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Centralized Spectrum Sharing and Coordination Between Terrestrial and Aerial Base Stations of 3GPP-Based 5G Networks

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Abstract—**The objective of this paper is to estimate performance of a new approach for spectrum sharing and coordination between terrestrial base stations (BS) and On-board radio access nodes (UxNB) carried by Unmanned Aerial Vehicles (UAV). This approach employs an artificial intelligence (AI) based algorithm implemented in a centralized controller. According to the assessment based on the latest specifications of 3rd Generation Partnership Project (3GPP) the newly defined Unmanned Aerial System Traffic Management (UTM) is feasible to implement and utilize an algorithm for dynamic and efficient distribution of available radio resources between all radio nodes involved in process of optimization. An example of proprietary algorithm has been described, which is based on the principles of Kohonen neural networks. The algorithm has been used in simulation scenario to illustrate the performance of the novel approach of centralized radio channels allocation between terrestrial BSs and UxNBs deployed in 3GPP-defined rural macro (RMa) environment. Simulation results indicate that at least 85% of simulated downlink (DL) transmissions are gaining additional channel bandwidth if presented algorithm is used for spectrum distribution between terrestrial BSs and UxNBs instead of baseline soft frequency re-use (SFR) approach.**

Keywords—**5G, spectrum sharing, Unmanned Aerial Vehicle**

I. Introduction

FROM several years the Unmanned Aerial Vehicles (UAV) are gaining attention of telecom industry and therefore are subjects of academic studies and research projects. All this activity is focused on theoretical and practical issues in the most typical paradigms of UAV-related wireless communication. This quickly maturing sector has been recognized and addressed also by the 3rd Generation Partnership Project (3GPP) – the joint venture for development of global standards for cellular networks. 3GPP in the latest releases of its standards for the 4th Generation – Long Term Evolution (4G LTE) and the 5th Generation – New Radio (5G NR) systems has included a wide range of requirements, which allow UAV-related wireless communication to co-exist with the cellular 4G and 5G networks. As summarized in [1], recently the following areas have been addressed by 3GPP:

1. Enhanced LTE Support for Aerial Vehicles (Release 15) [2],
2. Remote Identification of Unmanned Aerial Systems (UAS) (Release 16) [3],
3. Study on application layer support for UAS and 5G Enhancement for UAVs (Release 17) [4].

From the perspective of two typical paradigms of UAV-related wireless communication, the co-existence between UAV and cellular 4G/5G networks brings advantages to both sides. The foundation for this co-operation is connectivity between UAV and its controller via 4G/5G networks, usage of licensed spectrum and standardized network protocols. This way the new practical use cases of UAV and cellular networks are enabled and lead to two typical paradigms, as shown in Fig. 1 [5,6]:

1. UAV-Assisted Cellular Communication - In this case the cellular network gains from the presence of UAV, which are deployed as aerial base stations (BS), called by 3GPP as On-board radio access nodes (UxNB). Main purpose of UxNBs is to complement the coverage of terrestrial BS or temporally increase the cellular network capacity.
2. Cellular-Assisted UAV Communication – By the usage of licensed spectrum and standardized communication protocols originated from cellular networks the UAVs are gaining more efficient control and traffic data flow in comparison to operation in unlicensed frequency bands.

This paper is focusing on the first of the abovementioned paradigms, i.e. UAV-Assisted Cellular Communication. One of the main challenges faced here is efficient spectrum sharing between cells served by terrestrial BSs and those served by UxNBs. Deployment of every UxNB inside the coverage area of 4G or 5G networks implicates allocation of spectrum resources to given UxNB. If UxNB is supposed to serve ground user equipment (UE) with the same quality of service (QoS) as UEs served by terrestrial BSs, the spectrum resources must be distributed in optimal way between all cells in given coverage area. Due to the mobile character of UxNBs it is also foreseen that spectrum resources will be allocated in dynamic way, which creates a new area for UAV related studies, i.e. cognitive UAV networks [6]. Main subject of these studies is spectrum allocation for UxNBs by dynamic utilization of the existing frequency bands used by terrestrial BSs. Several different approaches for spectrum sharing between UxNBs and terrestrial BSs can be found in the literature. For example, Sboui *et al.* [7] and Huang *et al.* [8] propose methods for dynamic control of power transmitted by lower priority UxNBs under constraints of limited interference towards higher priority terrestrial BSs. In both cases the power control algorithms aim to maximize the energy efficiency or data rate of UAV connections, which are optimized jointly with three-dimensional (3D) trajectory or altitude of UxNBs. Similar approach has been used by Hattab and Cabric [9], however here the transmit power of ground UEs connected to UxNBs is subject of control algorithm to minimize

