The agent-based model of the dynamic spectrum access networks based on the bilateral bargaining

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Abstract. This paper describes a simple bargaining mechanism that allows autonomous agents to engage in a bargaining decisions taking place in the dynamic spectrum access market. The agents take on the role of operators which aims to purchase the frequency spectra on the wholesale market and in turn, provide the services towards the end-users. In the paper, the wholesale distribution of the resources in the agent-based model is governed by the bilateral bargaining between the operators and the spectrum broker. The aim of such an interaction is to reach agreements (agreement in terms of the negotiated wholesale price and number of contracted channels) through an iterative bargaining. The operators aim to attract the end-users via dynamic retail pricing scheme. The activity of the end-users follows the truncated Gaussian distribution, which mimics the activity of the end-users throughout the daily cycle. The numerical results suggest that the model is capable of capturing the stochastic activity of the end-users, which reflects itself in the variable operator's profit and retail price.

Keywords: agent-based modeling, cognitive networks, electronic markets, MASCEM

1 Introduction

The spectrum trading allows the holders of the certain spectrum licenses to transfer or lease all or part of their rights and obligations under their license to another party. Several countries have implemented spectrum trading, but the trading process is often time-consuming, hence hampering the usage. The UK regulator Ofcom is in the forefront on the spectrum trading arena, allowing spectrum sale and spectrum leasing [1]. The relevance of the spectrum leasing raises its further importance in conjunction with the concepts of the software-defined radio (SDR). SDR enhances the efficiency of the frequency spectrum utilization through the embedded software allowing the terminal to operate in multiple frequency bands using multiple transmission protocols [2]. Spectrum leasing and SDR are technologies coined throughout the paper as the dynamic spectrum access (DSA) strategies.

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DSA strategies fundamentally change the traditional telecom model based on "vertical integration". Here the single entity delivers the service, maintains the network and the network infrastructure [3]. Originally, the available services were mainly limited to the telephony, the radio, and the television. However we do witness the convergence of these services nowadays and also the roles of the service provider and the network owner are separated, and the service providers get access to the network and the end customers through the secondary spectrum trading on fair and non-discriminatory conditions [4]. This telecommunication concept is recognized as the open access network.

Most trades today are direct trades between organizations with the regulator as an intermediate giving the final consent to commit the trades. However, in order to facilitate spectrum trades on a shorter time scale an organizational unit such as a band manager could be introduced to mediate between the traders. Furthermore, the organizational units could be introduced to monitor for compliance with the committed trades and that the spectrum is not misused. Overall, an ecosystem is required in order to realize the spectrum micro-trading. Therefore, in this paper, we propose an agent based model of dynamic spectrum access network capable of capturing key network characteristics.

2 Agent-based model

In order to simulate the spectrum trading in the open access spectrum network, we propose the model based on a MASCEM [5] which simulates a behavior of a subjects taking place in the electricity markets. Similarly to the DSA network, MASCEM includes both the wholesale and the retail market where the bilateral negotiation is implemented. Inspired by the electricity markets, our model uses the following price shaping functions on the wholesale market:

$$starting\_offer_{i+1} = starting\_offer_i \pm \delta_{i+1} \quad (1)$$

$$\delta_{i+1} = starting\_offer_i \times \left(\beta + \frac{\Delta_i}{BWavail_i \times \alpha}\right) \quad (2)$$

$$\Delta_i = BWavail_i - BWleased_i. \quad (3)$$

The new starting offer $starting\_offer_{i+1}$ depends on the $starting\_offer_i$ from the previous period's offer. The formula scales the change by a ratio to lease all the available capacity. The amount of change increases with the difference between the amount of the bandwidth (BW) administrator wanted to lease and the amount it actually leased. α and β are price-shaping parameters.

The negotiation itself consists of the time bounded series of rounds during which the operators and the administrator negotiate the contract conditions according to:

$$offer_{i+1} = offer_i \pm \varepsilon. \quad (4)$$

The price-change value is denoted as ε. While the administrator lowers its price with the given ε, the operators do increase their offers with the ε. When negotiating, neither of the stakeholders exceeds its $limit\_price_i$ which is set at the beginning of the each series according to:

$$limit\_price_i = starting\_offer_i \pm \vartheta\ , \tag{5}$$

where the ϑ represents the limit offer parameter. When the negotiation successfully finishes, the operators consider the amount of spectrum according to the negotiated price. Higher the final price, lower the amount of the channels will be leased. Due to the different characteristics of the frequency spectrum and the electric energy, it is necessary to define suitable rules that will be applied when the trading takes place on the retail market. The acceptance probability function was adopted from [6] with some slight modifications. The spectrum obtained via bilateral negotiation is sold to the end-users on the retail market for the prices accommodated by the end-users demand. The following equations are used for the per channel retail price calculation:

