The techno-economic models for CR and SDN in 5G

Christos Bouras*†, Anastasia Kollia†, Eleftheria Maligianni†,
*Computer Technology Institute & Press "Diophantus", Patras, Greece

†Computer Engineering & Informatics Dept., University of Patras, Greece

bouras@cti.gr, akollia@ceid.upatras.gr, maligianni@ceid.upatras.gr

***Abstract*—5G is closer than ever, considering that in 2020 it will have been released. Existing technologies do not adequately cover the 5G demands, therefore new or modified versions of the existing technologies should be introduced. Telecommunication operators remain skeptical about the costs induced by 5G technologies. In this context, it is fundamental that 5G enabling technologies are analyzed in a techno-economic way. In this paper, authors present models of Cognitive Radio (CR) and Software Defined Networking (SDN). They develop economic models based on the Stackelberg competition, opt for the experimentation parameters and conduct Sensitivity Analysis (SA) experiments that show which are the most influential factors for each technology proposing ways to limit them.**

***Keywords*—5G, cost models, SDN, cognitive radio, Stackelberg game, Sensitivity Analysis**

I. INTRODUCTION

The most substantial requirements of 5G networks should be met immediately, because the 5th generation is closer than ever. In 2020, the first commercial products of 5G will be released. A lot of alternative technologies could assist in covering the demands of 5G networks, such as Cognitive Radio (CR), Massive Multiple Input Multiple Output (Massive MIMO), Software Defined Networks (SDN), Network Function Virtualization (NFV), Ultra-dense deployments, Internet of Things (IoT), Device to Device Communications (D2D), Cloud Computing etc. [1].

Although, most of these technologies improve the network efficiency and distribute the available resources in a more efficient way, providers have yet to be rewarded by the investments they have made in new equipment/networking technologies regarding the 4G networks. As a result, they tend to be skeptical for the introduction of novel equipment and in favor of using the existing ones. Today's technologies are not sufficient to cover the 5G services.

It is therefore of extreme significance that techno-economic models of future network technologies are developed. In these terms, a Sensitivity Analysis (SA), namely the method that helps indicating, which of the network parameters, presented in the economic model, have a strong impact on the overall model and their limitations could improve the overall image of a technological advancement alongside with leading to its adoption. SA is used among sets of parameters on different types of models (e.g. financial) to determine to what extent a specific or a specific set of these parameters affect the overall model.

What is more, the Stackelberg game is a game theoretic approach that could contribute not only in reducing the costs but also finding the appropriate equilibrium among the different parameters and the participants in the "game" [2]. In particular, the Leader and the Follower(s) participate in a Stackelberg game. Both parties try to reach the most appropriate solution for them by contemplating the moves of their opponent(s) and end up obtaining the maximum possible profit.

CR is one of the key technologies for 5G networks. In this technology, there are primary and secondary networks and therefore users. The primary users pay for the licensed spectrum and thus, they are priority users in these networks. Secondary Base Stations (BS) include cognitive capabilities, since they should be aware of whether the network is accessed by priority users or not. Although CR has been thoroughly analyzed in a technical perspective e.g. in terms of performance and efficiency in [3], [4] and in terms of energy consumption and efficiency [5] there are not many technoeconomic analyses in the field. [9] analyzes the CR from a techno-economic point of view in a factory-based scenario. A thorough investigation in all the different aspects of the CR has been presented in [6] and [7]. A CR business scenario and how it could contribute and benefit the users is analyzed in [8].

SDN is a technology that helps splitting the control and the data planes leading to more effective controlling mechanisms in the network. It offers the possibility to better allocate the available resources and it also better controls the different devices in the network, as they are depicted in the SDN interface. Its combination with NFV, namely the technology that is responsible for replacing several network components with software, contributes in developing cost-effective and high-performance network models [10]. Ultra-density is a huge trend nowadays, as users alongside their demands tend to largely augment. Therefore, the re-usage of bandwidth without cost increment, provided by small cells (picocells, femtocells, etc.) could consist a viable solution for the mobile networks of the next generation.

This paper extends the techno-economic models of SDN and CR technologies proposed in previous papers.

ISBN 978-3-903176-18-8 ©2019 IFIP

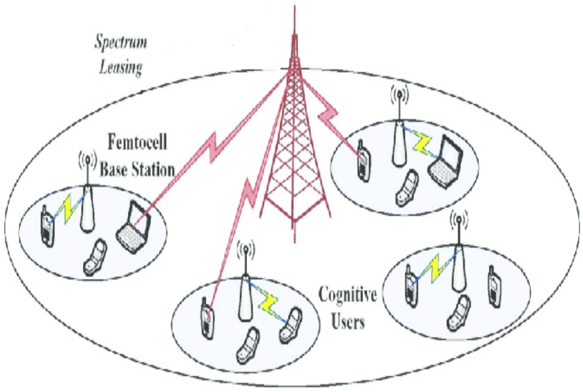


Fig. 1: CR System model based on femtocells [5].

