Towards spectrum micro-trading

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Abstract: Spectrum trading is an important tool to increase overall spectrum utilization and to open up opportunities for businesses to get access to desired spectrum. It has been implemented in some countries for some spectrum bands. At the same time, systems and architectures for cognitive radio technologies are being developed that are able to dynamically use spectrum bands in more flexible manners including functionalities such as dynamic bandwidth, spectrum band concatenation, sensing, channel switching and cognition. However, the current spectrum trading regimes usually require long times to execute a trade, hence limiting the flexibility over short time scales. In this paper we study spectrum micro-trading as a concept to enable trading of spectrum at the micro scale in at least three dimensions; on the micro-spatial, micro-temporal and micro-frequency scale. The ecosystem required for spectrum micro-trading and the most important metrics are defined; market viability, spectrum utilization, channel quality and social welfare. Furthermore, we propose a model for spectrum micro-trading, the Micro-trading Pixelation Model, which addresses the three dimensions on the micro scale. We then discuss the main challenges and issues that have to be solved for the realization of spectrum micro-trading with the proposed model. Finally, some initial simulation results are provided to demonstrate the performance of spectrum micro-trading.

Keywords: Cognitive Radio; Spectrum Trading; Spectrum Micro-trading; Spectrum Market; Trading Metrics; Ecosystem

1. Introduction

Secondary spectrum trading allows the holders of certain spectrum licences to transfer or lease all or part of their rights and obligations under their licence 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]. It has also taken steps towards streamlining the trading process and allowing trades without requiring notifications of trades. We consider this to be steps in the direction of spectrum micro-trading which has the potential to improve spectrum utilization and promote innovation.

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 traders. Furthermore, organizational units could be introduced to monitor for compliance with committed trades and that the spectrum is not misused. Overall, an ecosystem is required in order to realize spectrum micro-trading. We therefore identify an ecosystem for spectrum micro-trading and discuss the responsibilities and critical challenges for each of the roles in the ecosystem.

Many models for spectrum trading have been studied by using different simulation tools and methods such as discrete-event simulation [2], agent-based computational economics
[3][4], multi-agent reinforcement learning [5][6], and game theory [7][8]. Many of these tools and models are suitable for the modelling of a spectrum micro-trading market; however, we find limitations in that none of the models currently support implementation of spectrum micro-trading in all dimensions (spatial, temporal, frequency, price). Therefore, we propose a model with high flexibility referred to as the Micro-trading Pixelation Model, whose main aim is to implement spectrum micro-trading in all dimensions, especially on the micro-spatial, micro-temporal and micro-frequency scale. Furthermore, we discuss the major challenges that are introduced with spectrum micro-trading and the proposed model.

The main contributions of this paper are the definition of an ecosystem (Section 3), the definition of the most important metrics for spectrum micro-trading (Section 4), the proposal of a flexible model for spectrum micro-trading (Section 5) and finally the initial simulation results which demonstrate the validity of spectrum micro-trading (Section 6).

2. Related Work and State of the Art

Peha et al. [2] quantitatively assess real time secondary markets for the special case of a cellular licence-holder. It is demonstrated that many secondary users can access spectrum with little impact on the primary cellular customers, and that cellular carriers profit, even if the price for secondary access is quite low. The results also indicate that the break-even price of secondary access would be roughly proportional to bandwidth, and to distance from secondary transmitter to receiver.

Caicedo et al. [3,4] focus on determining the conditions for viability of spectrum trading markets by considering scenarios with different market structures, number of trading participants and amount of tradable spectrum by using Agent-based Computational Economics (ACE) to analyze each market scenario and the behaviours of its participants. As the main and important result, they indicate that spectrum markets can be viable in a service, if sufficient numbers of market participants exist and the amount of tradable spectrum is balanced to the demand. Interestingly, they conclude that given that a minimum of five to six active spectrum users are necessary in a particular service area, it seems unlikely that spectrum markets will be viable in mobile markets unless barriers for market entry are lowered.

An auction based approach for service provider spectrum trading was studied in Abji et al. in [5] using a bid-proportional auction and multi-agent reinforcement solutions. They show that for a single provider, revenue can be maximized by artificially limiting supply and creating contention. However, when there are multiple providers from which the customers can dynamically choose, there is no longer an incentive to restrict supply between service providers. Abji et al. demonstrate in [6] that the allocation of spectrum is efficient and fair, that customers and service providers of varying size benefit from the approach while system spectrum efficiency is significantly improved.

