:

- **Service provided:** Nomadic broadband in urban and suburban areas

- Mostly non-real time services (best effort)

- **Sensing architecture:** Both an externally deployed network of fixed sensors and embedded sensing capability in the terminals (integrated sensors).

- **Communication architecture:** 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. This study will only consider the centralized part of the architecture, i.e. communication via base stations. There may be local ad hoc networks, but these are assumed to not affect the business case.

The deployment of the cognitive radio network in the city will be done in three stages. The network for the downtown area (50 km^2) will be deployed in 2015. The network in the suburban area will be deployed in 2016 (75 km^2) and 2017 (75 km^2).

3.2.2.2 Revenues

REVENUES FROM SUBSCRIPTIONS

To estimate the subscription fee that can be charged for the SENDORA service, we will compare to the corresponding fee for mobile broadband services. The main use of both the SENDORA service and the mobile broadband service will be for providing Internet connectivity for different types of terminals. However, the SENDORA service will have inferior QoS support and do not support mobility. On the other hand, the SENDORA service can offer higher peak capacities when sufficient spectrum is available and better coverage (including indoor coverage) since it can use a larger range of frequencies. But all in all, the SENDORA service is clearly a somewhat lower grade service than mobile broadband, and hence its subscription rates should also be somewhat lower.

To find what a typical mobile broadband subscription rate could be, a simple survey of prices offered was done in June 2010. Table 1 gives the results of the survey. The minimum and maximum subscription rates are 23.90 and 38.00 € / month respectively. The average rate is 31.9 € / month.

Operator	Country	Subscription rate	Data allowance
Vodafone	UK	£25 / month (29.90€ / month)	5 GB/month
T-Mobile	Germany	34,99 € / month	Unlimited, but reduced capacity when exceeding 5GB/month
Telenor	Norway	299 NOK / month (38€ / month)	Unlimited, but reduced capacity when exceeding 5GB/month
Telia	Sweden	229 SEK / month (23.90€ / month)	10 GB/month
SFR	France	32.90€ /month	Unlimited, but reduced capacity when exceeding 500 MB/month

Table 1 Examples of subscription rates for mobile broadband services in June 2010

We will assume that there is a moderate yearly reduction of the subscription fee. This reflects the trend that the operators often choose to increase the performance parameters (e.g. the throughput and data allowance) and keep the fees fixed, however some reduction should still be expected due to the competition. We will assume an average yearly reduction of the subscription fees of 2%. We thus expect the average mobile broadband subscription fee to be about 28.7€ in 2015.

To determine exactly how much lower the subscription rate for the SENDORA service will be, is of course very difficult. Hence any estimate will be very uncertain. We have chosen to assume a subscription rate for the SENDORA service of 20 € / month in 2015. This is about 30% lower than the expected average mobile broadband subscription fee.

In reality there are important dependencies, like price elasticity between the mobile/nomadic broadband services from the other operators and the nomadic broadband services from the joint venture (i.e. if one operator increase its tariffs, it will get less users because of competition). These aspects are complicated and not taken into account in the business case calculations.

As the model for the number of customers we will assume that the joint venture has 10,000 subscribers in 2010 (end of the year) and 100,000 subscribers in 2020. Since we assume that the city has 1 million inhabitants, this corresponds to assuming that 10% of the city's population are subscribers of the joint venture operator in 2020.

In the business case it will be assumed that the number of subscribers as a function of time will follow an S-curve often referred to as a generalized logistic curve or Richard's curve [2]. The number of subscribers at the end of each year in the study period is given in Table 2.

Year	2015	2016	2017	2018	2019	2020
Number of subscribers	10 000	25 785	40 894	59 951	80 654	100 000

Table 2 Number of subscribers at the end of each year in the study period 2015-2020

REVENUES FROM SELLING SENSOR INFORMATION

The joint venture can also get some income from selling sensor information to e.g. other companies, the regulator or public authorities. Some examples of data that can be sold are:

- Electromagnetic field strength measurements to monitor the exposure people in the area experience to such radiation.
- Measurements of pollution level, e.g. to detect illegal emissions from factories in the area
- Weather data (temperature, air pressure, wind speed, precipitation, etc.)
- Spectrum holes (not utilized by the joint venture)

The addition of such measurement capabilities can increase the price of the sensors.

We will not assume any income from selling sensor information in our business case.

3.2.2.3 Sensor network related assumptions

The sensor network related assumptions consists of the costs related to purchasing and operating the fixed sensor network and the fusion centre, and the possible costs for subsidizing user terminals with sensing capabilities.

To calculate the CAPEX and OPEX for the fixed sensor network, it is necessary to know the number of sensors needed or equivalently the required fixed sensor density.

REQUIRED FIXED SENSOR DENSITY

One of the most important parameters for SENDORA systems is the required fixed sensor density. This parameter again depends on other parameters, like what sensing technology is used, what primary system(s) that must be detected and the regulatory requirements.

The fixed sensor density used in the business cases is based on results obtained in Work Package 6. There a case study with LTE as the primary system was performed. The parameter input set for the study is given in Table 3.

Two input parameter sets are considered since the exact value of many of the input parameters is not known. The strict parameter set includes parameters that make sensing more challenging, while the loose parameter set relaxes some physical constraints and requirements.

