Small cells deployment in TV White Spaces with neighborhood cooperation

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Abstract

In this paper, we consider allocation of spectrum resources in the so-called TV White Spaces (TVWS) to small cells for their realistic deployment based on *first-come, first-served* principle. Three allocation rules are analyzed with a focus on channel bartering between the neighboring cells. Simulation results show that neighborhood cooperation can improve the performance of spectrum allocation in terms of the efficiency of spectrum and power resource usage. Moreover, cooperation with more distant cells significantly improves this performance at the expense of complexity.[1]

1. Introduction

Small cells (pico- and femtocells) in cellular networks are envisioned as a method of traffic offloading in densely populated areas. They are supposed to cover areas up to ~200 m (picocells) or in the order of ~10 m (femtocells), and therefore transmission power requirements are also moderate or low. Small cells can share frequency channels with macro cells, however in such a case, interference between small cells and a macrocell is an issue. Uncoordinated spectrum sharing between small cells may cause interference between them, what further degrades the benefit of small cells deployment. TV White Spaces (TVWS) defined as unused digital television (DTV) spectrum, interleaved in frequency and space, provide an opportunity for such a deployment due to the fact that small cells require low power.

Different works have recognized recently the potentials of applying spectrum sharing in TVWS to small cell scenarios. In [1], feasibility of utilizing TVWS spectrum for LTE TDD is discussed. The particularization to small cell scenarios is identified as a relevant use case to enhance the capacity while avoiding co-channel interference between adjacent small cells and between a macrocell and a small cell. In [2], it is concluded that the use of TVWS as a microcellular capacity booster in limited local areas is a plausible approach. It is found in [3], that, due to the high interference from TV towers, it is difficult to find channels that allow for good performance of cellular networks at the cell edge, while the inner part of the cell can obtain more benefits from TVWS. It is concluded that TVWSs are primarily suitable for traffic offloading and spotty coverage. In [4], the deployment of a cellular network in TVWS is analyzed, deriving a methodology to maximize the downlink capacity at the cell edge using a heuristic power allocation algorithm. It is concluded that only through dense cellular networks (i.e. small cell sizes) it is possible to efficiently exploit the secondary spectrum. The operation of a spectrum broker that assigns TVWS bands is presented in [5] considering the problem of matching multiple-bids to buy, and spectrum portfolio (offered by a spectrum broker). In turn, in [6] an auction approach for using TVWS with LTE and LTE-A is proposed. Resource allocation is modeled as a combinatorial auction with heterogeneous objects and profit maximization allocation rule. In [7] the use of TVWS is proposed to deal with the interference suffered by LTE macrocell users from nearby femtocells. The proposed approach is based on sensing of the interfering femtocells.

Based on the above, it is observed that many works have identified that the use of TVWS is seen as particularly relevant for extending the capacity of LTE and LTE-A networks with small cell scenarios. This paper intends to contribute to this problem by proposing neighborhood cooperation algorithm for assigning TVWS to small cells. It is based on a *first-come, first-served* principle. We focus on Region 1 spectrum, where the TVWSs lay between 470-790 MHz.

2. Spectrum broker operation for small cells with neighborhood cooperation

The emerging consensus for protection of the DTV incumbents is the geolocation database-controlled access by the secondary systems. These databases are supposed to contain: the area coordinates, the DTV channels available in this area and a maximum allowable transmission power for a specific radio transmitter with a predefined spectrum mask. The geolocation spectrum database has also been developed for Munich, Germany within the European project COGEU [8]. The methodology of the transmit power limit calculation in TVWS is described in [9]. The considered area of 60-by-60 km is divided to pixel areas of 200-by-200 m. For each pixel the maximum allowable transmission power is calculated in channels 40–60 (622–790 MHz) assuming fixed or mobile reception of the DVB-T that needs to be protected.

The spectrum broker is an entity managing and coordinating TVWS bands allocation to secondary users. Such a broker is responsible for planning, packaging the spectrum for secondary disposal, and resolving interference caused by its customers to the primary DTV systems or between themselves [5].

