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Techno-economic analysis of cognitive radio models in 5G networks

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Abstract

The first commercial products of 5G will be released within 2020 and therefore, it becomes an absolute necessity to research whether the key enabling technologies are advantageous for the operators to invest in. One of the most fundamental technologies Cognitive Radio (CR), since there is not much research in the field. This paper develops a techno-economic framework for the CR technology and is contrasted with an already existing model for Software Defined Networks (SDN). A Sensitivity Analysis (SA) indicates the cost parameters that are the most expensive ones and should be reconsidered for the model's wide adoption and viability.

Keywords: 5G; cost models; mobile networks; SDN; cognitive radio

1. Introduction

In 5G networks modern and existing network technologies are combined in order to meet the high expectations, provide new services and augment the income of the telecommunication companies. Although novel technologies and services should be introduced and telecommunication operators should invest in them, there is a lot of distrust yet, not only for financial reasons but also in terms of efficiency and performance.

On the other hand, there are several substantial problems that exist in mobile networks and have not been faced adequately, such as the under-utilization of the available resources e.g. spectrum, frequency, bandwidth etc. Technologies, such as Machine to Machine Communications (M2M), Cognitive Radio (CR), Software Defined Networking (SDN), Network Function Virtualization (NFV), Ultra-density, Massive Multiple Input Multiple Output (Massive MIMO) are the key enabling technologies and are going to star [2] in 5G.

SDN applied in the Radio Access Network (RAN) infrastructure could help better inspecting the available sources. Statistical representation of the network traffic could be able to indicate the need for more resources. Another way of

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enhancing the network exploitation is the CR technology. It is built at the top of the RAN and enables the intelligent configuration of the radio system so that it adapts to the instantaneous state of spectrum environment and real time requirements [3]. The spectrum access could be opportunistic/dynamic [8]. The radio spectrum is the most valuable resource in wireless communications [9]. There are several types of spectrum in the CR, such as (full CR, licensed band CR, unlicensed band CR) and also several spectrum sensing methods (energy detector, waveform-based sensing, cyclostationarity, matched filtering techniques).

The CR could also be combined with heterogeneous networks [7]. The cooperative spectrum sensing among CR nodes operating at the same frequency improves the probability of detection and the efficiency [4]. The gains of CR in business and real time applications [6] [5]. Although other techno-economic studies exist for 5G (e.g. [10]) there are not many concerning the CR.

In this paper, a techno-economic model for the CR is presented and is compared with the already existing developed pricing models for SDN. A Sensitivity Analysis (SA) is conducted to indicate which cost parameters are the most dissuasive factors for the model's adoption. Although there is a lot of existing research concerning the CR and its main components, functionalities, advantages and disadvantages, there is not much activity in terms of the pricing of the CR. There are not many papers comparing the economics of the SDN and CR.

The remaining part of this paper is structured as follows: In Section 2 the proposed architectures are analyzed and explained. In Section 3 the proposed financial models are summarized. In Section 4 the experimentation parameters are opted. In Section 5 several experiments concerning the models' viability are conducted. In Section 6 conclusions are summarized and future research is proposed.

2. Proposed Models

In this section, general schemes concerning the proposed architectures are described.

2.1. Software Defined Networking (SDN)

SDN networks offer a generic view of the network and consist of three different planes (control, data, application). The data plane communicates with the control plane via the southbound API and with the application plane via the northbound API. The control plane exploits all the information and informs the network about the resources.

SDN's main feature is the split of the data and control. The network extracts knowledge from usage patterns to ensure security and protection. Exploiting all data and statistics, conclusions about the network are extracted. Basic network mechanisms should be replaced by Virtual Network Functions (VNFs) so that the network becomes more efficient [1].

2.2. Cognitive Radio (CR)

CR aims to perform intelligent allocation of the radio spectrum. It interacts with the users, sensors, network Applications, Network and Data Link layers and offers spectrum sharing capabilities. Its main problem is the resource management.

CR architectures include a primary and possibly a secondary network. In the primary network, there are some Primary Users (PU) or Base Stations (BS). These PUs are licensed to use the spectrum. The primary Base Station (BS) coordinates this usage. The PUs communicate with one another by interacting with the primary BS. The secondary network includes Secondary Users (SU) and occasionally a secondary BS.

The PUs use the licensed bands, while the SUs cannot use them if the bands are not idle or PUs are transmitting. If a SU is transmitting, but a PU starts transmitting, the SU has to identify the transmission, stop its own and find an available band and start transmitting there. In case there is a secondary BS in the network, it is "informed" by the SUs that there is a PU transmission. The secondary BS prevents all SUs from transmitting. Fig. 1 depicts a basic CR architecture, where the PUs transmit in the licensed bands, while the SUs wait for the PUs to become idle or transmit in unlicensed and/or available bands.