Case Study	**LTE Strict**	**LTE Loose**
Channel Model Parameters		
Path-loss exponent	4	3.5
Total AWGN power on the sensed band	-96dBm	-100dBm
Lognormal zero-mean shadowing	5dB	5dB

Primary System Parameters		
Signal Bandwidth	5MHz	5MHz
Signal Power	24dBm	24dBm
Maximum probability of interference	10^{-6}	10^{-3}
Interference radius	400 meter	300 meter
Design Parameters		
Sensing Bandwidth Unit	200kHz	200kHz
Sampling Frequency	400kHz	400kHz

Table 3: Parameter input set for the LTE Case study

The following measures are defined:

- **Cognitive capacity**: is the portion of narrow band bandwidth one cognitive user receives. For example, a cognitive capacity of 50% means 100kHz bandwidth per cognitive user.
- **Probability of interference**: the probability that a channel used by the primary system is miss-detected and allocated for a cognitive user.

Furthermore, the following description of the networking environment applies:

- Primary system load is characterized by the probability that a channel is used.
- All sensors sense the same set of channels.
- Channel allocation in the secondary system is modelled by the fair sharing of channels that are detected free.
- Interference control is characterized by the interference radius, which is the minimum distance of primary and secondary transmitters, such as no primary receiver experiences interference, assuming fixed transmission power at both the primary and the secondary transmitters. Interference happens if a secondary transmitter within this radius transmits on the channel that is used by the primary system.

The fixed sensors density required depends on the density of user terminals. As the density of user terminals increase, they will provide more sensing information through their integrated sensing capability. But since the capacity demand also increases with increasing user terminal density, more accurate sensing data is required. The obtained results for the strict and loose LTE scenarios are given in Table 4 and Table 5 respectively.

Secondary User Density [users/km^2]	Fixed sensor density [sensors/ km^2]
10	120
25	122
50	90
75	75
100	125
150	170
200	220
300	450

Table 4: Required fixed sensor density for different cognitive user densities for the LTE strict case. The primary system load is 10% and the cognitive capacity is 10%. All user terminals have sensing capability.

Secondary User Density [users/km^2]	Fixed sensor density [sensors/ km^2]
5	10.5
10	8
15	5
25	4.5
30	4
35	1
40	6

50	25
100	52

Table 5: Required fixed sensor density for different cognitive user densities for the LTE loose case. The primary system load is 10% and the cognitive capacity is 55%. All user terminals have sensing capability.

To optimize the business case the number of sensor sites should be minimized. As can be seen from Table 4 and Table 5, the minimum number of fixed sensors occurs when the cognitive user density is about 75 and 35 users/km^2 respectively.

In order to minimize the required fixed sensor density, the users can be divided into groups using different and disjoint sets of frequencies. The number of users in each group should be optimized such that the number of fixed sensor sites is minimized. For example, using the strict LTE results, if the number of users is 300 they can be divided into 4 groups each having 75 users. Each group use a different set of frequencies, so they can be seen as 4 independent groups operating in parallel. Hence, from Table 4 it can be seen that it is sufficient to have 75 fixed sensor sites. However, at each site there must be sufficient sensing capacity to cover all 4 sets of frequencies.

Figure 5 shows the minimum density of fixed sensor sites as a function of the secondary user density for a targeted cognitive capacity of 10% for the strict LTE case. The relationship between user density and fixed sensor density has been calculated from Table 4 by using linear interpolation. The corresponding curve for the loose LTE case is shown in Figure 6.

As can be seen from Figure 5, the required fixed sensor density for the strict LTE case is highest when the secondary user density is low. At each multiple of 75 users/km^2, the required fixed sensor density takes its minimum value of 75 sensors/km^2. In between these multiples, the fixed sensor density has local maxima which become lower as the secondary user density increases.

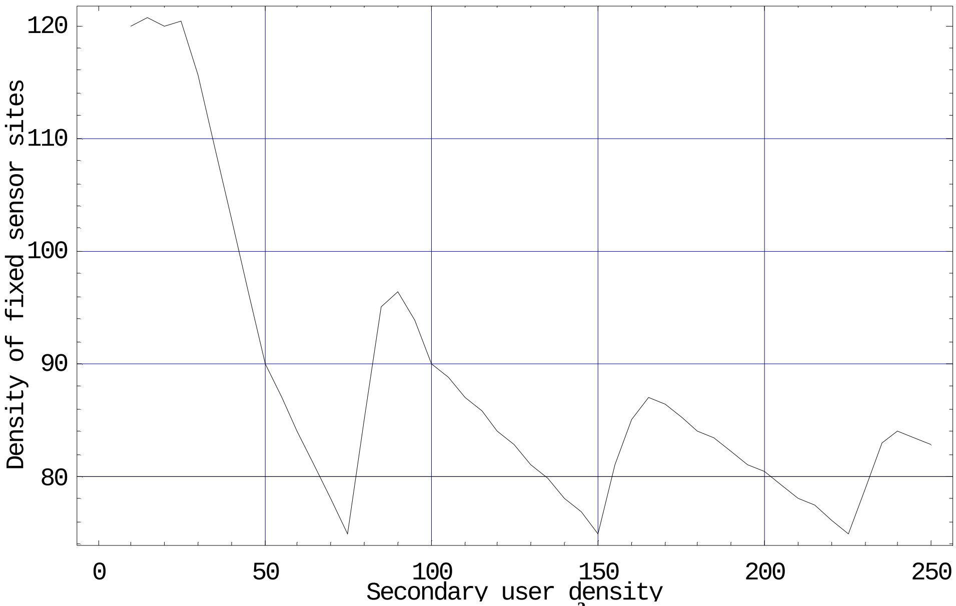

Figure 5 Required fixed sensor density (sensors/km^2) as a function of secondary user density (users/km^2) for the strict LTE case.