Niyato and Houssain [7] propose an approach for a distributed set of traders with imperfect information about offered prices. The authors propose a learning algorithm, which is an exponentially-weighted moving average of past prices. In [8], they look at an approach without a central spectrum broker. Buyers can adjust their buying behaviour by monitoring variations in the price and quality of available spectrum opportunities available from sellers. Sellers adapt their pricing of spectrum opportunities to maximise their own utility functions.

The UK regulator Ofcom has addressed many regulatory issues related to spectrum trading [9]. This involves topics such as what type of transfers that are possible, the steps and information required in a transfer process, authorization of a transfer and the legal background. Many of the issues discussed will be applicable for spectrum micro-trading, but the trading process is often complex and should be automated to execute on a micro time-, geographical- or frequency-scale. However, it is important to maintain security and trust while automating this. Therefore it is important to have well-defined interfaces and contracts between actors in a spectrum market.

The different types of transfers allowed by Ofcom [10] are summarized in Table 1.
Spectrum trading has been limited to certain bands until 2011, but a notice of proposals was published in [11] to extended spectrum trading to mobile and cellular bands (900MHz, 1.8GHz and 2.1GHz). Recently, Ofcom also introduced spectrum leasing which mainly differs from the spectrum transfer in that the responsibility for compliance with the licence regulations remains with the spectrum lessee. Furthermore, Ofcom simplified the spectrum trading by simplifying the leasing process and allowing limited sub-leasing [1].

3. Ecosystem for Spectrum Micro-trading

The ecosystem for spectrum micro-trading will be very similar to the general ecosystems for telecommunication markets and cognitive radio networks, studied for example by Grøndalen et al. [12], but an entity such as a spectrum broker that arranges transactions between spectrum traders might be necessary in order to mediate between traders in most market structures. The roles identified to be involved in a spectrum market are illustrated in Figure 1.

3.1 Spectrum Trader

The spectrum trader is an organizational unit that buys, sells, leases or rents spectrum. Furthermore, each spectrum trader can both be a seller and buyer or a leaser and lessee. It will therefore also be possible for a spectrum trader to speculate in the spectrum market. The spectrum trading actors that can be expected to participate in the spectrum market are:

**Spectrum licence owner:** this actor owns spectrum that it wants to sell or lease on the spectrum market. Typical spectrum licence owners are TV broadcasters, wireless and mobile operators, the military, radar communications operators, public safety operators (health care, fire brigade, police), and aviation operators.

**Secondary or cognitive radio operator:** this actor will participate in the spectrum market as a spectrum buyer or lessee in order to buy or rent spectrum. This will typically be a new operator without existing wireless spectrum licences that needs spectrum to offer a wireless service. However, a spectrum licence owner that needs more spectrum in order to serve increasing spectrum demand could also act as a secondary or cognitive radio operator.

**Secondary or cognitive radio device:** this actor will have the same role as the secondary or cognitive operator, but will differ in that it is the radio device or end-user that participates in the spectrum market as a buyer or lessee instead of the operator. This could be machine to machine (M2M) communications such as wireless metering that rents spectrum for a very short period in order to transmit metering information.
**Spectrum speculator:** this actor will participate in the spectrum market with the intention to make profit by buying spectrum at low prices and selling at higher prices. They are expected to have a positive effect on the trading system, as they will take the roles as market makers. The fact that the speculators will profit from their activity should be seen as a consequence of their willingness to take risk associated with the trading of spectrum.

3.2 **Spectrum Broker**

A spectrum broker in the spectrum trading market is analogous to a broker in the stock exchange market, or analogous to an electronic stock exchange. The spectrum broker can then be defined as a party which arranges transactions between a buyer and a seller or lessee, and gets a commission when a deal is executed. A spectrum broker might have several additional properties such as providing market information about prices, spectrum details and market conditions. A spectrum broker would behave differently depending on the marketplace used such as in auction-, price- and order-driven markets.