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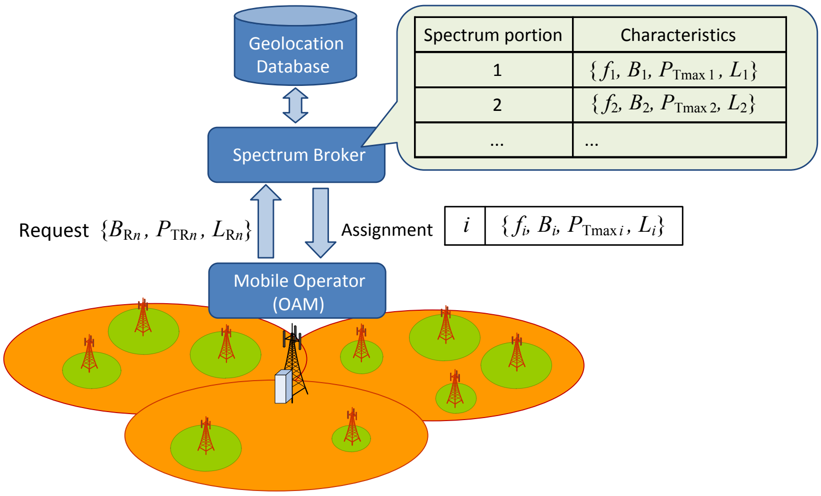


Figure 1. Framework for TVWS assignment to small cells.

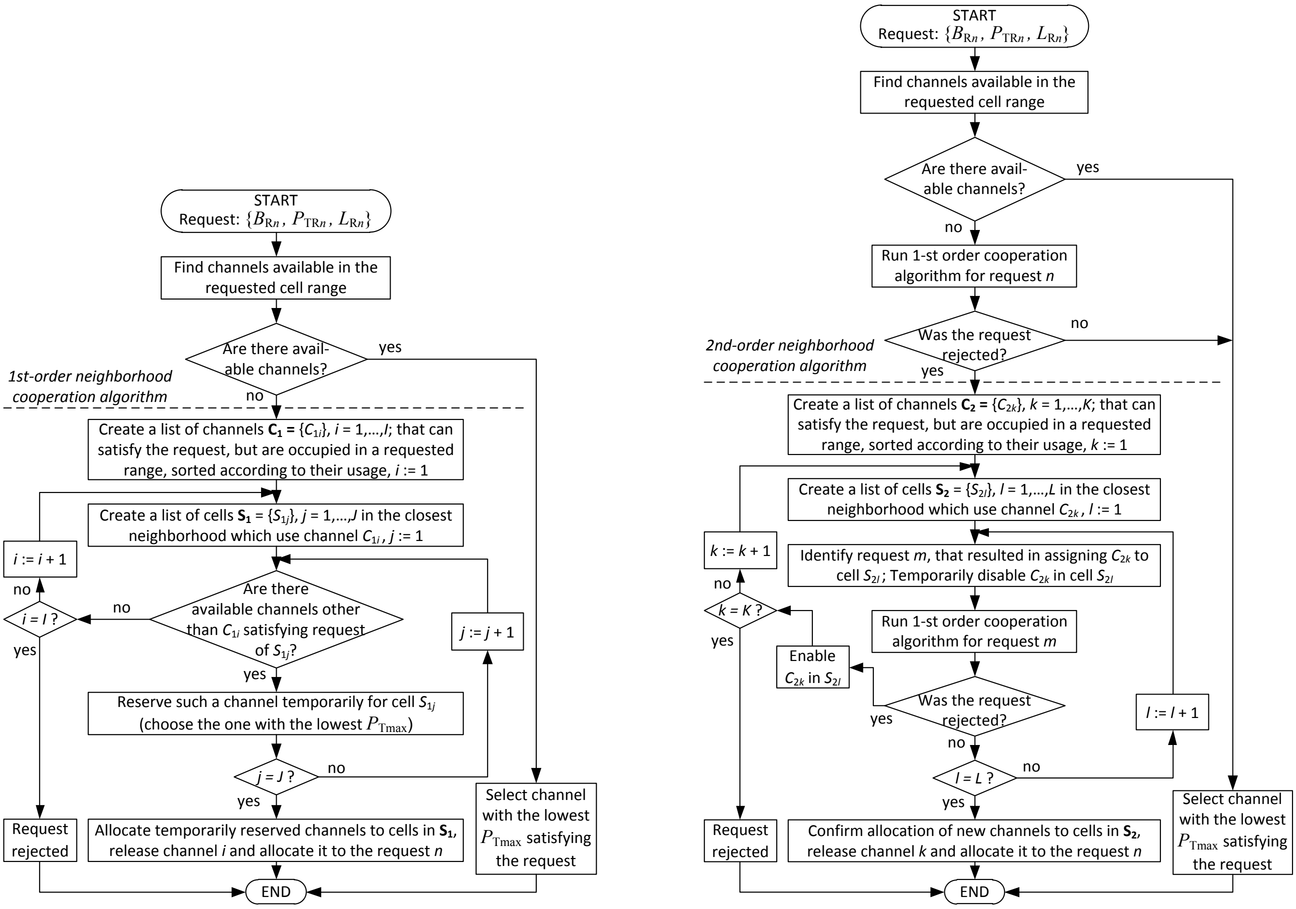
For the small cells (e.g. femtocells) it is envisioned that the base stations will be installed by the users themselves without any coordination, what may cause inefficient use of resources. One envisioned option is to direct the subscribers to the spectrum broker, as the coordinating entity. However, given the variety of the DTV channels availability at different locations and diverse power constraints, the variety of locations and bandwidth requirements, dependencies and interference constraints, it is a complicated task. Moreover, this optimization has to be performed every time a new femtocell is installed, what may be very dynamic. Thus, reassignments of resources may cause frequent connectivity problems in the given area. The other option for dynamic resource allocation to small cells is the assignment based on *first-come, first-served* rule. To this end, a new customer should go to the broker to access the geolocation database, and the local repository of DTV channels already in use. Before assigning a particular DTV channel, the broker has to make sure that there is no cell using the same channel at a distance at which interference from this channel can be observed. Because the frequency assignments cannot be optimized over all TVWS as new customers apply to the broker, there should be also some mechanism to update the TVWS channels assignment for better spectrum usage and efficient energy management.