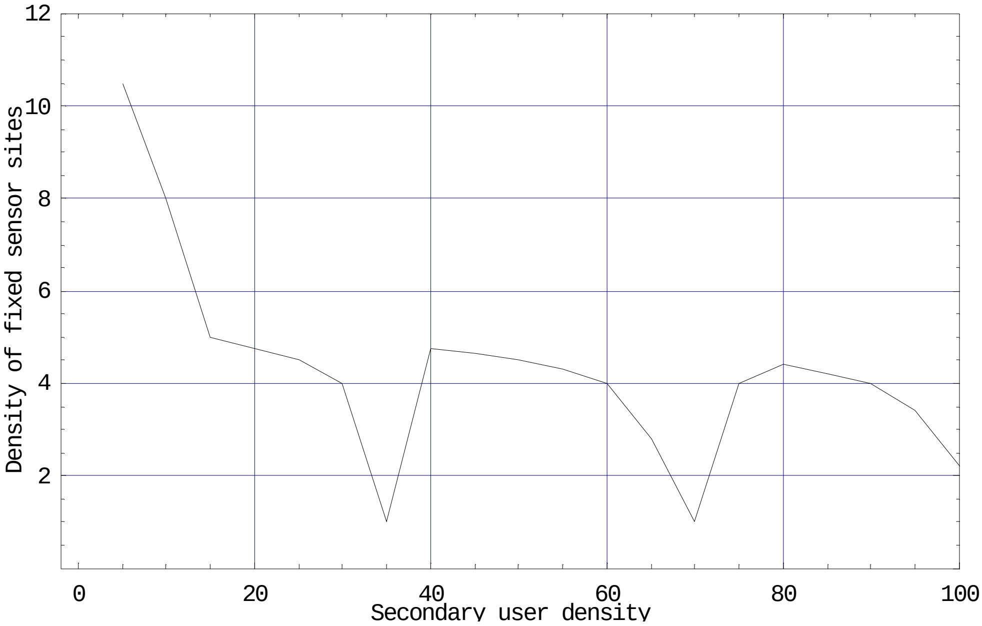

Figure 6 Required fixed sensor density (sensors/km^2) as a function of secondary user density (users/km^2) for the loose LTE case.

The number of cognitive terminals in an area varies randomly. The number shows both short term variations from one minute to the next as users enter and leave the area, medium term variations from high values during peak hours to low values during silent periods and long term variations from low values right after the network has been deployed to higher numbers as the operator gets more customers. The dimensioning of the fixed sensor network must be done in such a way that the primary systems are given the required protection at all times. Hence, generally it is the maximum values shown in Figure 5 and Figure 6 that should be considered.

The difference between the required fixed sensor density for the strict LTE and loose LTE case is very large, which is partly due to the very different maximum interference probability requirements (10^{-6} versus 10^{-3}). These requirements can be specified by the regulator or the cognitive operator can make an agreement on this depending on the situation. Since the probability of interference requirements probably will be set in an agreement between the owners of the joint venture, it should be expected that these requirements will be somewhat lower in this case than when the regulator specifies the requirements. Hence the required number of fixed sensors is expected to be somewhere between the maximum values shown in Figure 5 and Figure 6 (i.e. 120 and 10.5 sensors/km^2). We will use 65 sensors/km^2 in this business case, which represents the mean of the values for the strict LTE and loose LTE cases.

Further details on the LTE study can be found in the coming deliverable D6.3. At the time of writing the studies on required fixed sensor densities are not completely finished. Hence, it is possible that later studies with other primary systems than LTE and with other spectrum sensing algorithms can give results that deviates from that assumed here.

FIXED SENSOR NETWORK ROLL-OUT

It is assumed that the fixed sensor network will be rolled out in three stages. In the first stage taking place in 2015, it will be rolled out in the downtown area. Then the fixed sensors will be deployed in the suburban areas of the city in two stages, the first in 2016 and the second in 2017.

FIXED SENSOR PRICE

As an input from WP3 to this business case study, the complexity of a fixed sensor was estimated to be about the same as that of a Wi-Fi Access Point. In addition it must be taken into account that these sensors will be placed outdoors and must stand different types of weather conditions.

With these inputs a natural assumption is that the price of a fixed sensor will be about the same as the price of an outdoor Wi-Fi Access Point. This price is typical several hundred Euro today. Taking into account the technical development and price reduction expected from now until 2015, we will assume that the price of a fixed sensor is 300€ in 2015 decreasing to 177.1€ in 2020.

FIXED SENSOR INSTALLATION COSTS

The fixed sensor installation costs include truck roll, mounting the sensor, connect it to the mains and provide a wired or wireless connection.

All fixed sensors in an area should be mounted at the same time to minimize the truck roll expenses. We will assume that one man will mount a sensor in 1 hour on average including the time it takes to drive between the sensor sites, and that the hourly costs for him and the van is 50€ in 2015 decreasing to 45.2€ in 2020.

FIXED SENSOR OPERATIONAL COSTS

The fixed sensor operational costs cover sensor site rental, power consumption and maintenance.

It is important that the fixed sensors are robust with a very high mean time between failures. Most of the reconfiguration and adjustment of the sensors should be controlled through its wired or wireless sensor network connection. If a maintenance visit is required once every 3 years (36 months) on average and the cost of a maintenance visit is 50€, the average monthly costs would be 1.4€/month/sensor.

We assume that a fixed sensor consumes 10W at average, giving a monthly electricity consumption of 7.2 kWh. With a tariff of 0.30€/kWh, the monthly electricity costs is about 2.2 €/sensor/month.

