Business case proposal for a Cognitive Radio Network based on Wireless Sensor Network

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Abstract—**This paper describes a business case scenario and gives the results of a business case analysis for deployment of a sensor network aided cognitive radio system in a typical European city. The main idea behind the business case is that several spectrum owners will establish a joint venture and this joint venture will get the right to use the "unused" spectrum resources of all the companies in a cognitive way. The joint venture will base its operation on a Wireless Sensor Network aided Cognitive Radio concept, which means that a network of fixed sensors is deployed in order to improve the system's capabilities for detecting primary users and spectrum holes. The main value of the business case calculation is to identify critical aspects influencing the profitability so that future research and development work can focus on them. It is found that the most critical aspects are the fixed sensor density, the fixed sensor operational costs and the number of new cognitive base station sites required.**

Keywords: cognitive radio, business case, sensor network

I. INTRODUCTION

Most research and development work on cognitive radio focuses on pure technical aspects of the technology. However, in order for an operator to be interested in deploying cognitive radio based networks the anticipated costs must be in proportion to what the users are realistically willing to pay for the service. Hence, techno-economical studies should be done in parallel with the technical research and development work to ensure that the solutions found are both technically and economically viable.

Since cognitive radio is an open and relatively new research field, there is a lot of uncertainty associated with many of the parameters needed in business case analyses. But even with uncertain input parameters the business case studies can be used for identifying critical parameters that must be considered in the technical studies. A good way to proceed towards a viable solution is to do the business case calculations and technical calculations iteratively, each time using the latest results of one to derive the input parameters to the other.

This paper presents the results of such a study conducted within the EU FP7 project SENDORA [1] for a sensor network aided cognitive radio system.

II. SENDORA SYSTEMS

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 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.

The sensor network aided approach will significantly improve the system's ability to detect primary users compared to cognitive radio solutions based only on sensing performed by the terminals. The sensor network will consist of an externally deployed sensor network and possibly 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.

Digital Object Identifier: 10.4108/ICST.CROWNCOM2010.9209
http://dx.doi.org/10.4108/ICST.CROWNCOM2010.9209

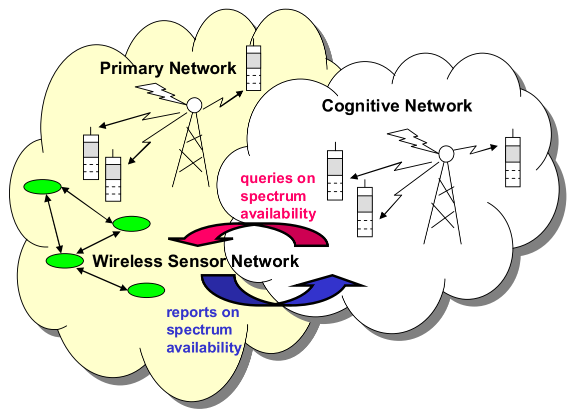

Figure 1. General SENDORA scenario

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 is a functional entity that 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.

III. Business case scenario

The main idea behind the business case is that several spectrum owners will establish a joint venture and this joint venture will get the right to use the "unused" (in space and in time) spectrum resources of all the companies in a cognitive way based on the SENDORA concept. It is assumed that at least one of the companies is an operator having an existing wireless access network deployed in the area of interest.

The joint venture will build a sensor network and provide cognitive nomadic broadband services 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 service offered by the SENDORA system will be either complementary or different from the services offered by the participating operators. For example, for a mobile broadband operator, the SENDORA network can be complementary by offering improved indoor coverage by utilizing lower frequency bands or offering higher maximum bitrates by using larger channel bandwidths.

It is assumed that the joint venture will base its cognitive access network as much as possible on the existing infrastructure (e.g. base station sites) owned by the participating operators. However, the joint venture must pay a rent to the operator for using these sites. The joint venture is assumed to have free access to all frequency resources of the participating operators.

The frequency band used by the cognitive access network must be different from the one used by the operator owning the site in order to avoid interference between the two systems. Hence, it's advantageous that the operators involved are as complementary as possible with respect to spectrum.

The main advantage of this joint venture concept is the possibility to utilize freely in a flexible cognitive way a wide variety of frequency resources (from below 1 GHz to several GHz). This is assumed to be more advantageous for the participating operators than to acquire a (often expensive) new license for a specific limited spectrum area.

The joint venture's use of the participating operators' infrastructure can be seen as a form of infrastructure sharing, a concept that has attracted much interest from operators lately.

From a regulatory point of view the concept of a joint venture exploiting the owners' spectrum resources has many advantages. The spectrum will be better utilized providing better service to the users. There will be no regulatory issues between the owners of the spectrum used, as this will be regulated in the joint venture agreement instead. The concept is one form of infrastructure sharing and therefore it may raise regulatory issues regarding limited competition. It is however assumed that this is not the case.

IV. Assumptions

The business case is calculated for a hypothetical European city with 1 million inhabitants and with an area of 400 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 technologies used in the SENDORA concept lies some years ahead. To allow for this, the study period is assumed to be from 2015 to 2020. A traditional cash flow analysis is used to get an indication of the profitability. This is enhanced with sensitivity analysis to identify which parameters that are most important to focus on when improving the system. The discount rate for present value calculations is set to 10%.