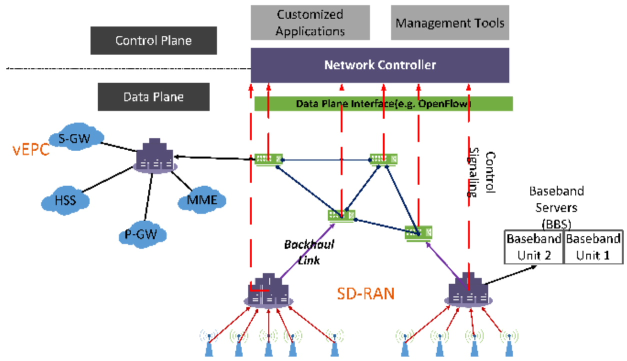


Fig. 2: SDN System model based on [12].

Although, these mathematical models exist, the authors do not conduct a SA. In this paper, a SA is conducted. In this analysis, a lot of different values of the parameters are tested recording the model's behavior. The conducted SA elaborates on the most influential types of costs and indicates, which network parameters have a huge impact on the model and thus limit them, could help reducing the costs or enabling obtaining more profits in these network architectures.

The remaining part of this paper is structured as follows: In Section II the proposed architectures are analyzed and explained. In Section III the developed financial and mathematical models are summarized. In Section IV the experimentation parameters are opted and explained thoroughly. In Section V several experiments concerning the models' viability are conducted. In Section VI conclusions are summarized and future research activity in the field is proposed.

II. Proposed Models

In this section the proposed models are analyzed in a technical way.

A. Cognitive Radio (CR)

The CR model suggested in this paper, includes a telecommunication system, which is a CR network based on femtocells. The combination of CR with femtocells improves the efficiency of the overall system. The network is composed of Multiple Secondary Users (MSUS), a BS, multiple femtocells and Secondary Femtocell Users (FSUS). CR and femtocells are both "aware" of the condition of the channel [11]. CR shares the spectrum between the Primary Networks and/or the femtocells and/or the MSUS. For each femtocell, there is a BS that provides the FSUS with the services needed. It is supposed therefore, that there are L primary networks each one offers a price c_l of a part w_l of the total spectrum. The CR BS buys the w_l amount of spectrum by the primary network L and shares it [5]. Fig. 1 presents the indicative architecture assumed for the CR model.

B. Software Defined Networking (SDN)

NFV enables developing network functionalities using software, instead of conventional network components. SDN splits the control and the data plane and cuts down on the time needed to add novel functionalities. It also reduces the Total Cost of Ownership (TCO). RAN provides with the opportunity to assess the processing in a data center reducing the cost of the network. What is more, RAN offers easier development of services and significantly improves the total functionality of the network by updating the signal using the Evolved Packet Core (EPC). The virtualized interface provides access to the EPC by presenting the natural sources, that are related to the RAN BS [12]. Isolating EPC from RAN allows the optimization of both areas without affecting negatively the communication or an existing demand for constant signaling for the reception of information of the overall network [12]. Fig. 2 depicts the overall architecture that is considered in the SDN scenario.

III. Pricing Model

In this section the developed financial models are presented.

A. Cognitive Radio (CR)

The CR pricing model is based on the Stackelberg Game and is presented below:

1) Stackelberg Game: The Stackelberg game is a strategic game used in the economics. If a company (Leader) makes the first move during the game, its followers should move successively. In accordance to the terms of the Game Theory the participants of the game are the Leader and the Follower(s) and compete purposing to obtain the highest profit. There are several limitations concerning the maintenance of the balance in the Stackelberg game. The Leader should be aware beforehand that the follower monitors his actions. The Follower should not have any means of commitment in any future Stackelberg action and the Leader should also be aware of this fact. The Subgame Perfect Equilibrium (SPE) alongside with the Nash theorem are used in order to ensure the optimized solution of the model and the balance. [2]

- **Nash equilibrium:** If each player has chosen a strategy and no player benefits in the changing of strategies, then the current set of strategy choices and their corresponding payoffs constitutes a Nash equilibrium.

- **SPE:** Each subgame of the overall Stackelberg game has to comply with the Nash equilibrium.

The economic model is developed based on the Stackelberg game. A game between the operator and the users is considered. At the Stage I, the operator that has assumed the role of the Stackelberg Leader determines the total cost of the network. At Stage II the Leader determines the demand of spectrum for the CR BS. At Stage III, given the strategy used for power sharing, the efficiency of the femtocell BS is optimized [5].

2) Inverse Stackelberg Game: In the Stackelberg game, the SPE can be defined using inverse induction, namely starting with Stage III, the qualitative power sharing. In Stage II the size of the spectrum is determined. Finally, in Stage I, the operator determines the optimized decision concerning the price. This technique ensures that a SPE exists.