The average fixed sensor site rental cost is more difficult to estimate. The sensors will be relatively small (size similar to an outdoor Wi-Fi access point). They will typically be placed where there is an easy access to the mains, for example at top of lamp posts. We estimate the average sensor site rental to be in the order of 10€/month/sensor.

Based on these considerations we assume that the total fixed sensor operational costs is 15 €/month/sensor in 2015 decreasing to 13.6€ in 2020.

FUSION CENTRE COSTS

The fusion centre costs consist of the purchasing, installation and operational costs. We assume that one fusion centre is sufficient and that this is located at the joint venture office so that the place rental, electricity costs and maintenance are included in the company's general operating costs.

The fusion centre will consist of a powerful computer with high communication capacity. We will assume that the price for the fusion centre is 150,000 € and that the installation costs are 10,000€.

SUBSIDIZATION OF USER TERMINALS

Having sensing capabilities in the terminals can reduce the need for fixed sensors. Hence, it can be a good idea for a SENDORA operator to subsidize user terminals with sensing capability to reduce costs for the fixed sensor network.

However, we will not consider such subsidies in the business case calculations.

3.2.2.4 Cognitive radio access related assumptions

The cognitive radio access related assumptions consists of the costs for installing and operating the cognitive radio base stations and for establishing new base stations sites.

NUMBER OF COGNITIVE BASE STATIONS

As specified in deliverable D2.1, the geographical density of base stations for SENDORA systems is assumed to be similar to that for mobile broadband networks. Hence, a SENDORA operator that can exploit the base stations sites of a mobile broadband operator as in the joint venture case can often get the required coverage and capacity without having to establish any new base station sites.

The number of cognitive base stations required in the targeted city is assumed to increase from 50 the first year to 450 after 5 years. These numbers are based on operator experience from deploying 3G cellular networks.

Year	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Number of cognitive base stations	50	175	250	350	400	450

Table 6 Number of cognitive base staiton deployed at the end of each year in the study period

As the base case it is assumed that the operator will get sufficient capacity and coverage by sharing infrastructure with the operators behind the joint venture, such that it is not necessary to establish new base station sites. Establishment of new base station sites will however be considered in the sensitivity analysis.

COSTS FOR INSTALLATION OF COGNITIVE FUNCTIONALITY IN BASE STATIONS

It is assumed that at least one of the owners of the joint venture is a cellular operator having an infrastructure of base stations and backhaul in the area. The joint venture operator can outsource the cognitive base station functionality to the cellular operator(s). The cellular operator can update his base stations, which by 2015 is based on software defined radio solutions.

It is assumed that the costs for updating/upgrading a base station with cognitive functionality is 5,000€ in 2015 decreasing to 2,953€ in 2020.

COST FOR ESTABLISHING NEW SITES

If updating/upgrading existing base station with cognitive functionality doesn’t give the required coverage and/or capacity, it will be necessary for the SENDORA operator to establish some new sites. The cost for establishing a site consists of costs for identifying and acquiring the site, for building the antennas and housing and for providing it with power and backhaul.

It will be assumed that the costs for establishing a new SENDORA base station site is comparable to that of establishing a new 3G cellular base station site. Based on operators’ experience we will estimate this cost to be 60,000€.

In the base case it is assumed that no new sites are required.

COSTS FOR COGNITIVE BASE STATION MAINTENANCE, BACKHAUL RENTAL AND SITE RENTAL

The costs associated with renting the base station site, renting backhaul capacity and for maintaining the base station is assumed to be 1,000€/month/site in 2015, decreasing to 904€/month/site in 2020.

GENERAL OPEX

This OPEX reflects the general efficiency of the joint venture and covers e.g. customer acquisition (sales and marketing) costs and general operation of the company. Its value is highly uncertain and difficult to benchmark due to different accounting principles in different companies and countries.. It is mostly independent of the SENDORA concept. The value used for general OPEX is 8€/subscriber/month in 2015 decreasing to 5.6€ in 2020.

3.2.3 Results

3.2.3.1 Base case

The business case calculation was first done with the assumptions given and explained in the previous sections. By combining costs (CAPEX and OPEX) with revenues the yearly cash flows and standard profitability indicators, like NPV (Net Present Value), IRR (Internal Rate of Return) and pay-back period, was calculated. For an explanation of these terms, see section 1.3.

It is important to emphasize that SENDORA is an innovative concept and much research remains before it becomes a mature technology. This means that many basic assumptions in the business case calculations will remain (very) uncertain for a long time. Hence, the results will not give definite answers but only indications to whether it is possible to make business utilizing the SENDORA concept.

Figure 7 shows the accumulated cash flow for the study period 2015 – 2020 with the assumptions given in the previous sections.

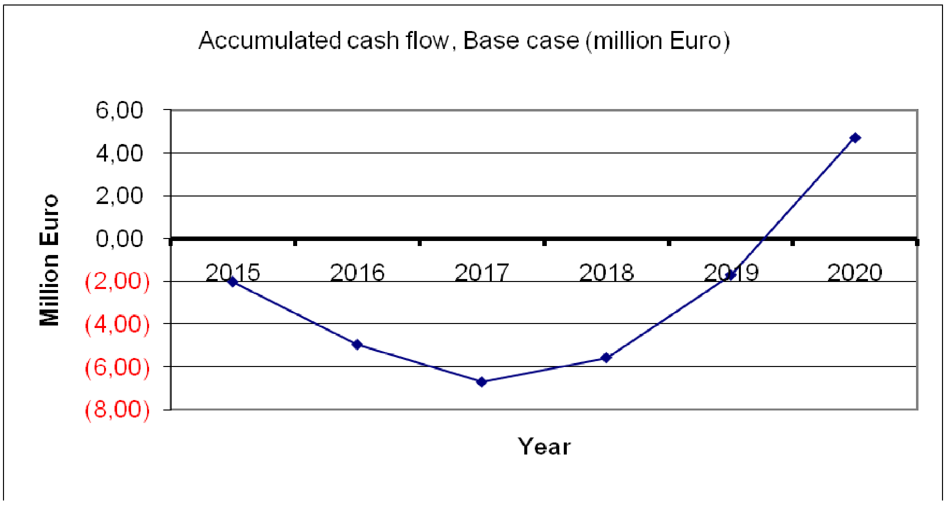

Figure 7 Accumulated cash flow for the “SPECTRUM SHARING“ business case

NPV for the study period 2015-2020 is 1,36 million Euro, IRR is 16 % and the pay-pack period is about 5 years.