Figure 1 presents the general high-level framework considered in this paper for the assignment of TVWS to small cells. Based on the information from the geolocation database, the broker will have the spectrum portions, each one with a central frequency f_i, bandwidth B_i, power limitations $P_{\mathrm{Tmax}\,i}$, and locations L_i, where each portion can be used. This list will be dynamically updated by the spectrum broker taking into consideration previous assignments. When the operator, or more specifically the OAM (Operations, Administration and Maintenance) functionality, identifies that additional spectrum is required in a certain area for a small cell, it will request this shared spectrum to the broker. The request made at the nth moment should include the requirements in terms of requested bandwidth $B_{\mathrm{R}n}$, transmit power $P_{\mathrm{TR}n}$ and location $L_{\mathrm{R}n}$ where spectrum is needed. Then, the spectrum broker will provide an assignment of the spectrum portions.

Based on the described framework, the task of the OAM at the operator's network is to identify additional spectrum needs for specific geographical areas (i.e. deployed cells) that can be solved by allocating TVWS spectrum. As for the requested bandwidth, if considering LTE or LTE-A as a reference system, it will depend on the carrier bandwidth that belongs to the set {1.4, 3, 5, 10, 15, 20} MHz [10] and on the number of requested carriers. As for the transmit power, focusing on the downlink, it will be given by the envisaged coverage area, while if considering the uplink the required power will be given by the terminal. Being this paper mainly focused on the operation of the spectrum broker, spectrum requirements will be considered only for the particular case that a small cell requires just one DTV channel in TVWSs.

If we consider the *first-come, first-served* principle, an easy algorithm for the TVWS spectrum assignment to a new small-cell request would scan the available DTV channels in a given location, and assign a first available channel or an available channel with the lowest allowable transmit power. By this *availability* we mean that the allowable transmit power in this channel is higher or equal to the requested power. In such a case, a request to which there are no available channels would be rejected. Let us consider an algorithm for the TVWS spectrum assignment for small cells, which does not reject requests but employs neighborhood cooperation to rearrange the assignments to satisfy such requests. It is presented in Fig. 2 a. The algorithm starts with checking the database to see, if there are DTV channels in the new small-cell location with the power limit equal or higher than the requested value for the assumed coverage (checking this availability includes co-channel interference analysis in the neighborhood area). If there are available channels the one with the lowest power limit satisfying the TX power requirements for the new cell is chosen. If there is no available channel, the algorithm checks if there are channels occupied in this area, which can be released by allocating different channels to the existing cells. If so, the channels are rescheduled in this area and the released channel is assigned to a new cell. The allowable transmit power limit in this channel is decreased in the surrounding area to limit the co-channel interference.