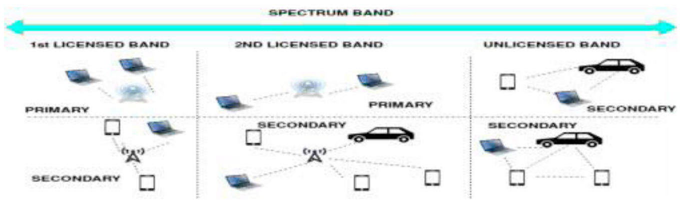

Fig. 1: The basic model of the CR architecture.

3. Pricing model

In this section, the proposed financial models are described. CAPEX includes the costs spent when the infrastructure is created. The OPEX includes all the costs related to the day-to-day management, coordination activities and running of the network. The Total Cost Of Ownership (TCO) includes all the costs that are related to the acquisition and operation of a technology. A Sensitivity Analysis (SA) is a technique that helps determining the most fundamental parameters that mostly affect the cost model.

3.1. Software Defined Networking (SDN)

According to previous research, SDN RAN includes both hardware and virtualized parts [1].

3.1.1. CAPEX

In future network BSs are Super Base Stations (SuperBS). In this approach virtualized resources are shared among BSs on demand.

The number of sliced virtual BSs per SuperBS is denoted by the parameter n_{vs}. The density of users in a specific area is represented by the l_{SBS}. In a specific area e.g. A, the number of the SuperBS is given by the coefficient N_{SBS}. The BS are able to transmit in a specific radius, so the maximum coverage radius, that could be succeeded in a network is represented by the coefficient R_{max}, which denotes the distance that the BS is able to properly transmit. The cost per cell site of the SuperBS is denoted by C_{CS-SBS} and also a cost per SBS unit that are represented and C_{SBS} respectively and they are calculated in [1]. The total number of users N_{UE} in a specific area is:

$$N_{UE} = l_{SBS}A = n_{vs} l\pi R_{max}^2 N_{SBS} \tag{1}$$

where l denotes the coverage radius in the area A, N_{SBS} denotes the number of SuperBSs in the given area A.

The cost for cell site construction C_{site} for the SBS network is:

$$C_{site} = C_{CS-SBS} N_{SBS} \tag{2}$$

where N_{SBS} denotes the number of SuperBSs in the given area A.

The total CAPEX for the SDN RAN results from the previous analysis:

$$CAPEX_{RAN}^{SDN} = \frac{N_{UE}}{n_{vs} l\pi R_i^2} C_{CS-SBS} \tag{3}$$

3.1.2. OPEX

The OPEX consists of the costs for power consumption of the network components. The components that induce power consumption alongside with the parameters that represent them are: Transceiver (P_{trans}), Rectifier (P_{rect}), Digital signal processor (P_{DSP}), Power Amplifier (P_{PA}), MicroWave (MW) Transmission (P_{MW}), Air cooler (P_{air}) Given a specific area e.g. A, there are N_{SBS} SuperBS in this area and n_{vs} virtual BSs. In [1], it is considered that power consumption is higher for the MW link and the air cooler. The power consumption of the SBS could be increased up to 20%, with every slide added in the system [1]. In this case, the virtual operators are sharing the antenna infrastructure and the power consumption is further reduced. Therefore, for a given SBS, the consumed power is given by the following relation:

$$P_{rfSBS} = (P_{air} + P_{mw} + P_{trans} + P_{rect} + P_{A})[1 + 0.2(n_{vs} - 1)] \tag{4}$$

The total power consumption of a SBS using the Equations (4) is given by the following:

$$P_{SBS} = n_a P_{rfSBS} + n_{vs} P_{DSP} + PairSBS + PmwSBS \tag{5}$$

where n_a is the number of antennas existing in the architecture.

The total OPEX for the RAN infrastructure is the outcome of the number of BSs in the area multiplied with the energy consumption per BS and the Cost for the kW per hour C_{kWh}. Therefore, the total OPEX is given by the following:

$$OPEX_{RAN}^{SDN} = P_{SBS} N_{SBS} C_{KWH} \tag{6}$$

3.1.3. TCO

Considering the previous analysis [1], the TCO of the technology is given by adding (3) and (6):

$$TCO_{RAN}^{SDN} = \frac{N_{UE}}{n_{active} l \pi R_i^2}(C_{CS-SBS} + CSBS) + P_{SBS} N_{SBS} C_{KWH} \tag{7}$$

3.2. Cognitive Radio (CR)

The CR includes several BS in its basic structure (both primary and secondary). Although two different BS types (PUs, SUs) exist and seem to differ regarding their costing, (because of their cognitive and not cognitive capabilities), the BSs are considered to cost equally, because BS of 5G networks are going to have cognitive and SDN capabilities, so that they are compatible with all the enabling 5G technologies [2]. The pricing model developed for the CR is structured as follows: Most of the costs in both cases are similar, therefore only differences in the cost models are going to be pinpointed. In this paper, it is considered that several BSs are active and other are not active. Lower energy consumption and cost is succeeded.