The accumulated cash flow and the associated economical results are quite similar to many others telecommunication infrastructure projects. That means that it will be tough and a long-term business case, where the operator (joint venture) must be patient and have financial strength (long term financing) to wait a longer period for the return on investment.

3.2.3.2 Sensitivity analysis

As already underlined, the input assumptions for this kind of future oriented business case are uncertain. Therefore it is interesting to see how changes of the value of different parameters affect the results.

There are many aspects, which are independent of the SENDORA concept, but have crucial influence on the profitability. Examples of these are the operational efficiency of the joint venture (influencing OPEX) and the competition situations (influencing Average Revenue Per User (ARPU) and number of customers). We do not evaluate these aspects further, except doing sensitivity analysis on ARPU, but concentrate on aspects where the SENDORA concept has crucial influence.

Sensitivity analysis is done here by changing the value of one (critical) input parameter and showing how the economical results are changing. All other input parameters are as in the “Base case”. NPV is used as the indicator of profitability.

FIXED SENSOR DENSITY

Since the novel idea in SENDORA is to combine cognitive radio with sensor networks, the required number of fixed sensor per km2 is one of the most crucial parameters for the SENDORA approach. Also, as explained in section 3.2.2.3, there are large uncertainties associated with this number. For example is it uncertain what probability of interference the spectrum owners will accept.

Table 7 lists the NPV for different values of the fixed sensor density.

Number of fixed sensors per km^2	NPV [million Euro]	
10	11.44	
30	7.77	
65	**1.36**	**Base case**
72	**0**	
120	-8.72	

Table 7 NPV sensitivity for changes to the fixed sensor density assumption

As can be seen, the business case is very sensitive to changes in this parameter. Just by increasing the sensor density from 65 to 72 sensors/km^2, which is a very small change from a technical perspective, the NPV starts getting negative.

In section 3.2.2.3 the fixed sensor density for two cases, strict LTE and loose LTE, were presented. The required sensor densities ranged from 10.5 sensors/km^2 in the loose LTE case to 120 sensors/km^2 in the strict LTE case. Clearly, these values give extremely different results for the business case.

The fixed sensor density requirement can for example be reduced by employing more advanced sensing techniques or complementing sensing data with other information (e.g. from the primary operators). Also, this analysis shows that it is important that regulators and spectrum owners have this in mind when deciding on the interference probability limits.

FIXED SENSOR PRICE

The sensitivity of the business case to changes in the fixed sensor price is interesting since it concerns the sensor network, which is central to the SENDORA concept. The price for the fixed sensor is uncertain since such equipment has not been produced yet, but is still researched on and exists as prototypes at best. The price used in the base case was derived by comparing it to outdoor Wi-Fi access points, which is expected to have similar complexity and enclosure requirements.

Table 8 lists the NPV for different values of the fixed sensor price.

Fixed sensor price [Euro]	NPV [million Euro]	
50	3.98	
150	2.93	
300	**1.36**	**Base case**
430	**0**	
500	-0.74	

700	-2.84
1000	-5.99

Table 8 NPV sensitivity for changes to the fixed sensor price assumption

The table shows that the fixed sensor price must be raised from 300€ to 430€ (43%) before the NPV gets negative. A similar moderate change in the NPV can be seen if the price is halved from the base case value.

It can be concluded that the fixed sensor price is not the most sensitive, but still important, parameter. It will be a challenge to meet the cost assumptions used in the base case, but moderate deviations (say ±10%) from this is not critical for the business case.

FIXED SENSOR OPEX

The operating cost of fixed sensors (electricity, maintenance, sensor site rental) is a very uncertain parameter, especially the sensor site rental component. It is important to determine the sensitivity of the business case for this parameter to assess the importance of fixed sensor power consumption, durability and space requirements.

Table 9 lists the NPV for different values of the fixed sensor OPEX.

Fixed sensor OPEX [€/month/sensor]	NPV [million Euro]	
5.0	6.82	
10.0	4.09	
15.0	**1.36**	**Base case**
17.5	**0**	
20.0	-1.37	
25.0	-4.10	

Table 9 NPV sensitivity for changes to the fixed sensor OPEX assumption

The table shows that if the OPEX is increased from 15 to 17.5€/month/sensor, the NPV starts getting negative. This is a small increase (16%); much smaller than the uncertainty of this parameter. Hence, this is certainly a parameter that a cognitive radio operator must have under control before deciding to build such a network.

The high sensitivity for this parameter shows that it is critical that the fixed sensor power consumption is low and that the mean time between failures is long. The first requirement can be achieved by exploiting the appropriate integrated circuit technologies, while the second requirement can be met by ensuring that the sensors have high quality and/or integrate "self-healing" capabilities in the units.