The last step in the above described algorithm is crucial for efficient spectrum allocation in the considered scenario. The goal is to use as little resources as possible to satisfy the customers requirements. The algorithm handles the neighborhood cooperation, where by *neighborhood* only the adjacent neighboring cells are meant. In the remainder of this paper, this kind of neighborhood will be called *closest neighborhood* and the cooperation among cells in this closest neighborhood will be called *1*st *order neighborhood cooperation*. Extension of this notion to more distant cells will be called *2nd order neighborhood*. In such a case, if there is no possibility of bartering the channels with the adjacent cells, each of these cells are examined on the possibility to exchange channels within its own closest neighborhood, and to release the channel that can be used by the new arriving small-cell request. This option is characterized by increased complexity. Both, the 1st-order and the 2nd-order neighborhood cooperation algorithms are presented in Figure 2.



(a) (b)

Figure 2. The 1st-order (a) and the 2nd-order (b) neighborhood cooperation algorithms.

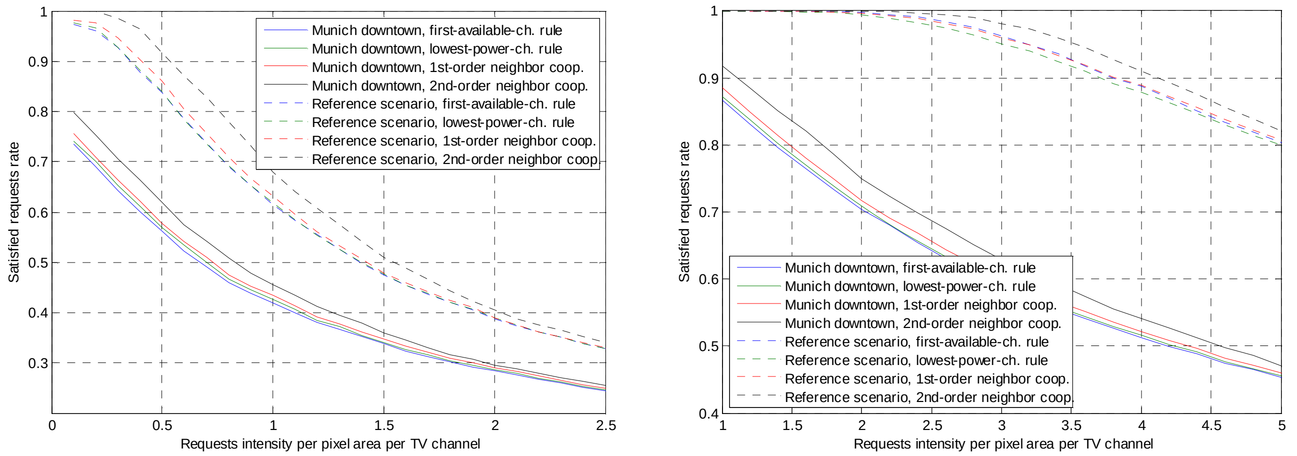
3. Numerical Results

The above described algorithms have been examined through computer simulations in two scenarios: Munich city center of 1.8-by-1.8 km using TVWS geolocation database [8], and a hypothetical reference environment with availability of TVWS generated randomly in all pixel-areas. In this reference scenario, the degree of freedom in DTV channel assignment is very high and should provide upper-bound results in TVWS utilization by small cells. The granularity of Munich geolocation database has been increased by introducing pixels of 10-by-10 m. The same has been assumed for the hypothetical environment mentioned above, thus, introducing correlation of TVWS availability in such a region.