3.2.1. CAPEX

In this case, there is a number of sliced virtual BSs per SuperBS and is denoted by the parameter n_{vs}. Only the BS of the Primary Network alongside with the Secondary ones, which are located out of the licensed spectrum are active each time. Thus, n_{vs}= n_{active} + $n_{not-active}$, therefore: n_{active}= n_{vs}-$n_{not-active}$.

Therefore, the total CAPEX for the CR is given by:

$$CAPEX_{RAN}^{CR} = \frac{N_{UE}}{n_{active} l \pi R_i^2}(C_{CS-SBS} + CSBS) \tag{8}$$

Table 1: TCO Cost Parameters and System Variables.

RAN Costs			
Parameter	**Description**	**Value**	**Value Range for SA**
n_{vs}	Number of BS per SBS	6	[2, 12]
n_{active}	Number of active BS per SBS in CR	4	[1, 10]
l_{SBS}	Number of users	500	[100, 1000]
N_{SBS}	Number of BSs per km^2	10	[1, 1000]
C_{CS-SBS}	Cost of the Cell construction of the SBS	5000 €	[1000, 10000]
C_{SBS}	Cost for the vBSs deployed	15596 €	[7798, 31192]
P_{trans}	Power Consumption of the Transmitter	100 W	[50, 150]
P_{rect}	Power Consumption of the Rectifier	100 W	[50, 150]
P_{DSP}	Power Consumption of the Digital Signal Processor Power	100 W	[50, 150]
P_{PA}	Power Consumption of Power Amplifier	10 W	[5, 15]
P_{mw}	Power Consumption of Microwave	80W	[40, 160]
P_{air}	Power Consumption of air-cooler	225 W	[112.5, 450]
n_a	Number of Antennas	4	[2, 8]
C_{KWh}	Cost of the kW per hour	0.25 €	[0.12, 0.5]

The analysis for OPEX and TCO is the same as it was for the SDN therefore, it in not going to be repeated.

3.2.2. OPEX

The total OPEX is given by the following:

$$OPEX_{RAN}^{CR} = P_{SBS} N_{SBS} C_{KWH} \tag{9}$$

3.2.3. TCO

The TCO is the sum of the CAPEX and OPEX and therefore, it is given by the following equation:

$$\begin{aligned} TCO_{RAN}^{CR} = & \frac{N_{UE}}{n_{active} l \pi R_i^2}(C_{CS-SBS} + CSBS) + \\ & + P_{SBS} N_{SBS} C_{KWH} \end{aligned} \tag{10}$$

4. Parameter selection

In this section, the parameters of the proposed models are opted. Table 1 includes all the parameters and variables that are related to the pricing models. Most values were extracted by [1]. In order to perform the SA, the actual values variegate at about almost +/- 50%. It is probable that prices augment due to financial factors or reduced if novel technologies are introduced and as a result, several costs, such as power consumption, site acquisition, development etc. will be limited.

5. Experimental procedure

In this section, the experiments concerning the proposed models are conducted as presented in the Experimental process 1 explained below.