SHARE OF NEW SITES

In this business case it is assumed that at least one of the spectrum owners owning the joint venture is a cellular operator, and that the joint vendor operator can exploit the existing infrastructure (e.g. sites, base stations and backhaul). However, it might turn out that it is necessary to establish some new sites in addition to the existing ones in order to get the wanted coverage and capacity.

In the base case it is assumed that no new sites are built. In a real situation this assumption might turn out to be optimistic, and it is hence interesting to see how the business case is affected if different shares of the sites are new sites.

Table 10 lists the NPV for different shares of new sites.

Share of new sites	NPV [million Euro]	
0 %	**1.36**	**Base case**

6 %	**0.00**
10 %	-0.89
20 %	-3.03
30 %	-5.28
40 %	-7.43
50 %	-9,67

Table 10 NPV sensitivity for changes to the share of new sites assumption

The table shows that the NPV starts getting negative if the share of new sites exceeds 6%. If a large part of the sites are new sites, the business case will be strongly negative. Hence, it is important that new sites are avoided. However, if the share of new sites can be limited to a few percent, the business case will be only moderately affected.

SUBSCRIPTION FEE

An important parameter for the business case is the subscription fee, also called the Average Revenue Per User (ARPU). This is a parameter that depends mostly on what price level that is formed in the market for wireless broadband services, and is therefore not directly related to the SENDORA concept. However, the ARPU depends on how the customers grade the service provided by the SENDORA network. If the joint venture operator is able to provide a service which is better than assumed here, the ARPU will be higher than assumed in the base case. If the grade of the service provided is lower than assumed, the ARPU will be lower than in the base case.

Table 11 lists the NPV for different ARPUs.

ARPU [€/month]	NPV [million Euro]	
15.0	-9.33	
18.0	-2.92	
19.4	**0**	
20.0	**1.36**	**Base case**
25.0	12.04	

Table 11 NPV sensitivity for changes to the ARPU assumption

The table shows that the ARPU is a very critical parameter for the business case. The NPV starts getting negative after a reduction of the ARPU with only 3%. Larger changes of the ARPU give dramatic changes of the NPV.

The ARPU assumption used in the base case was based on a comparison with current mobile broadband subscription fees. Since it is uncertain how much lower the subscription fee for a SENDORA service will be, this assumption is much more than a few percent uncertain.

This results shows that it is of crucial importance to be able to offer a service that is preferably better, or at least not much worse, than that of mobile broadband services with respect to average and peak capacity, coverage, delay, QoS, etc.

3.3 BUSINESS CASE 2: SPECTRUM BROKER

This business case will be calculated from the point of view of a spectrum broker. The spectrum broker is an entity that deploys (builds and operates) a sensor network and sells either sensing information or information on spectrum usage opportunities to one or more cognitive radio operators. It is assumed that the spectrum broker is only charging money to cover its expenses, that is it is assumed that its revenues should be such that the broker will have NPV = 0 for the study period 2015-2020 for building and operating the fixed sensor network. This non-profit broker could be the regulator or an entity set up by the government or local authorities.

This business case scenario is more challenging than the previous business case from a regulatory point of view. Cognitive radio operation must be allowed in the spectrum used and there must be sufficient amounts of such spectrum available to allow a small number of cognitive radio operators to offer an attractive service with these spectrum resources. The regulatory process for opening frequency bands for cognitive operation can be complex and take long time, where multiple stake holders are consulted and detailed rules governing the cognitive radio operation have to be developed.

It is assumed that the spectrum broker or the cognitive radio operators will not pay anything to the owners of the spectrum. Since the spectrum owners are not part of this specific SENDORA ecosystem and they will not get any compensation of that others are using their spectrum, it is fair to assume that they should not experience any noticeable interference from the cognitive operation. Therefore it is reasonable to assume that there will be stringent requirements for the interference generated into the primary systems. Taking into account the results on the required fixed sensor density presented in section 3.2.2.3, we will use the strict LTE case as the basis for the assumptions made. Hence, it will be assumed that the spectrum broker must deploy 120 sensors/km^2 both in the downtown area and the suburban area of the city.

The marginal (additional) OPEX for the broker to handle the relations to the cognitive operators is set to 200,000€/year.

All other assumptions regarding sensor network establishment and operation are the same as in the first business case. The broker is not a cognitive operator, so all items related to cognitive operation is not included to this case.

This business case will only give one results, and that is how much the broker must charge from the cognitive radio operators in order to have NPV=0 for the study period 2015-2020. This number will be an important input to the next business case, which considers a new cognitive radio operator that will use information of vacant spectrum from the broker.

Since it takes some time for the broker to build the fixed sensor network, the service it can provide to the cognitive radio operators will be reduced in the start. To take this into account we assume that the broker will only charge half of the yearly fee the first year.

The business case calculations shows that the fees the broker must charge from the cognitive radio operators using his information are 2,693,000€ in 2015 and 5,386,000€ for each of the remaining years.

3.4 BUSINESS CASE 3: NEW ENTRANT

This business case takes the perspective of a new cognitive radio operator that does not have any existing infrastructure or frequency licenses in the area in question. The operator wants to use a SENDORA system to offer a nomadic mobile broadband service.

The new entrant will build a cognitive radio access network, both by sharing infrastructure with existing wireless operators in the area and by building new base station sites. The spectrum needed will be borrowed or rented from the spectrum broker addressed in the previous business case. It is assumed that the spectrum broker has deployed a sensor network and all related infrastructure, so the operator does not have to deploy a sensor network of its own. However, the cognitive terminals will have sensing capability that the operator might use to improve the quality and resolution of the information received from the broker.