The cash flow constitutes of revenues and costs as illustrated in Figure 2. The revenues are assumed to come solely from the subscription fees. Other revenues are possible,

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e.g. from selling spectrum measurement data to other operators or the public authorities, but this is not considered here. The costs can be grouped in two categories: capital expenditure (CAPEX) and operational expenditure (OPEX). CAPEX represents the investments, while OPEX represents the operational costs.

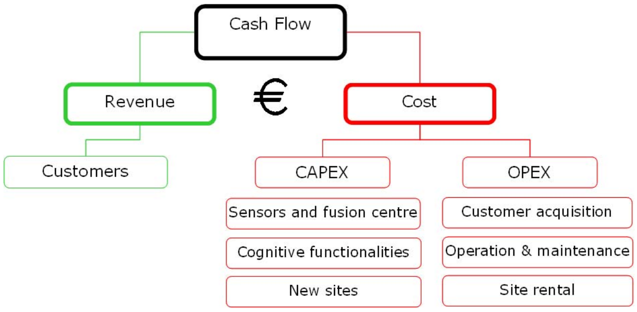

Figure 2. Cash flow components

A. *Revenues*

The joint venture will provide nomadic broadband for the inhabitants and businesses in the studied city. It will do so with competition from several other providers. It is assumed that the joint venture will have 10 000 nomadic broadband subscribers in the first year (2015) growing to 100 000 subscribers in the last year (2020). The amount of subscribers per year is modeled with an S-curve as illustrated in Figure 3.

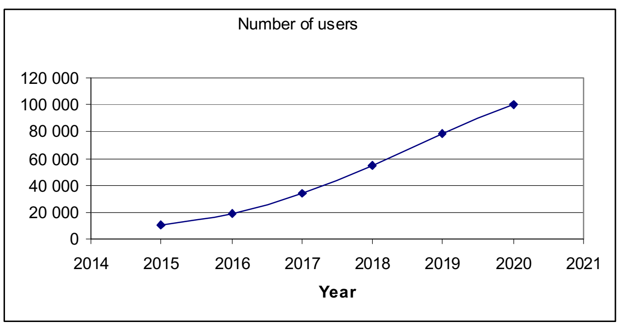

Figure 3. Assumed number of subscribers

The average revenue per user (ARPU) per month is assumed to be 20 Euro in 2015 decreasing gradually to 18,1 Euro in 2020. This is on the lower edge compared to most of the advanced mobile and nomadic broadband offers in Western Europe today.

B. *Capital expenditures (CAPEX)*

1) Sensor network CAPEX: The joint venture will establish a sensor network based on fixed sensors covering gradually the total area of the studied city. In addition it is assumed that 50% of the terminals belonging to the customers of the joint venture have an integrated sensor. Other assumptions for the sensor network are given in Table I.

TABLE I. SENSOR NETWORK CAPEX ASSUMPTIONS

Parameter	Assumption
Fixed sensor density	100 sensors/km2 (see [2])
Fixed sensor price	40€ in 2015 decreasing to 23.6€ in 2020
Fixed sensor installation costs	25€ in 2015 decreasing to 22.6€ in 2020
Cost of sensor in terminal	20€ in 2015 decreasing to 11.8€ in 2020
Cost of fusion centre	160,000€ including installation costs

2) Cognitive access network CAPEX: The joint venture will use existing base stations as much as possible. Cognitive functionality will be added to these by software upgrades and/or additional hardware. The cognitive functionality in the user terminals is assumed to be included as part of the normal terminal development, hence this cost will be paid by the users and is not included in the business case calculations. Other assumptions for the cognitive access network are given in Table II.

TABLE II. COGNITIVE ACCESS NETWORK CAPEX ASSUMPTIONS

Parameter	Assumption
Number of cognitive BS sites	50 in 2015 increasing to 450 in 2020
Cost for cognitve functionaliy in BS	1000€ in 2015 decreasing to 590€ in 2020
Cost of establishing a new BS site	60,000 €/site
Share of new BS sites[a]	0 %

a. Higher shares of new BS sites will be considered in the sensitivity analysis

C. *Operational expenditures (OPEX)*

OPEX is the periodic operating costs for the joint venture when it's running its nomadic broadband business. The OPEX assumptions are given in Table III.

TABLE III. OPERATIONAL EXPENDITURE ASSUMPTIONS

General OPEX assumptions	
Customer acquisition and operation of the company	10 €/customer/month in 2015 decreasing to 6.9€ in 2020
OPEX for the fixed sensor network and for the cognitive communication	
Electricity and maintenance costs	7€/sensor/month in 2015 decreasing to 6,3€ in 2020
Maintenance of cognitive base stations	250€/BS/month in 2015 decreasing to 226 Euro in 2020
BS site rental fees	350 €/BS site/month

Digital Object Identifier: 10.4108/ICST.CROWNCOM2010.9209
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V. RESULTS

A. *Base case results*

Combining costs (CAPEX and OPEX) with revenues gives yearly cash flows and from cash flows the standard profitability indicators, like NPV (Net Present Value), IRR (Internal Rate of Return) and pay-back period, can be extracted.