Little practical experience on spectrum brokerage exists, but in theory several different actors could operate a spectrum broker. A first option is that an independent third party operates the spectrum broker, which either could be a non-profit organization established by the regulator, or it could be a commercial company aiming to profit from running the spectrum broker. In both cases, the spectrum broker could be independent of the interests of the spectrum sellers or buyers. Another option is that the regulator operates the spectrum broker itself. As a third option, in the case where a primary operator owns many licences that it wants to lease, the primary operator could operate the spectrum broker itself.

The number of spectrum brokers in a spectrum market is not limited to one. Several models are possible. In the simplest model, one spectrum broker organization is responsible for operating the spectrum market and the whole frequency band. In this model, several spectrum brokers could operate in a hierarchical structure serving different geographical areas or spectrum bands. In a second model, different spectrum broker organizations could operate different regions or spectrum bands. Finally, several spectrum broker organizations could compete for customers while operating in the same regions and spectrum bands.

In cases where spectrum bands are unlicensed, the only fee from the traders could be to obtain information about spectrum. In this case, the spectrum broker could operate as a relay towards the spectrum databases.

3.3 **Spectrum Database**

A spectrum database contains information about the radio spectrum to be traded. This could be information about who owns the licence of the spectrum, who uses the spectrum, spectrum occupancy, spectrum availability, noise and interference in a spectrum band etc. This information could be retrieved from sensor networks, geo-location databases, wireless communication operators or it could be downloaded from databases held by the regulator.

The spectrum database owner could be the same actors identified to operate a spectrum broker; an independent third party, the regulator or a primary operator.

The number of spectrum databases and spectrum database owners is not limited to one. For instance, in the US, 10 spectrum database owners will operate a database system for the same secondary spectrum resources (TV White Spaces [13]) in the same areas, which is considered to be important for increased innovation. Communication between the spectrum databases is then required since the databases maintain the same spectrum bands.

3.4 **Wireless Sensor Network**

A wireless sensor network (WSN) will monitor the radio spectrum to be traded for a given area. The WSN can provide much of the same information as a database. However, it can provide more detailed information about the real-time spectrum status, such as noise, interference and detailed location information of radio emitters. This information can also be reported (sold) to a spectrum database. This concept was studied in detail in the EU FP7 project SENDORA [14]. The WSN can be embedded in the cognitive radio terminals, or it
can be a separate standalone WSN. It can also be a hybrid approach. The density of the standalone WSN must be sufficiently high to ensure an acceptable probability for detecting primary users. The required density was estimated by Grøndalen et al. [12] for the case of a LTE network as the primary system. Solutions for dense sensor networks in WSN aided cognitive radio systems have been proposed and evaluated both technically by Grønsund et al. [15] and economically [12].

There can be multiple WSN owners present in a spectrum market. These could sense different spectrum bands or cooperate to enhance the performance of spectrum detection.

As a potential solution to the problem of monitoring compliance of committed spectrum trades and of ensuring that the spectrum trading regime is not misused, the WSN could act as spectrum police. Sensors could be stationary or mobile operating as the spectrum police. Handhelds with embedded sensors could also go undercover.

3.5 Spectrum Regulator

The spectrum regulator is interested in having a high utilization of the spectrum resources and in ensuring that people get high quality services. Since a spectrum market will simplify access to spectrum and enable more dynamic use of spectrum leading to higher spectrum utilization, the regulator will be interested in this. However, with incautious regulation of a spectrum market there might be a risk that the spectrum market will lead to unfair spectrum allocations, increased interference and unhealthy competition. The main task of a spectrum regulator in a spectrum market will be to set out the rules, policies and processes that must be adhered to in a spectrum market. The UK regulator Ofcom and US regulator FCC have implemented spectrum trading as reported in Section 2, but especially the trading process must be simplified in order to execute spectrum trades on a micro timescale. We have seen that Ofcom is taking steps towards a simpler trading process for spectrum leasing [1].

An important area for the regulator is to control the impact of trading on competition. This is one of the reasons why long periods are required to execute a spectrum trade in order to conduct competition checks before committing a trade. Alternatively, ex-post regulation could be used for competition checks and take effect only if unhealthy competition is found.

3.6 Vendor

Both hardware and software vendors will be important in the ecosystem. For example, terminal, base station and core network vendors are important in order to implement the required cognitive functionality and trading functions in wireless networks. The vendor will also be important for implementing the spectrum broker, spectrum database and WSN.