The business case of a new SENDORA operator is somewhat similar to a corresponding business case of a new mobile broadband operator, e.g. a new LTE operator. The difference is that a new mobile broadband operator has to acquire a spectrum license, while the SENDORA operator will base its operation on borrowed or rented spectrum.

All revenue assumptions (number of customers and ARPU) for this business case are the same as for the "SPECTRUM SHARING" business case presented in section 3.2. The main difference is that the new entrant will not have to build and operate a sensor network as the joint venture operator does, but it can utilise the sensor network information either free (base case for new entrant) or by paying to the broker an annual fee (section

3.3).When building and operating the cognitive network we assume that the new entrant in some aspects will have higher costs than the joint venture:

- We will assume that the SENDORA operator has to establish new base station sites for 20% of the base stations needed (the total number of base stations is the same as in the joint venture case, see Table 6). It is assumed that it costs 60,000 € to establish a new site.

- For the cognitive functionalities in the base stations 10,000 € (decreasing to 5,905 € in 2020) is assumed for equipping it with the needed cognitive radio base station components (antennas, modems, amplifiers, etc.). In the joint venture case a lower value (5,000€) is used.

- We will assume that the new cognitive radio operator has to pay a 50% higher rent for sharing infrastructure with the existing operators in the area than in the business case from section 3.2.It is assumed that the new entrant must pay a rent to other operators for sharing the base station site, maintenance expenses and backhaul sharing of 1,500 €/month/base station site decreasing to 1,356 € in 2020.

As the base case we will assume that the new entrant do not have to pay anything for the spectrum. This means that the broker must cover the costs of building and operating the sensor network, i.e. this has then to be financed by public money. The base case will however be complemented with a sensitivity analysis to assess how the business case is affected if the operator has to pay for using the spectrum. In this case the price that the new cognitive operator has to pay for the spectrum will be derived from the revenue the broker, presented in the business case in section 3.3, must have in order to get NPV=0 in the study period 2015-2020. This cost might be shared with other cognitive radio operators in the area also using sensing information from the broker.

Figure 8 shows the accumulated cash flow for the base case.

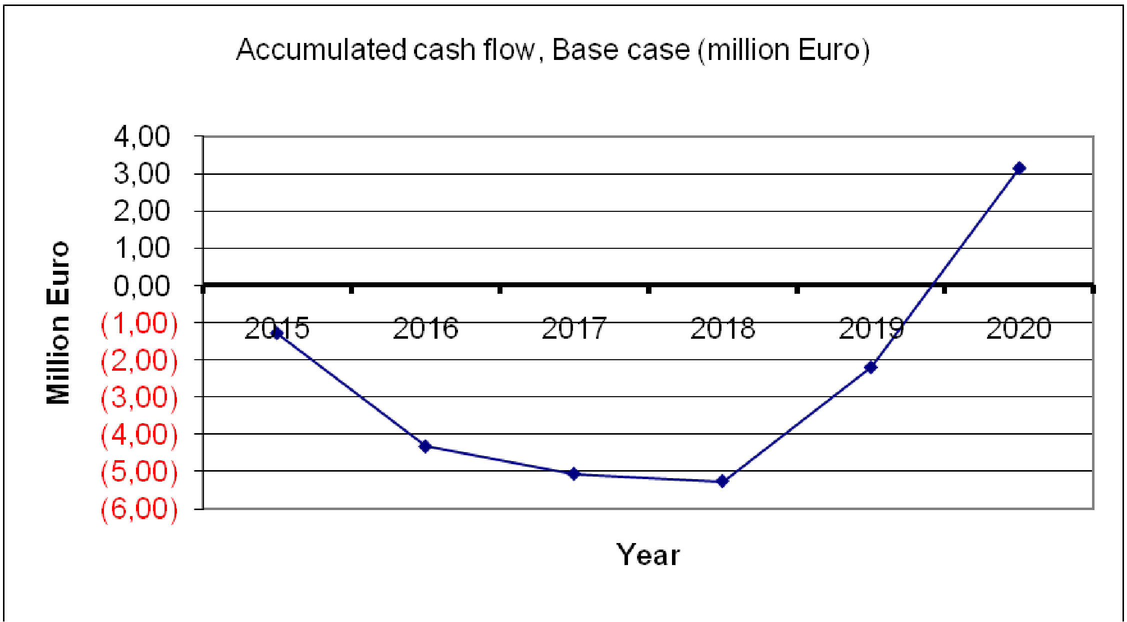

Figure 8 Accumulated cash flow for the base case

NPV for the study period 2015-2020 is 0.61 million Euro, IRR is 14 % and the pay-pack period is somewhat less than 5 years. This case is even more uncertain than the spectrum sharing case (section 3.2) and it is quite impossible to state on a general level how profitable a new entrant could be. It depends on local conditions, efficiency of the new entrant, competition situation, timing, regulatory conditions etc. It is important to note that in this base case the new entrant do not have any spectrum costs, which may be an unrealistic assumption even on a longer term.

A sensitivity analysis was performed for the number of new base station sites and for having to pay for the spectrum.

Table 12 lists the NPV for different shares of new base station sites.

Share of new base station sites	NPV [million Euro]	
0 %	5,00	
20 %	**0,61**	**Base case**
22 %	**0**	
40 %	-3,78	
100 %	-16,96	

Table 12 NPV sensitivity for changes to the share of new base station sites

The table shows that the NPV starts getting negative when the share of new sites is increased from 20% to 22%. The uncertainty of how many new sites that is required is typically much larger than this. Hence, this is a parameter that a new entrant must have good control of. If the share of new sites can be reduced below the 20% assumed in the base case, it will affect the business case very positively.