$$p_i = p_{i,t} + \left(\Psi_{i,t-1} - 0.5\right) \times \mu \tag{6}$$

$$\Psi_{i,t-1} \begin{cases} 1/2 & (BWavail_i = 0) \wedge (S_i = 0) \\ 0 & (BWavail_i > 0) \wedge (S_i = 0) \\ S_i^{idle \rightarrow conn}/S_i & (BWavail_i > 0) \wedge (S_i > 0), \end{cases} \tag{7}$$

where $BWavail_i$ represents the amount of the available frequency channels, S_i is the total number of the end user connection attempts towards a particular operator and $S_i^{idle \rightarrow conn}$ denotes the number of successful connections.

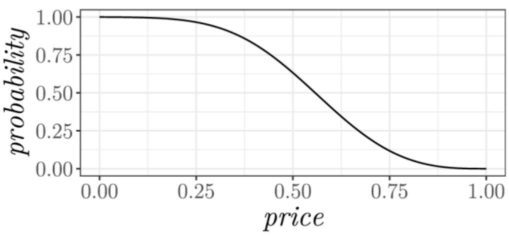

Figure 1 Acceptance probability according to retail price

The behavior of the end-users introduces the stochasticity to the model. During the simulation, their state is being switched between the following three different options: IDLE, ACTIVE and CONNECTED. The state change IDLE → ACTIVE occurs randomly with a probability that changes during daytime on the interval $\langle 0.1; 0.8 \rangle$ with the Gauss-like curve. In the ACTIVE state, the end-users in order to obtain the available frequency channels actively search for the most suitable operator providing the best offer. Each offer is evaluated with the acceptance probability AP by:

$$AP_i = 1 - e^{-c(1-p_i)^{\gamma}} \tag{8}$$

The higher the value of AP the more probable the connection will be successful. The values of c and γ adjust the end-users sensitivity towards the price p of the i-th operator. Figure 1 shows the end-users sensitivity when the parameters c and γ are set according to Table 1.

3 Simulation Results

The presented data illustrate the key aspects of the model behavior during the period of the five simulated days, each consisting of 500 virtual time units. The model was set according to the Table 1 in order to imitate the real world. The end-users sensitivity towards the utility reflects the signal decay and also affects the overall activity of these users. The values of price-shaping and the negotiation parameters of MASCEM inspired mechanism, as was found, are tightly bounded with the model configuration and were therefore found using a modified model which had an ability to vary the parameter values on fly in order to maximize the profit and the spectrum utilization. The retail market mechanism was set according to [6].

Table 1 Simulation parameters

Parameter	Value	Description
N_{bts}	1	Number of base stations
BW_{total}	200	Total number of available channels
N_{inv}	2	Number of operators
$N_{end-users}$	$\langle 300; 500 \rangle$	Number of end-users
α_{adm}	-0.7	Price-shaping parameter of administrator
β_{adm}	0.02	Price-shaping parameter of administrator
α_{inv}	-3	Price-shaping parameter of operator
β_{inv}	0.1	Price-shaping parameter of operator
p_{min}	0.15	Minimum wholesale price
ε	0.01	Negotiation parameter
P_{act}	$\langle 0.1; 0.8 \rangle$	End-users' activation probability
P_{disc}	1	End-users' disconnection probability
ϑ	0.3	Limit offer parameter
γ	3	End-users' price sensitivity parameter
δ	0.5	End-users' utility sensitivity parameter
μ	0.2	Price coefficient
c	8	Acceptance probability parameter

Figure 2 illustrates the most important characteristic of our agent based model. The presented data were collected from the simulation with the fixed number of the end-users (450 users). In the Negotiation process plot, the price lag can be observed. The situation, when the price increases much slower than the end-users' demand. The consequences of the described lag can be seen in the Operators' profit plot which is higher at the beginning of a day despite a significantly lower demand. After the peak utilization, the negotiation starts the prices to decay to the preset minimum and the retail price becomes more volatile, due to the smaller number of the active end-users.