Stage III, Power sharing: The spectrum (w_l) is shared among the k femtocell BSs, and an optimized energy and power sharing is desirable. According to [5]:

$$\frac{\partial \pi_k(p_k)}{\partial p_k} = \frac{R'_k(p_k)(p_a+p_k) - R_k(p_k)}{(p_a+p_k)^2} = \frac{\phi(p_k)}{(p_a+p_k)^2} \tag{1}$$

where p_k stands for power sharing variable, p_a additional power consumption π represents a function of cost and $R_k(p_k)$ equals the sum $\sum_{l=1}^{L}((\varsigma_{-c_b)x_{lk}w_l log_2(1+\frac{h_{lk}^2 p_k}{\sigma^2}))}$, where ς_k are the expenditures made concerning the femtocell BS, c_b is the spectrum sharing cost of the cognitive BS, x_{lk} is the spectrum sharing indicator, w_l is the spectrum, h_{lk} the energy efficient transmission and finally, σ^2 is the white noise.

Stage II, Spectrum demand of the BS of the CR: After the completion of Stage II, the CR BS determines the size of spectrum that needs to be bought by the primary networks. According to [5] it is defined as:

$$\frac{\partial \pi_b(w)}{\partial w_l} = (\sum_{k=1}^{K} c_b x_{lk} h_{lk} + \sum_{i=1}^{I} \xi_i x_{lili}) - w_l - \theta \sum_{q \neq l} w_q - c_l = 0 \tag{2}$$

where $_{lk}$ signifies that the transmission is energy efficient, xi_i represents the cost of the MSUS of the cognitive BS and θ is the spectrum substitution capability.

Solving the previous equation it is assumed that the amount of spectrum that will be bought by the primary networks is:

$$w_l^* = \frac{(\sum_{k=1}^{K} c_b x_{lk} h_{lk} - c_i)(\theta(L-2)+1)}{(1-\theta)(\theta(L-1)+1)} - \frac{\theta \sum_{q \neq l}(\sum_{k=1}^{K} c_b x_{qkli} + \sum_{i=1}^{I} \xi_i x_{qiqi} - c_q)}{(1-\theta)(\theta(L-1)+1)} \tag{3}$$

where θ is the spectrum restoration capability, L is the number of primary networks, I is the number of secondary users and K is the number of femtocells.

Stage I, Definition of the network pricing: After completing the second stage, the cost of the primary network depends on its own price c_l and by other prices c_{-l} of the other primary networks. For this reason, the definition of pricing among all primary networks is a game $G = Nc_l, \pi_l(\cdot)$, where $N = 1, 2, ...L$ is the number of the players participating in this game and $\pi_l(\cdot)$ is the function of cost for each one of the primary networks l. In this case, the theorem of the Nash equilibrium is applied and in accordance to [5] the following equations arise:

$$\begin{aligned} \frac{\partial \pi_l(c)}{\partial c_l} &= a_1 k_l \frac{(\theta(L-2)+1)}{(1-\theta)(\theta(L-1)+1)} \\ &\quad - \frac{c_l(\theta(L-2)+1)}{(1-\theta)(\theta(L-1)+1)} \\ &+ \frac{(\sum_{k=1}^{K} c_b x_{lk} h_{lk} + \sum_{i=1}^{I} \xi_i x_{lili} - c_l)(\theta(L-2)+1)}{(1-\theta)(\theta(L-1)+1)} - \\ &\frac{\theta \sum_{q \neq l}(\sum_{k=1}^{K} c_b x_{qkqk} + \sum_{i=1}^{I} \xi_i x_{qiqi} - c_q)}{(1-\theta)(\theta(L-1)+1)} \end{aligned} \tag{4}$$

B. Software Defined Networking (SDN)

According to previous research, SDN RAN includes both hardware and virtualized parts [12].

1) CAPEX: 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, there is a number of N_{SBS} SuperBS. The BS are able to transmit in a specific radius, so the maximum coverage radius is represented by R_{max}. There is a specific cost per cell site of the SuperBS and also a cost per SBS unit that are represented by C_{CS-SBS} and C_{SBS} respectively. The total number of users in a specific area is:

$$N_{UE} = l_{SBS} * A = n_{vs} * l * p_i * R_{max}^2 * N_{SBS} \tag{5}$$

The cost for cell site construction for the SBS network is:

$$C_{site} = C_{CS-SBS} * N_{SBS} \tag{6}$$

The total costs for the Super BS in the network will be given by the following:

$$N_{SBSO} = C_{SBS} * N_{SBS} \tag{7}$$

The total cost for the acquisition of the required number of servers and the respecting equipment is:

$$C_{servers} = n_{servers*C_{perServer}} \tag{8}$$

where $n_{servers}$ represents the total number of servers needed in the network, $C_{perServer}$ is the cost of a unit. Then, the total cost of licensing for obtaining the software is given by the following:

$$\begin{aligned} C_{license} &= C_{HSS} + C_{MME} + C_{S-GW} \\ &+ CP - GW + C_{oVS} + C_{OFcontroller} \end{aligned} \tag{9}$$

C_{HSS} is the cost of the subscriber service, C_{MME} is the cost of the mobility management entity, C_{S-GW} is the cost of the gateway service, C_{P-GW} is the cost for the data gateway network, C_{oVS} represents the Open vSwitch cost, $C_{OFcontroller}$ the cost for the flow control and the C_{place} cost for the data space.