Table 13 lists the NPV when the new entrant has to pay for the spectrum for different numbers of cognitive radio operators in the area (when the number or operators is 1, this means that the new entrant is the only cognitive operator in the area).

Number of cognitive radio operators in the area	NPV [million Euro]
1	-22,50
2	-10,95
3	-7,09
4	-5,17

Table 13 NPV when a new entrant has to pay for the spectrum for different numbers of cognitive radio operators in the area

The table shows that the business case is negative if the new entrant has to pay the broker for spectrum information, even if the broker's costs are divided between 4 cognitive operators in the area. Taking into account the market share that has been assumed (100,000 subscribers in 2020 of a population of 1 million), it is even unrealistic to assume that there will be room for four cognitive radio operators. Two or three operators is probably the most realistic number.

4 SUMMARY AND CONCLUSIONS

This report presents the background, assumptions and results for a study of three business case scenarios based on the SENDORA concept. The calculations in each business case are done from the perspective of a particular actor in the ecosystem.

SENDORA is an innovative concept and much research and development remains before commercial applications will appear. Therefore the input data to the SENDORA business cases is uncertain and the results from the business case calculations can only give indications, not yet definite answer or strong conclusions. The main value of the business case calculations is to identify critical aspects for SENDORA profitability, so that future technical R&D work can focus on them.

A traditional cash flow analysis has been used to get an indication of the profitability. Due to large uncertainties in the input parameters, the cash flow analyses have been enhanced with sensitivity analysis. Sensitivity analysis is done by changing the value of one (critical) input parameter and showing how the economical results are changing.

The first business case considered a scenario where cognitive radio is used for spectrum sharing. The spectrum owners form a joint venture company, which is a cognitive radio operator that offers a nomadic broadband service using “unused” parts of the owners’ spectrum. The business case calculations are done from the perspective of the joint venture company.

The results of the cash flow analysis indicate that it might be possible to make profitable (long term) business by using the SENDORA concept in this business case scenario. The accumulated cash flow and the associated economical results are quite similar to many other telecommunication infrastructure projects. That means that it will be a long-term business case, where the operator (joint venture) must be patient and have financial strength (long term financing) to wait a longer period for the return on investment.

The “spectrum sharing” business case is probably one of the best possible cases for SENDORA because the joint venture operator has free access to frequency resources of the mother companies, detailed knowledge of the primary systems and good possibilities for sharing infrastructure with the owning operators.

The sensitivity analyses focused on aspects of the business case which depend on the SENDORA concept. The most critical SENDORA related aspects influencing the profitability are the required fixed sensor density and the fixed sensor OPEX. Hence, future technical R&D work should focus on these aspects. The fixed sensor density requirement can for example be reduced by employing more advanced sensing techniques or complementing sensing data with other information (e.g. from the primary operators). The required fixed sensor density also depends strongly on what interference limits are set to protect the primary operators. By using different, but all realistic, values for the interference limits, it was shown that the required density of fixed sensor could vary by a factor of 10 or more. An important conclusion from this is that it is very important that regulators and spectrum owners have this in mind when deciding on the interference probability limits. The high sensitivity for the fixed sensor OPEX showed that it is critical that the fixed sensor power consumption is low and that the mean time between failures is long. The first requirement can be achieved by using the appropriate integrated circuit technologies, while the second requirement can be met by ensuring that the sensors have high quality and/or integrate “self-healing” capabilities in the units.

In addition to the sensitivity analysis for the SENDORA critical parameters, a sensitivity analysis was also done with respect to the subscription fee. The analysis showed that the business case was very sensitive to the subscription fee, and that a change of only a few percent from the assumed value had a great impact on the economical results. The subscription fee assumption used in the base case was based on a comparison with current mobile broadband subscription fees. Hence, this results shows that it is of crucial importance that the SENDORA operator has to be able to offer a service that is preferably better, or at least not much worse, than that of mobile broadband services with respect to performance parameters like average and peak capacity, coverage, delay and QoS.

The second business case considered a broker that builds and operates a spectrum sensing network to detect vacant time/frequency slots in an area. This information is then given or sold to cognitive radio operators. The goal of this business case was to estimate what revenues this broker must get in order to cover its expenses. The revenues can be public money, fees from the cognitive radio operators or a combination of both. The required revenues were then used as an input parameter to the next business case.

The third business case considers a new entrant, without any existing infrastructure in the area, that wants to build and operate a cognitive radio network to provide a nomadic wireless broadband service. The new entrant gets, either for free or for a fee, information about vacant time/frequency slots from the broker considered in business case two. When building and operating the cognitive network, it is assumed that the new entrant in some aspects will have higher costs than the joint venture operator studied in business case one. Further it is assumed that the new entrant must build 20% of its cognitive radio base station sites as new sites, whereas it was assumed that no new sites was required in business case one. With these assumptions the analysis indicates that it might be difficult for the new entrant to get a positive business case unless he get access to the spectrum for free. If it has to pay the broker what he needs for covering his expenses, the business case gets strongly negative even when these expenses are shared with three other cognitive operators also using information from the broker.

It is too early to give a definite answer about the profitability of different SENDORA business cases. The main value of these business case calculations is the identification of the critical aspects for SENDORA profitability. The most critical aspects seem to be the costs for building and operating the fixed sensor network. The costs for building the fixed sensor is strongly dependent on the regulatory requirements and should be taken into consideration when these are decided.

5 REFERENCES

[1] http://www.investopedia.com/dictionary/

[2] Richards, F.J. 1959 A flexible growth function for empirical use. J. Exp. Bot. 10: 290—300