To verify the model's stability with a different environment setup, we run multiple simulations with the increasing number of the end-users. The each setup was run multiple times and it consisted of 30 simulated days during which data were collected and each plotted dot represents mean value of 15000 entries.
From the Figure 4, we can conclude that increasing number of end users, results in the increasing spectrum demand and its variance too. Higher demand causes the higher wholesale prices that have the higher variance due to the MASCEMs characteristics of the negotiation process. The mean retail prices are also raised but unlike the wholesale price, more active users result in the less volatile prices.

4 Conclusion

This paper describes the implementation of a spectrum trading mechanism in a NetLogo agent based model inspired by the electricity market model called MASCEM. An administrator owning the spectrum license, the operators providing the services using a rent infrastructure and the end-users benefiting from the operators' competition were included into the model in order to simulate an operation of such network. The presented results show that the bilateral negotiation between the stakeholders, an administrator and the operators, on the wholesale market produces the satisfactory results in capturing the stochastic activity of the end-users whose activity follows the truncated Gaussian distribution in order to mimic a daily cycle. However, the observed price lag makes space for further improvement.

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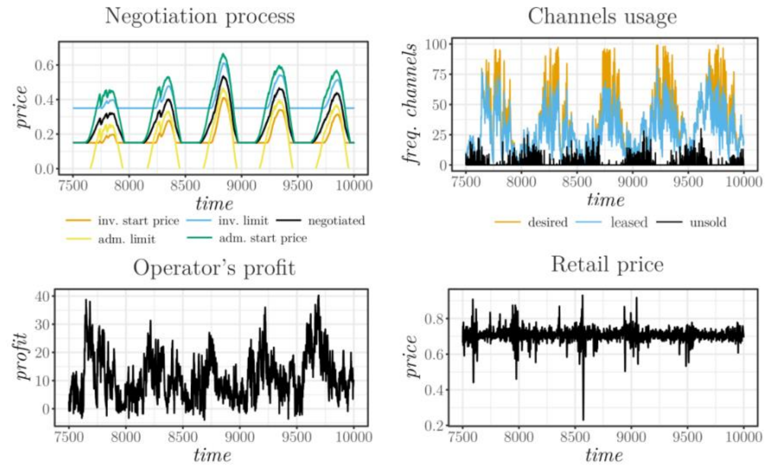

Figure 2 Real-time behavior of spectrum trading model inspired by MASCEM

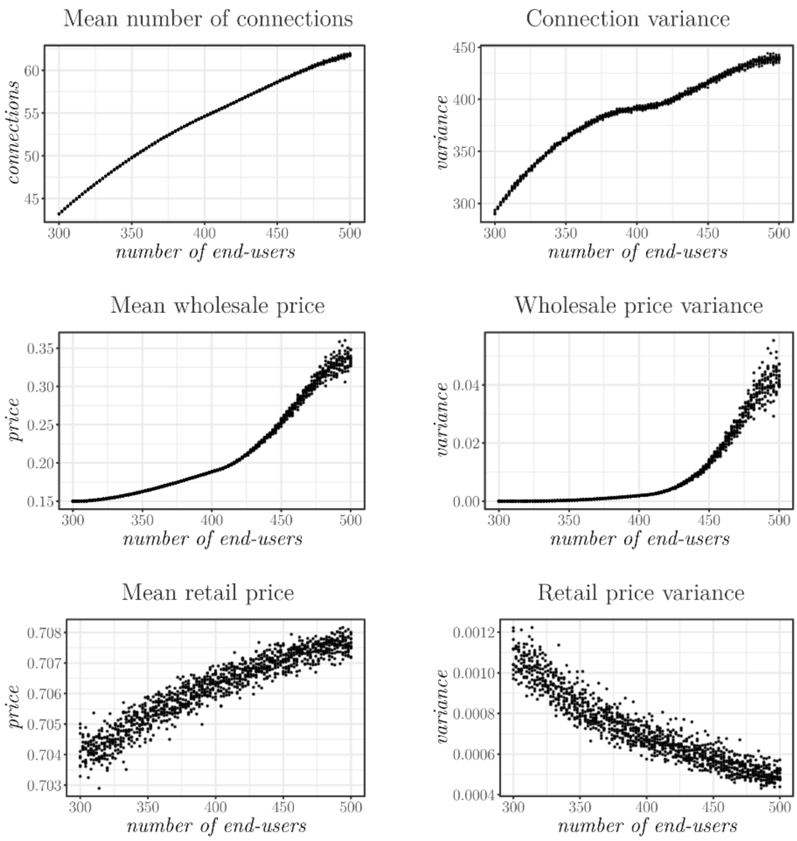

Figure 3 Model behavior with increasing number of end-users