The metrics used will depend upon the market structure; for example, it could be a primary-secondary regime, or a regime where market participants are only primary or only secondary users. When studying state-of-the-art on spectrum trading, we notice that many different metrics are used to study the performance of the assumptions and models used. Therefore we have done a detailed study to define the main high level metrics for spectrum micro-trading:

A. Market Viability: Will the micro-trading market be viable?
B. Channel Quality: How will the channel quality be impacted by micro-trading?
C. Spectrum Utilization: Will the micro-trading improve spectrum utilization?
D. Social welfare: Will social welfare be improved, and who benefits from micro-trading?

The metrics might be specific to one or more of the roles and actors defined in the ecosystem; for example, social welfare could be specific to the regulator. These metrics are further divided into a set of sub-metrics as given in Table 2.
Table 2 Submetrics for spectrum micro-trading

<table>
<thead>
<tr>
<th>Description of sub-metrics for spectrum micro-trading</th>
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<tbody>
<tr>
<td><strong>A.1 Liquidity</strong>: Market liquidity can be defined as an asset’s ability to be sold without causing a significant movement in the price and with minimum loss of value. High liquidity in a market is a good indicator that the market is viable. A measure for liquidity could be the bid-ask spread (i.e. the spread between the buying and the selling price) relative to the price of a spectrum block in a market (defined as relBA=bid-ask spread/spectrum block price in [3]). High and low values of relBA would indicate high and low marked liquidity. If relBA is high, there would be high resistance in the market to go from a selling position to a buying position. If relBA is low, the resistance to trade is low since it would be easy for a trader to establish a trade with only a small change in price.</td>
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<tr>
<td><strong>A.2 Trading Volume</strong>: can be measured as the trading activity (e.g. the number of completed trades). This is a good indicator for market sustainability that relates to the running behaviour of the market.</td>
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<td><strong>A.3 Profitability</strong>: The main motivation for most actors in the ecosystem is to increase profitability. The best measure for one actor would be ROI (Return on Investment), including both revenues and costs.</td>
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<td><strong>A.4 Spectrum price</strong>: Low values of spectrum price would indicate that there is an excess in supply of spectrum, whereas high values would indicate low supply or high demand.</td>
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<td><strong>A.5 Blocking rate</strong>: can be characterized by the number of spectrum buyers or lessees that fail to acquire spectrum through the spectrum market. If this number is high, it might either be that the demand is higher than the supply in the market, which indicates low market viability.</td>
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<tr>
<td><strong>B.1 Interference</strong>: should be measured both from and to spectrum lessees that fail to acquire spectrum through the spectrum market. If this number is high, it might either be that the demand is higher than the supply in the market, which indicates low market viability.</td>
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<td><strong>B.2 Throughput</strong>: is dependent on the technology used (e.g. bps/Hz), but experienced throughput might be degraded by interference, propagation effects and allowed transmit power. Throughput is a well-known measure for the perceived channel quality that can be normalized for comparison.</td>
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<tr>
<td><strong>C.1 Spectrum Exploitation</strong>: indicates exact spectrum exploitation as used spectrum blocks in the market.</td>
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<tr>
<td><strong>C.2 Allocation efficiency</strong>: can be defined as the time used to allocate spectrum. Since spectrum will remain idle for the period required to allocate spectrum, this measure effects spectrum utilization.</td>
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<tr>
<td><strong>D.1 Social welfare function</strong>: a real-valued function that ranks conceivable social states from lowest to highest. Useful to find the model for spectrum micro-trading that maximizes the utility of all actors.</td>
</tr>
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</table>

5. A Practical Approach to a Spectrum Micro-trading Market

The main requirement for a micro-trading model is that a required number of parameters and units should be defined such that the trading market can be able to match asks and bids in trades. The second requirement is that the spectrum micro-trading model should support micro trading in three dimensions; the spatial, the temporal and the frequency dimensions:

- **Micro-spatial scale**: the model is required to support spectrum transfers of small areas (e.g. 50m²) as well as larger areas (e.g. 1000km²).
- **Micro-frequency scale**: the model is required to support transfers of narrow frequency blocks such as down to 100kHz and wide frequency blocks such as 100MHz.
- **Micro-temporal scale**: the model is required to support short time intervals between spectrum transfers such as down to 1 second as well as longer time periods up to 10 years.