Algorithm 1 Experimental procedure

```
procedure MATHEMATICAL MODELS
    Calculate CR TCO & SDN TCO

procedure PARAMETERS SELECTION
    Opt for the parameters for CR & SDN
    Opt for the price ranges

procedure SENSITIVITY ANALYSIS

    SA for the parameters:
n_vs, l_SBS, N_SBS, C_CS-SBS, C_SBS,
P_trans, P_rect, P_PA, P_mw, n_a
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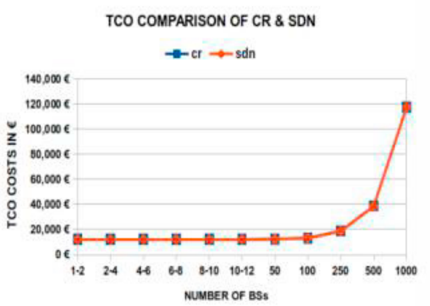


Fig. 2: The comparison of the TCO of the SDN and CR in relation to the number of BSs n_{vs}.

5.1. Cost Comparison of SDN & CR

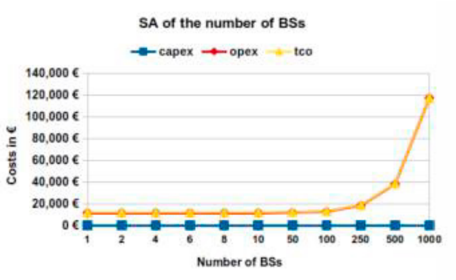
In this section, the cost comparison of the two different models is presented. Both models (SDN, CR) are similar, but CR includes less functioning BSs, as there are several secondary BSs that cannot access the spectrum in an authorized way. On the other hand, in the SDN model all the respective BSs function and support potential users.

In particular, the CAPEX cost is stable and equal for both models. Therefore, the number of BSs n_{vs} does not play a very important role in the formation of the CAPEX cost. In these terms, it seems that the cost for a new investment in these technologies will not be prohibitive for the operators and they should invest in the CR and/or SDN.

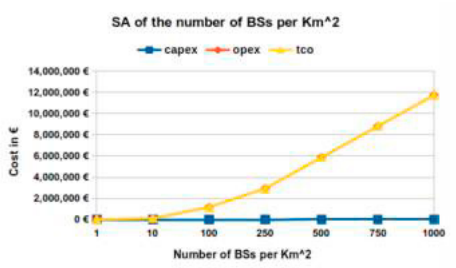
The OPEX cost and therefore the TCO (Fig. 2) depends on the augmentation of the number of BSs. There is not a large fluctuation until the number of BSs becomes 100. The costs augment in an exponential way and therefore, these costs highly affect the costs of both models. It seems very important that the number of BSs becomes optimized within an architecture. In this direction, several techniques, such as optimization algorithms could result in providing cost and performance efficient structures, which include an optimal number of BSs.

5.2. Sensitivity Analysis of CR

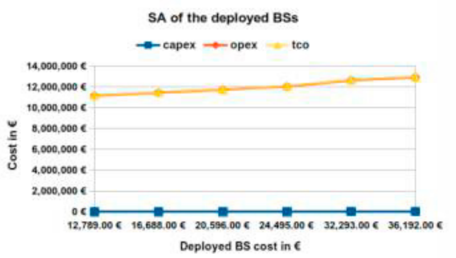
The CAPEX cost is stable and equal for both models (Fig. 3). Therefore, the number of BSs does not play a very important role in the formation of the CAPEX. The OPEX depends on the augmentation of the number of BSs. The TCO cost depends on the augmentation of the number of BSs. Although there is not a large fluctuation until the number of BSs is 100. Then, the number of BSs and the the number of antennas. Although there is not a large fluctuation until the number of antennas becomes 500. The number of users in the model does not affect the CAPEX, OPEX and the TCO, therefore it is not fundamental for the model. The number of BSs per km^2 does not play a role for the the CAPEX. The OPEX depends on the augmentation of the number of BSs per km^2. The TCO cost depends



(a) The SA of the number of BS n_{vs} per SBS in the CR model.



(b) The SA of the cost of the number of BSs per km^2 in the CR model.



(c) SA of the number of the deployed BSs in the CR model.

Fig. 3: SA of BS parameters in CR models.

on the augmentation of the BSs per km^2. Although there is not a large fluctuation until the cost of the BSs per km^2 becomes 100, the cost of BSs per km^2 augments in an exponential way and therefore, highly affect the costs of both models.

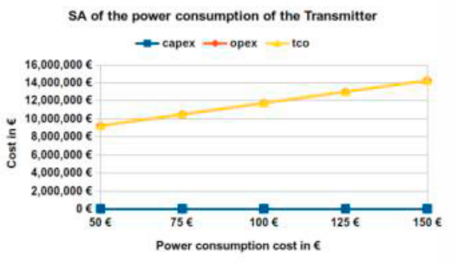
The power consumption costs do not affect the CAPEX. All the power consumption costs affect the OPEX and the TCO. Fig. 4 depicts the costs stemming from the power consumption of the transmitter. The transmitter is the part of the network that transmits the signal. What is more, Fig. 4 depicts the costs concerning the power consumption of the signal rectifiers, air cooler, micorwave, namely the power consumption costs.