Finally, EPC CAPEX is:

$$CAPEX_{EPC}^{SDN} = C_{servers} + C_{license} + C_{place} \quad (10)$$

The total CAPEX for the SDN RAN is given by the sum of the 5, 6, 7:

$$CAPEX_{RAN}^{SDN} = C_{site} + C_{SBSO} = \frac{N_{UE}}{n_{vs} * l * p_i * R_i^2} * (C_{CS-SBS} + CSBS) \quad (11)$$

2) OPEX: The OPEX consists of the costs for power consumption of the network components. The components that induce power consumption alongside with their respecting parameters 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. The power consumption of the SBS could be increased up to 20%, with every slide added in the system. Thus, power consumption is given by the following equations:

$$P_{airSBS} = P_{air} * [1 + 0.2 * (n_{vs} - 1)] \quad (12)$$

$$P_{mwSBS} = P_{MW} * [1 + 0.2 * (n_{vs} - 1)] \quad (13)$$

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 of the Radio Frequency (RF) is given by the following relation:

$$P_{rfSBS} = (P_{trans} + P_{rect} + P_A) * [1 + 0.2 * (n_{vs} - 1)] \quad (14)$$

The total power consumption of a SBS using the 12, 13, 14 is given by the following equation:

$$P_{SBS} = n_a * P_{rfSBS} + n_{vs} * P_{DSP} + PairSBS + PmwSBS \quad (15)$$

The total OPEX of the RAN infrastructure is the outcome of the number of BSs in the area multiplied with the energy consumption per BS and the cost of the Kilo Watt per Hour (KWH) C_{KWH}. Therefore, the total OPEX is given by the following:

$$OPEX_{RAN}^{SDN} = P_{SBS} * N_{SBS} * C_{KWH} \quad (16)$$

The software used for the EPC network functions within VMs and therefore, the OPEX for the EPC is defined by the power consumption of the servers, in which the VMs are located. Thus, the total OPEX for the EPC according to [12] is:

$$OPEX_{EPC}^{SDN} = n_{servers} * P_{perserver} * C_{KWH} \quad (17)$$

3) TCO: Considering the previous analysis [12], the TCO of the technology is given by adding 10, 11, 16 and 17:

$$TCO_{RAN}^{SDN} = \frac{N_{UE}}{n_{vs} * l * p_i * R_i^2} * (C_{CS-SBS} + CSBS) + P_{SBS} * N_{SBS} * C_{KWH} + n_{servers} * P_{perserver} * C_{KWH} + C_{servers} + C_{license} + C_{place} \quad (18)$$

IV. PARAMETER SELECTION

In this section, the parameters for the proposed models are opted. Table I includes all the parameters for both models. Since 5G is a future technology, different prices for the network parameters are opted. All network parameters value within a price range including the today's costs [10]. A +/- 50 % is considered for the price ranges, since financial instability /problems may augment the prices or technological advancements may lead to more efficient and low-cost deployments with lower CAPEX, OPEX and individual costs.

V. EXPERIMENTAL PROCEDURE

In this section, the experiments concerning the proposed models are conducted. In the Flow Chart 1, the experimental process is presented. Firstly, the Stackelberg game is used to consider the costs for the CR and the SDN costs. Several experiments are conducted based on the parameters opted.

Algorithm 1 Experimental procedure

```
1: procedure MATHEMATICAL MODELS
2:     Calculate CR TCO via inverse induction of the Stackelberg game
3:     Calculate SDN TCO
4:
5: procedure PARAMETERS SELECTION
6:     Opt for the parameters for CR
7:     Opt for the parameters for SDN
8:     Opt for the price ranges
```

A. CR vs SDN

In this section, several experiments are conducted in order to indicate which of the two models is the more economically viable and advantageous one. Therefore, the CR and SDN are compared and contrasted. SA is used for the different parameters and several scenarios, which are orchestrated so that the more advantageous architectures are shown.

In all the experiments conducted below for the CR model, θ, namely the parameter of the spectrum substitution, was supposed to be $\theta = -1$. The prices that are $\theta<0$ denote that the used spectrum is used by FBS or MSUS, that are complementary.