To meet these requirements, we introduce the model illustrated in Figure 2 for spectrum micro-trading, the “Micro-trading Pixelation Model”. In this model, we fix the parameters and units for the spatial, temporal and frequency dimensions in addition to the price unit.

![Figure 2 Illustration of the Spectrum Micro-trading Model](image)
5.1 The Spatial Domain

The geographical area is fixed into pixels of two geographical dimensions $X \times Y$ meters (e.g. 100·100 meters). $X$ describes the latitude and $Y$ describes the longitude. This concept is illustrated in Figure 2(a) and will be referred to as pixelation. Short range devices and services such as device-to-device communications can bid for a low number of pixels, and long range communications such as rural broadband can bid for several consecutive pixels.

Furthermore, a $Z$ axis could be used to describe height, which might be useful in densely populated urban areas with tall buildings. The pixels would then transform into boxes.

A set of information elements important for the trading process can be associated with each pixel. We have identified the following information elements; population, vegetation (for example, trees, building heights), propagation effects (e.g. average path loss exponent), height above sea, type of customers (e.g. business, school), and climate (e.g. rainy, snowy). Many of these information elements could for instance be used for spectrum pricing. The information could be accessible to the spectrum broker itself, the traders and the regulator.

The major challenge is to determine the optimal pixel size to maintain a dynamic system with high flexibility on the micro-scale and at the same time optimize the metrics in Section 4. A second challenge is the location accuracy of wireless devices, where one solution could be to force the spectrum trader to buy or lease pixels adjacent to the actual wanted pixel.

5.2 The Frequency Domain

The frequency dimension is divided into spectrum bandwidths of fixed spectrum blocks of $B$ Hz. To support micro-trading of narrow bandwidths, the bandwidth will typically be quite low (e.g. $B=100$ kHz). This will enable devices such as wireless microphones that require a narrow bandwidth to participate in the market. Simultaneously, other devices and services such as wireless broadband requiring wider bandwidths could participate in the market by bidding for consecutive bandwidth blocks.

One major challenge is to define the optimal value of the bandwidth $B$. Low values would enable a plethora of devices to participate in the market without having to acquire wide bandwidths. However, low values would not necessarily optimize all the metrics in Section 4. For instance, low values of $B$ could lead to fragmentation of the spectrum, hence spectrum utilization might be lower without sufficient technology able to utilize defragmented spectrum. Initially, to obtain market viability, the best solution might therefore be to set $B$ to the channel bandwidths set by the regulator as used by the already existing wireless systems.

5.3 The Temporal Domain

The time dimension is fixed into time blocks of $\Delta T$ seconds. Since we deal with spectrum micro-trading, the tradable $\Delta T$ should be quite small (e.g., $\Delta T=1$ second) to support different wireless service usage patterns. For instance, wireless metering might require 1 second each month to transmit the measured result, which with $\Delta T=1$ would be one block. To bid for longer periods the trader could bid for as many consecutive time blocks as desired.

Low values for the time block $\Delta T$ could lead to high defragmentation in the time domain, which would not necessarily increase spectrum utilization due to blockage of services requiring long consecutive time periods such as wireless broadband networks. Therefore, it will be important to define policies that ensure maximization of the metrics defined.

5.4 The Tradable Unit

The minimum tradable unit then becomes $\text{Pixel} \ast B \ast \Delta T$, where $\text{Pixel}$ is defined by its $X$ and $Y$ values (e.g. 100·100 m), $B$ is the bandwidth defined in Hz (e.g. 100 kHz) and $\Delta T$ is the tradable time unit defined in seconds (e.g. 1 second).

A trading bid or ask in a spectrum market (e.g. auction or exchange) can be described by $a_x a_y \text{Pixel} \ast b B \ast c \Delta T$, where $a_x$ determines the number of consecutive pixels on the x-axis and $a_y$ on the y-axis, $b$ the number of spectrum blocks and $c$ the number of time blocks to be traded. The trading market could also be regulated by setting minimum and maximum
values of $a$, $b$ and $c$ (e.g. $\min(a)$ and $\max(a)$ could be used to set the smallest and largest areas allowed to be traded).

The price will be a monetary unit such as euro or USD, and a single monetary unit $P$ to be used for trading can be defined such as 1 euro or USD.