All power consumption costs proportionally augment in relation to the power consumption. They affect the OPEX and therefore the TCO. These costs are repeated and are indispensable for the system's functionality. First of all, a possible solution would be to develop solutions that could reduce power consumption, use greener and energy efficient algorithms and methodologies. Another possibility would be the negotiation with the power consumption companies or the development of a specific coordination memorandum between the telecommunication and the power consumption company. A possible idea could be that the telecommunication infrastructure is endowed with power generator mechanisms, such as windmills, solar panels etc. so that the power needed is produced ecologically and economically.

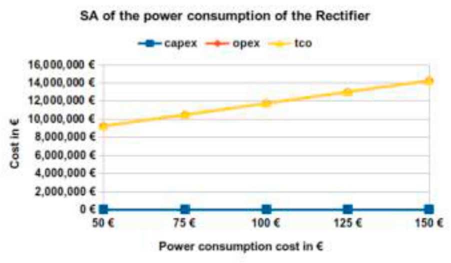
6. Conclusions & Future Work

To sum up, the CR and the SDN are efficient technologies. In order to reduce the overall costs of the proposed models, the OPEX needs to be reduced. There is a particular need in optimizing the number of the BSs needed for the network's proper operation. Much money is spent on power consumption, namely costs linked to the power consumed in transmitter, amplifier, rectifier, air cooling, microwave etc. As a result, several measures concerning the limitation of the power should be taken into consideration.

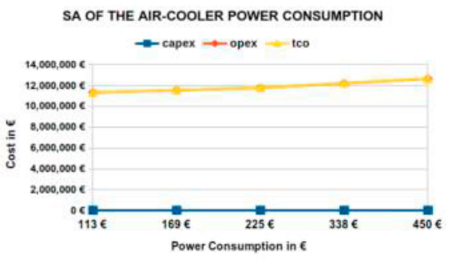
Future research activity in the field should focus on the techno-economic analysis of models of all the 5G key enabling technologies. It is fundamental that measures of reducing the power consumption are investigated, deployed



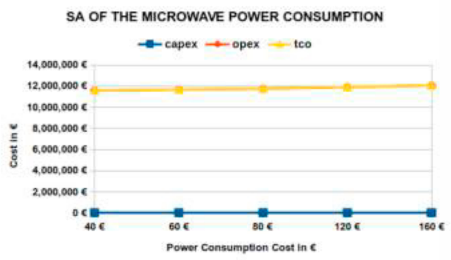
(a) SA of the power consumption of the Transmitter in the CR model.



(b) SA of the power consumption of the Rectifier in the CR model.



(c) SA of the power consumption of the air-cooler in the CR model.



(d) SA of the power consumption of the Microwave in the CR model.

Fig. 4: Power consumption in SDN models

and introduced in future network technologies. More efficient architectures should be developed so that they include smaller and more flexible models with fewer BSs, antennas and networking components.

References

[1] Bouras, Ntarzanos, and Papazois. (2016) "Cost modeling for SDN/NFV based mobile 5G networks." *2016 8th International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT)*: 56–61.

[2] Akyildiz, Nie, Lin, and Chandrasekaran. (2016). "5G roadmap: 10 key enabling technologies." *Computer Networks*. 106. 17–48.

[3] Fomin, and Medeisis. (2015). "Co-evolutionary analysis of cognitive radio systems." *In Modern Trends Surrounding Information Technology Standards and Standardization Within Organizations*. 107–124. IGI Global.

[4] Numan, Yusof, Suleiman, Bassi, Yusof, and Din. (2016). "Hidden node scenario: A case for cooperative spectrum sensing in cognitive radio networks." *Indian Journal of Science and Technology*. 9(46).

[5] Medeisis, and Delaere. (2011). "High-level scenarios for the future of cognitive radio business". *2011 IEEE 22nd International Symposium on Personal, Indoor and Mobile Radio Communications*. 2330–2334. IEEE.

[6] Barrie, Tytgat, Gonçalves, Yaron, Moerman, Demeester, and Delaere. (2011). "Techno-economic evaluation of cognitive radio in a factory scenario". *International Conference on Research in Networking*. 52–62. Springer. Berlin. Heidelberg.

[7] Xie, Yu, Ji, and Li. (2012). "Energy-efficient resource allocation for heterogeneous cognitive radio networks with femtocells." *IEEE Transactions on Wireless Communications*. 11(11). 3910–3920.

[8] Liang, Chen, Li, and Mahonen. (2011). "Cognitive radio networking and communications: An overview". *IEEE transactions on vehicular technology*. 60(7). 3386–3407.

[9] Preet, Kaur, and Sahib. (2014). "Review paper on cognitive radio networking and communications". *International Journal of Computer Science and Information Technologies* 5(4). 5508–5511.

[10] Smail, and Weijia. (2017). "Techno-economic analysis and prediction for the deployment of 5G mobile network". *2017 20th Conference on innovations in clouds, internet and networks (ICIN)*. 9–16. IEEE.