Fig. 3 examines the total gain acquired for the primary network for the various prices of c_l, given that there are $L = 10$ primary networks and the number of secondary users and femtocells are $I = K = 5$. Moreover, the pricing

TABLE I: TCO Cost Parameters and System Variables.

Parameter	Description	Value	Value Range for SA
n_{vs}	Number of BS per SBS	6 [10]	[2, 12]
l_{SBS}	Number of users	500 [10]	[100, 1000]
N_{SBS}	Number of BSs per km^2	10 [10]	[1, 1000]
C_{CS-SBS}	Cost of the Cell construction of the SBS	5000 €[10]	[1000, 10000]
C_{SBS}	vBSs deployed	15596 €[10]	[7798, 31192]
R_{max}	Maximum coverage of the BS	200 [10]	$R_{max} > 0$
P_{trans}	Power Consumption of the Transmitter	100 Watt [10]	[50, 150]
P_{rect}	Power Consumption of the Rectifier	100 Watt	[50, 150]
P_{DSP}	Power Consumption of the Digital Signal Processor Power	100 Watt [10]	[50, 150]
P_{PA}	Power Consumption of the Power Amplifier	10 Watt [10]	[5, 15]
P_{MW}	Power Consumption of Microwave	80 Watt [10]	[40, 160]
P_{air}	Power Consumption of Air-cooler	225 Watt [10]	[112.5, 450]
n_a	Number of Antennas	4 [10]	[2, 8]
C_{KWh}	Cost of the Kilowatt per hour	0.25 €[10]	[0.12, 0.5]
C_{place}	Cost for the data space	21 €[10]	10.000,00 e^3
$C_{servers}$	Total cost for the server equipment	72 €[10]	5.262,00 e^3
$C_{license}$	Total cost of licensing for obtaining the software	17 €[10]	5.000,00 e^3
l	primary network	5 [5]	[3, 6]
k	number of femtocell	5 [5]	[3, 6]
L	number of primary networks	10 [5]	[6, 12]
p_k	power sharing	1 [5]	$p_k > 0$
ς	income from the femtocell BS k	3 [5]	$\varsigma_k > 0$
c_b	cost of spectrum sharing of the cognitive BS	1 [5]	$c_b > 0$
σ^2	white noise	$h_{lk}/$ [5]	$\sigma^2 > 0$
p_a	additional power consumption	0.1W [5]	$p_a > 0$
w_l	amount of spectrum	25 MHz [5]	$w_l > 0$
c_l	pricing variable	6 [5]	[0,12]
x_{lk}	spectrum sharing indicator	0.1 [5]	[0, 1]
h_{lk}	energy efficient transmission	200 [5]	$h_{lk} > 0$
ξ_i	cost of the MSUS of the cognitive BS	1 [5]	$\xi_i > 0$
θ	spectrum substitution capability	-1 [5]	[-1, 1]

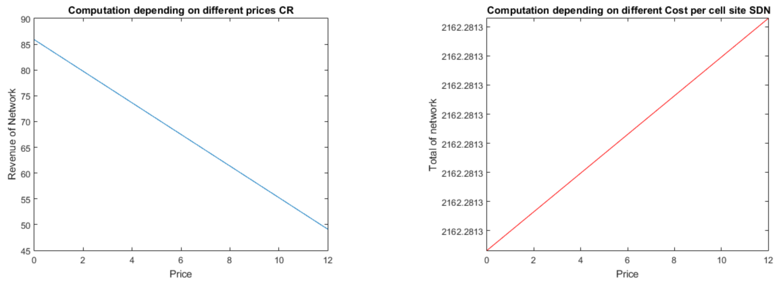
for the rest of the primary networks has been set to $c_q = 2$. Therefore, the larger the c_l the lower the gain of the network becomes. This happens because the gains induced in the network by selling the bandwidth to the secondary users and/or femtocells do not cover the expenses of its constantly increasing price. For the SDN model, the cost per SBS unit remained stable and equal to $CSBS = 2$, while the cost per cell fluctuated within the price range: $Ccsscb = [0, 2, 4, 6, 8, 10, 12]$. The number of users was set as $Nue = 5$. Therefore, as the value of c_l increases, the gain of the network is reduced. The profit of the network earned by the sub-users and femtocells does not cover the costs of its increasing price. At the same time, as the price of the cell increases, the TCO augments as well and the network gains decrease. Throughout the price range the Cost per cell site for the SDN model is constantly increased linearly to the augmentation of the price. On the other hand, the cost for the CR is constantly reduced and that has to do with the profits gained throughout the procedure that stems from the spectrum sharing. Therefore, it seems that CR offers financial benefits in the network.