6. Initial Modelling of a Spectrum Micro-trading Market

Initial modelling has been carried out using a multi-agent reinforcement learning mechanism with bid-proportional auctions. This is based on the framework described by Abji [5]. This current framework models a single cell and includes the ecosystem roles of two different spectrum traders: the spectrum owners who can be considered as the service providers and the cognitive radio devices which will be the end-users of any bought spectrum. Auctions are held at regular time intervals which could be on the order of seconds, which can be considered to be on a micro-temporal timescale. The single cell in this model could be considered as one or multiple pixels on micro-spatial scale. This can vary depending on the range of the service provider base station and the end-user devices.

In this simple scenario there is only one service provider and 50 end-users. The bandwidth owned by the service provider is normalised to unity. Each end-user has the same offered load and its own packet buffer. The size of the buffer determines the current state of the end-user. Ten states have been defined for this model. The lowest number states reflect a smaller buffer. The end-user state is updated after each auction interval based on the offered load into its buffer and the serviced traffic out of the buffer. The amount of serviced traffic depends on the amount of bandwidth allocated to that user in the most recent auction.

For each auction all end-users make a bid for bandwidth. The service provider distributes the available bandwidth in proportion to the bids of each end-user. This means that the smallest tradable unit of bandwidth can easily be considered to be on the micro-frequency scale. Each end-user uses reinforced learning to refine its future bidding behaviour. A so-called Q-table is maintained for each end-user which is the user’s current estimate of the quality of each action, and also is used to give the relative probability of each possible action given the end-user’s current state. The state is based on the end-user’s buffer level and the possible actions are for the next bid to be larger than, the same as, or smaller than the previous bid. Prior to each auction each end-user’s Q-table is updated using a heuristic formula from Q-learning theory based on their reward from the most recent auction.

Each end-user calculates its own reward (as in [5]), using its current state (the lower the state the higher the reward) and the amount bid for spectrum in the most recent auction (the lower the bid the higher the reward). This reward function is therefore based on two sub-metrics: spectrum cost (price) and throughput.

Figure 3 shows results from this modelling to show how the average end-user reward varies with the total system offered load. This is normalised to the system capacity. We see that when the total offered load is much lower than the system capacity the average reward is settled at a high score of around 0.95. This is due to the fact that an end-user receives the bandwidth it requires to stay in a low state while the spectrum cost remains low. When the total offered load is much higher than the system capacity the average reward settles at around 0.25. This is a reflection of the fact that spectrum costs are high and the end-user will struggle to maintain a low state. The intermediate area approaching the system capacity shows that there is a sudden drop in average reward where spectrum demand causes spectrum costs to rise and eventually it becomes difficult for a system to maintain a low state. From the end-user perspective, the micro-trading auction framework from [5] might only viable when the available bandwidth is not too low (relative to offered load). However, from a service provider perspective the micro-trading auction framework might fail if the
spectrum cost (service provider revenues) is too low. This suggests that there may need to be mechanisms (this could include admission control) to ensure that the bandwidth available in micro-auctions falls within viable thresholds.

7. Summary and Future Work

We have studied spectrum micro-trading as a concept to enable micro-trading of spectrum in at least three dimensions; on the micro-spatial, micro-temporal and micro-frequency scale. First we defined and discussed the roles and actors in the ecosystem required for spectrum micro-trading involving spectrum brokers, spectrum databases, wireless sensor networks, vendors and the regulator. Next, we presented the most important metrics for spectrum micro-trading: market viability, spectrum utilization, channel quality and social welfare. We then defined a practical model for spectrum micro-trading that addresses the three dimensions on the micro scale, the “Micro-trading Pixelation Model”. We discussed the main challenges and issues related to spectrum micro-trading and the proposed model. Finally, we showed some initial simulation results which demonstrated the performance of spectrum micro-trading for part of the proposed ecosystem.

For future work we plan to implement the proposed model by using agent-based computational economics. This will extend the initial simulations by performing simulations for the entire proposed ecosystem. The main goal is to study spectrum micro-trading on the micro-spatial, temporal and frequency scale in order to answer the research questions put forward in this paper. Furthermore we plan to conduct a market study with the implemented model. We will work on business case studies for different scenarios such as cognitive femtocells, cellular extension in white spaces, cognitive ad-hoc networks and rural broadband in white spaces, where input to and output from the trading market modelling will be important.

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