It is important to emphasize that SENDORA is an innovative and long term project. 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 indications to evaluate if it is possible to make business utilizing the Wireless Sensor Network aided Cognitive Radio concept.

The accumulated cash flow for the first preliminary SENDORA business case calculation is shown in Figure 4. This is accumulated cash flow for the "base case" using the input assumptions given in the previous section.

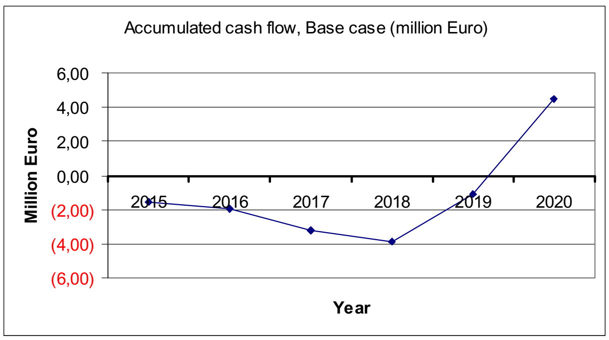

Figure 4. Accumulated cash flow for the Sendora business case

The NPV for this case is 1,9 million Euro (study period 2015-2020), IRR is 24 % and the pay-pack period is in the range of 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 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.

B. *Sensitivity analysis*

The input assumptions for this kind of future oriented business case are uncertain. 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 ARPU and the number of customers). We do not evaluate these aspects further, but concentrate on aspects where the Wireless Sensor Network aided Cognitive Radio 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.

1) Fixed sensor density: The results of the sensitivty analysis of the fixed sensor density are given in Table IV.

TABLE IV. NPV SENSITIVITY TO FIXED SENSOR DENSITY

Fixed sensors/km^2	NPV [million Euro]
50	7.70
100	1.91
117	0
150	-3.88

The density of the fixed sensor is definitely one very important SENDORA related parameter, because the number of fixed sensors must be sufficiently high to get reliable sensing and so it will have significant influence on the CAPEX and especially on the OPEX.

2) Fixed sensor price: The results of the sensitivity analysis of the fixed sensor price are given in Table V.

TABLE V. NPV SENSITIVITY TO FISED SENSOR PRICE

Fixed sensor price [€]	NPV [million Euro]
20	2.47
40	1.91
60	1.34
108	0
150	-1.20

The influence of the price of a fixed sensor network is not so significant because it is a one-time investment.

3) Fixed sensor OPEX: The results of the sensitivity analysis of the fixed sensor OPEX are given in Table VI.

TABLE VI. NPV SENSITIVITY TO FIXED SENSOR OPEX

OPEX per sensor [€/month]	NPV [million Euro]
5.0	4.66
7.0	1.91
8.4	0
10.0	-2.22
15.0	-9.10

This is a sensitive and at the same time uncertain parameter. The fixed sensor network planning (density, trade-off between CAPEX and OPEX e.g. high CAPEX for fixed sensor can mean robustness and lower OPEX requirements)

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and optimization with integrated sensors must be one of the focus areas for further technical work.

4) Need for new infrastructure: The results of the sensitivity analysis for the required share of new base station sites are given in Table VII.

TABLE VII. NPV SENSITIVITY OF THE SHARE OF NEW COGNITIVE RADIO BASE STATION SITES

Share of new sites	NPV [million Euro]
0 %	1.91
5 %	0.69
8 %	0
10 %	-0.34
20 %	-2.48
50 %	-9.12

Quite a moderate need for new site establishment means unprofitable business under our present assumptions. So the SENDORA project must try to find solutions which allow the co-location between primary and secondary systems as much as technically possible.

VI. CONCLUSIONS

The main value of this business case calculation is to identify what are the critical SENDORA aspects influencing the profitability, so that future research and development work can focus on them. The most critical aspects influencing the profitability are the fixed sensor density, the fixed sensor OPEX and the number of new sites required.

This first SENDORA business case calculation is based on uncertain inputs and therefore one should avoid drawing strong and definite conclusions based on the results.

This business case scenario is probably one of the best possible cases for Wireless Sensor Network aided Cognitive Radio, because it is based on the “joint venture” concept. The joint venture has free access to the frequency resources of the mother companies, detailed knowledge of the parameters used in the primary systems and good possibilities for co-location.

One very general conclusion from the present calculation is that it does not seem impossible to make profitable (long term) business by using the Wireless Sensor Network aided Cognitive Radio concept.

The SENDORA business case work will continue by improving the quality of the input assumptions for this business case and by calculating new business cases from the viewpoint of other actors in the SENDORA eco-system.

ACKNOWLEDGMENT

The research leading to these results was performed in the project SENDORA which receives funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 216076.

The authors want to thank the other participants in the SENDORA project for providing necessary input data and for giving us valuable feedback during the work.

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