The total gain of the primary network for the different values of other primary networks c_q is also examined. It is supposed that the number of primary networks is $L = 10$ and the number of secondary users and femtocells is $L = K = 5$. In addition, the value of the primary network is considered as $c_l = 2$. The cost per cell remains stable with $Ccsscb = 2$, while the cost per unit SBS variegated within $CSBS = [0, 2, 4, 6, 8, 10, 12]$. Finally, the number of users is supposed to be $Nue = 5$. (Fig. 4)

In Fig. 4 it is noted that initially the gain had a small decrease but then as the price of the other primary networks increases the gain increases as well, because CR BSs buy more spectrum by the primary network, when other primary networks are more expensive. It is also observed that as the unit cost per SBS increases, so does the TCO and thus, the network gain decreases. In this case, the CR model initially decreases, then its total profit increases, while SDN decreases continuously.

Then the values of the primary networks remain stable($c_l = c_q = 2$), but the number of primary networks is the same as the number of femtocells and secondary users. At the development of the model it was assumed that the sum of the number of femtocells and the number of secondary users equals the total number of primary networks. For the SDN model, during the experiment, the cost values per cell and cost per unit SBS were formed as $Ccsscb = CSBS = 2$ and remained stable, while the number of users variegated within the price range: $Nue = [3, 4, 5, 6, 7, 8, 9]$.

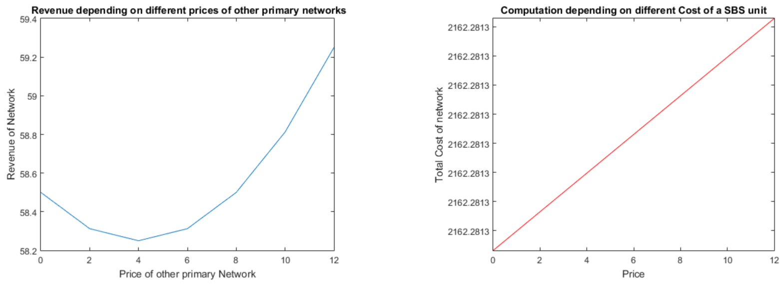
Fig. 5 indicates that the gain increases when the number of primary networks augments. In case there are multiple primary networks, CR BSs have the chance to buy more spectrum, succeeding in paying a lower price. Thus, CR BS revenue increases, and the spectrum demand is raised.



(a) Revenue computation depending on different prices of c_l

(b) Total cost computation depending on different prices C_{csscb}

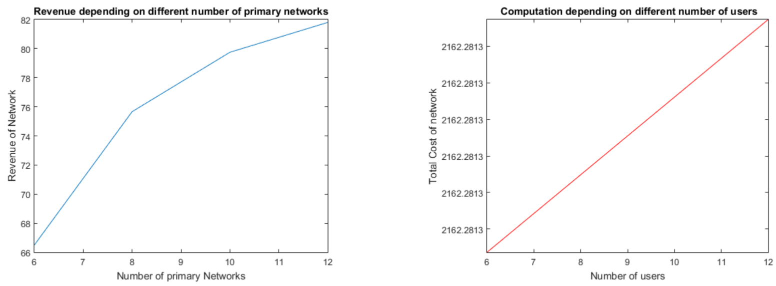
Fig. 3: CR vs SDN



(a) Revenue computation depending on different prices of c_q

(b) Total cost computation depending on different prices C_{scb}

Fig. 4: CR vs SDN



(a) Profit depending on different numbers of primary networks.

(b) Total cost computation depending on the number of users.

Fig. 5: CR vs SDN

It is clear that by increasing the number of users, the TCO increases, and therefore the total profit of the network is reduced. Therefore, the total profit of the CR model continuously increases, while the SDN model, constantly decreases. The Figures (Fig. 5) indicate this great difference and therefore, it seems fundamental to adopt the CR solution, as it brings a huge financial advantage when the number of users is big. What is more, a specific strategy that helps augmenting the users, e.g. throughout advertisement etc. should be developed as the benefits that stems from the augmented users outweighs the expenses of the network.

A case for the CR model is considered, there the number of primary networks and the c_q value fluctuate while the price of the examined primary network remains constant. In Fig. 6, there is an increase in the gain of the number of users because CR BS will buy more spectrum by the primary network when the other primary networks have higher prices, but also they have the chance to buy more spectrum by networks of a lower price. Thus, CR BS revenue increases, and the spectrum demand increases as well. Therefore, it seems that the more primary networks there are in the model the more augmented the revenue is, therefore, the selling of services into primary users becomes indispensable for the augmentation of the profit for the providers.

B. Spectrum substitution parameter $theta = 0$

In this section, several experiments are conducted for the CR case model comparing in accordance to the different prices of the spectrum substitution parameter.