We have examined two kinds of random small-cells requested-power Rayleigh distributions which relate to the requested coverage and impacts the number of available channels. This distribution has been truncated by maximum requested power values stated for femto and picocells. For femtocells the average and the maximum EIRP of 4 dBm and 17 dBm have been assumed respectively. For pico cells the average and the maximum EIRP has been set to 15 dBm and 21 dBm respectively. The associated coverage of the cells was 3−30 m for femto-, and 30−180 m for picocells. The so-called *safety belt* around each small cell area has been calculated for each cell to meet the requirement of the receiver protection ratio equal to −20 dB. The used propagation model was Extended Hata model for indoor environment [11].

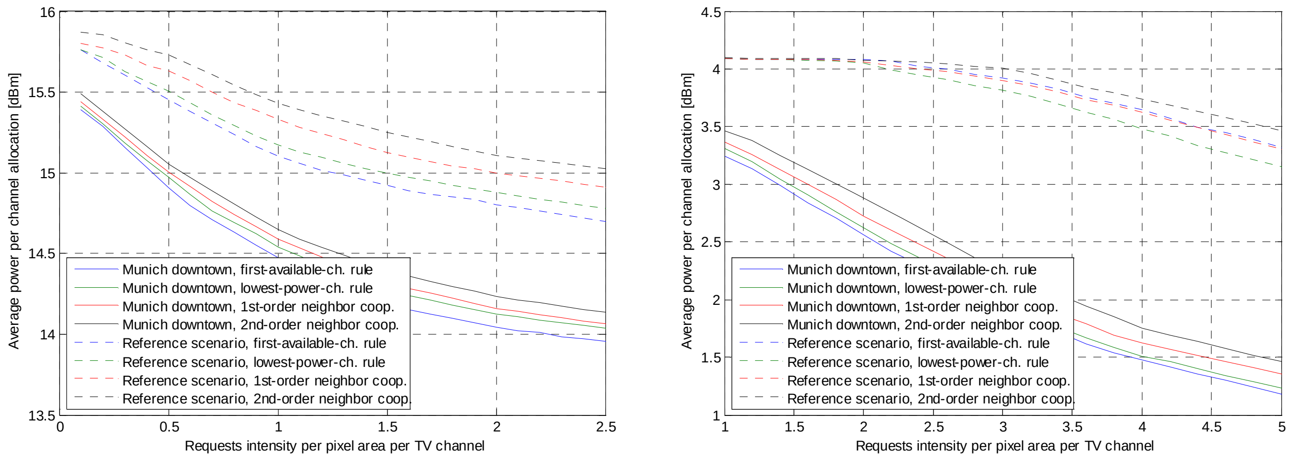
The following four algorithms of DTV channels assignment to small cells based on *first come, first served* have been considered: (i) assignment of the first available DTV channel in a given location, (ii) assignment of the channel with the lowest transmit power limit, higher or equal to the requested power, (iii) allocation based on the 1st-order neighborhood cooperation algorithm from Fig. 2.a, (iv) allocation based on the 2nd-order neighborhood cooperation (Fig. 2.b).

In Figure 3, the satisfied requests rate (the ratio between the number of satisfied requests and all occurring requests) is presented for our four allocation rules. This satisfied requests rate translates to the efficiency of TVWS spectrum resources usage. In Figure 4, the average transmit power levels per channel allocation are presented. This average power level is an indicator of how well the available power is used. Note that neighborhood cooperation can improve the performance in terms of the efficiency of TVWS spectrum resources usage and the available power-resources usage with respect to simple channel-allocation methods for both types of small cells dominating the requests: femto- and picocells.



(a) (b)

Figure 3. Satisfied requests rate in case of (a) 6 DTV channels available for the picocells dominating requests and (b) 13 DTV channels for the femtocells dominating requests.



(a) (b)

Figure 4. Average power per channel allocation in case of (a) 6 DTV channels available for the picocells dominating requests and (b) 13 DTV channels for the femtocells dominating requests.

4. Conclusions

We have presented a framework for allocation of spectrum resources in TVWS to small cells for their realistic deployment. We have shown that cooperation between cells in the closest neighborhood can improve the performance of this allocation in terms of both the efficiency of spectrum resource usage and the available power usage. Moreover, cooperation with more distant cells improves this performance at the expense of computational complexity.

5. References

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