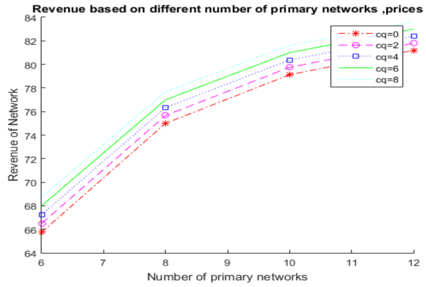


Fig. 6: Profit depending on different numbers of primary networks and c_q prices.

In the experiments conducted below for CR the θ, i.e. the spectrum substitution parameter, is considered as $\theta = 0$, namely that FBS or MSUS cannot be switched between the spectrum.

CR model generates the primary network's total profit for the various c_l values, the number of primary networks is considered stable as $L = 10$ and the number of secondary users and femtocells are considered as $L = K = 5$. Fig. 7 indicates that in both cases, as the price increases, the total profit of the network is reduced. However, it is noticeable that in the case where $\theta = 0$ and the units FBS or MSUS cannot be changed, the total network gain is larger compared to the case where $\theta = -1$. This phenomenon happens, because the spectrum is not shared and thus, more of it could be offered to be sold. Therefore, it is substantial that the revenue of the network is increased and more financial benefits are offered to the network provider.

The total gain of the primary network for the different values of the other primary networks c_q is also examined. Fig. 8 indicates that the total network gain remains stable after any changes in the pricing of the other primary networks. The spectrum is not shared in the other primary networks, so their value does not affect the overall network gain.

What is more, another case is examined in which, the values of the primary networks remain constant ($c_l = c_q = 2$), but the number of primary networks is altered and so does the number of femtocells and secondary users. During the development of the model, it was assumed that the sum of the number of femtocells and the number of secondary users equals the total number of primary networks. In Fig. 9 a slight decrease in the total network gain when the number of primary networks increases is observed. Thus, the gain of the femtocells and secondary users also decreases. So it seems that the augmentation of the primary networks has a negative impact in the revenue stemming from the network.

What is more, the revenue of the network is checked in terms of the prices of the c_l and c_q. In these experiments both prices augment simultaneously. Fig. 10 indicates that when both prices augment then the revenue of the network augments and actually it becomes of great value. Therefore, the pricing variables for the primary networks have a positive impact on the overall model and it is of great importance to augment them both simultaneously in order to find the most advantageous price for the end user and or the provider.

The revenue of the network is computed in relation to the energy transmission parameter h_{lk}. Fig. 11 indicates that the prices of the energy efficient are augmenting and so does the total revenue of the network. The revenue of the network linearly augments in relation to the prices of the h_{lk}. Thus, if the energy transmission cost augments largely it seems that the revenue of the network will also be augmented. As a result, the energy transmission cost is advantageous for the holder of the network, but on the other hand, a larger price in the energy transmission expense may mean that more energy is consumed and there is an environmental impact by the network's activity.

In general, it was shown that the spectrum affects much the TCO of the network. More specifically, the amount and the pricing of the spectrum have a huge impact on the overall TCO. This is normal, because spectrum needs specific licensing and amount of money in order to be acquired. What is more, the augmented number of primary users may augment the amount of money gained from the operators in the network, but there are Service Level Agreements (SLAs), that may burden the operator in case the agreed Quality of Service (QoS) is not met. Thus, this network component has controversial effect on the model. The energy consumption not only has an impact on the pricing of the model but it also augments the environmental footprint of the mobile networks.

VI. Conclusions & Future Work

To sum up, this paper indicates that the CR is not only a very efficient and technologically innovative idea, but it could also be very favorable from a techno-economic perspective. What is more, the CR smart logic could help femtocells and secondary users/BSs to obtain profits by the network's usage and therefore, restrict the costs of their infrastructure or even create new income. SDN offers rather many fundamental benefits for the networks and its TCO is not prohibitive for a provider. What is more, it offers a whole new approach in the network and its combination with NFV contributes in reducing a lot of its costs.

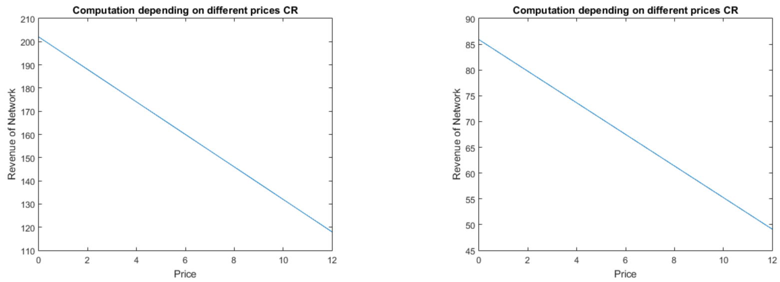
In the future, the bandwidth areas that are suitable for CR implementation should be further investigated. The development of CR architectural and economic models and algorithms as well as optimized protocols are an open issue and they will concern the scientific community. The SDN costs should be drastically reduced and it is of vital importance that technologically innovative ways that will contribute to this direction are developed. What is more, the precarious parts of the SDN should be solved immediately, before its actual set into operation so that the danger of Denial Of Service (DOS) or distributed DOS attacks is diminished.

References

[1] I. F. Akyildiz, S. Nie, S.-C. Lin, and M. Chandrasekaran, "5g roadmap: 10 key enabling technologies," *Computer Networks*, vol. 106, pp. 17–48, 2016.

[2] H. Von Stackelberg, *Market structure and equilibrium*. Springer Science & Business Media, 2010.

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



(a) Profit depending on different numbers of $= 0$

(b) Total cost computation depending on the different numbers of c_l, $= -1$

Fig. 7: $\theta = 0$ vs $\theta = -1$

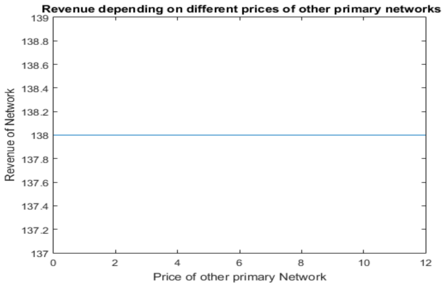


Fig. 8: Profit depending on different numbers of c_q.

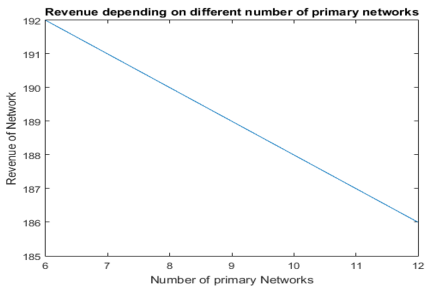


Fig. 9: Profit depending on different numbers of primary networks.

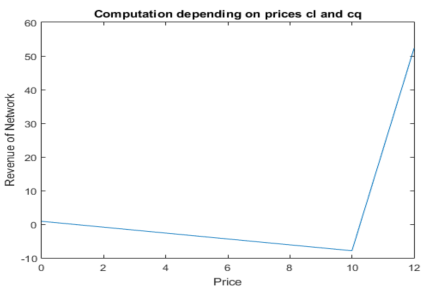


Fig. 10: Computation of the revenue of the network in relation to c_l and c_q.

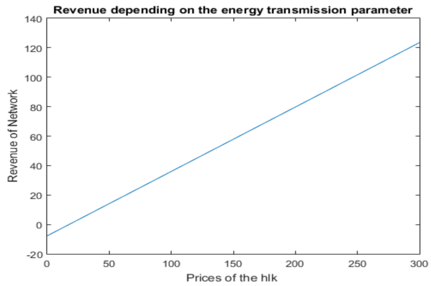


Fig. 11: Computation of the revenue of the network in relation to the energy transmission parameter h_{lk}.

[4] P. E. Numan, K. M. Yusof, D. U. Suleiman, J. S. Bassi, S. K. S. Yusof, and J. B. Din, "Hidden node scenario: A case for cooperative spectrum sensing in cognitive radio networks," *Indian Journal of Science and Technology*, vol. 9, no. 46, 2016.

[5] R. Xie, F. R. Yu, H. Ji, and Y. Li, "Energy-efficient resource allocation for heterogeneous cognitive radio networks with femtocells," *IEEE Transactions on Wireless Communications*, vol. 11, no. 11, pp. 3910–3920, 2012.

[6] A. Preet, A. Kaur, and S. F. Sahib, "Review paper on cognitive radio networking and communications," *International Journal of Computer Science and Information Technologies*, vol. 5, no. 4, pp. 5508–5511, 2014.

[7] Y. C. Liang, K. C. Chen, G. Y. Li, and P. Mahonen, "Cognitive radio networking and communications: an overview," *IEEE Transactions on Vehicular Technology*, vol. 60, no. 7, pp. 3386–3407, Sept 2011.

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

[9] M. Barrie, L. Tytgat, V. Gonçalves, O. Yaron, I. Moerman, P. Demeester, S. Pollin, P. Ballon, and S. Delaere, "Techno-economic evaluation of cognitive radio in a factory scenario," in *International Conference on Research in Networking*. Springer, 2011, pp. 52–61.

[10] C. Bouras, A. Kollia, and A. Papazois, "Sdn & nfv in 5g: Advancements and challenges," in *Innovations in Clouds, Internet and Networks (ICIN), 2017 20th Conference on*. IEEE, 2017, pp. 107–111.

[11] S. Haykin *et al.*, "Cognitive radio: brain-empowered wireless communications," *IEEE journal on selected areas in communications*, vol. 23, no. 2, pp. 201–220, 2005.

[12] C. Bouras, P. Ntarzanos, and A. Papazois, "Cost modeling for sdn/nfv based mobile 5g networks," in *2016 8th International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT)*, Oct 2016, pp. 56–61.