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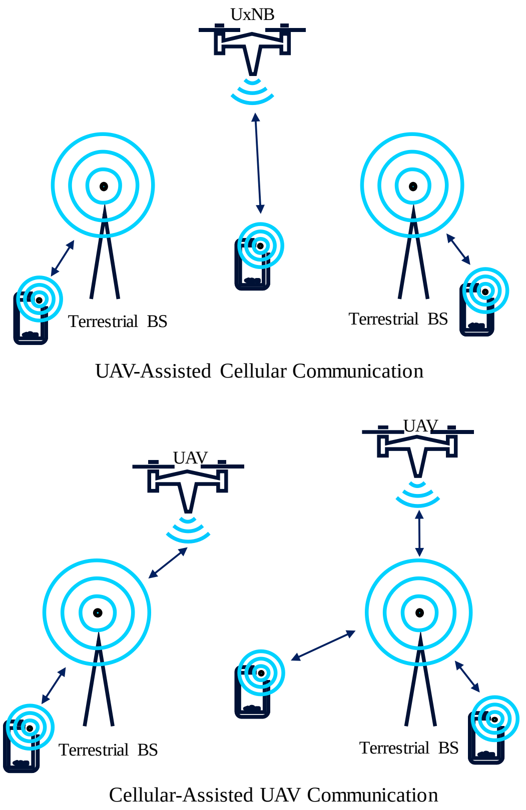

Fig. 1. Typical paradigms for UAV integration into cellular network [5,6]

interference received by terrestrial UEs. In this case the optimization process is performed by adaptation of time-division duplexing (TDD) protocol using stochastic geometry and comparison to the standard spectrum sharing and orthogonal allocation protocols. Zhang and Zhang [10] on the other hand propose a method for finding the optimal density of UxNBs based on the 3-D Poisson point process. Optimal density of UxNB network is found while maximizing its throughput and satisfying the terrestrial cells interference constraints.

According to the prepared review of literature, none of the abovementioned approaches is based on centrally implemented algorithm, which utilizes artificial intelligence (AI) or machine learning (ML). Therefore, the motivation of this paper is to describe and assess an example implementation of approach for centrally controlled spectrum sharing between UxNBs and terrestrial BSs, which is based on a neural networks algorithm.

Algorithm presented in the following parts of this paper is assumed to be implemented as one of the functions performed by Unmanned Aerial System Traffic Management (UTM), which according to 3GPP specification [4] is used to provide a number of services to support UAS (UAV and a UAV controller) in 4G and 5G networks. Therefore, Section II describes in more details the functions of UTM and UAS, as defined by 3GPP, and points to the enablers which allow for implementation of centralized algorithm for radio channels distribution. Section III presents description of the example algorithm for radio channels distribution between terrestrial and UxNB-served cells, which is based on the Kohonen neural networks theory [12]. This section includes also example simulation results of radio resource distribution obtained by the implementation of the proposed algorithm in terrestrial network with centralized controller, as well as indicates how the algorithm can improve the efficiency of radio channels distribution in comparison to soft frequency re-use (SFR) scheme. Section IV demonstrates the capability of the algorithm to distribute radio channels between 3GPP-defined Rural Macro (RMa) cells and UxNB-served cells for different densities of UxNBs. Conclusion and summary of the paper are included in Section V.

II. 3GPP-Based Control and Traffic Management for UAV

In December 2019, 3GPP approved the first version of Release 17 specification for support of UAS in 5G cellular networks [4]. It has been identified that 3GPP system can provide control plane and user plane communication services for UAS, i.e. UAV and its controller. Examples of services which can be offered to the UAS ecosystem includes data services for command and control (C2), telematics, UAS-generated data, remote identification, and authorization, enforcement, and regulation of UAS operation. Important role in this information flow via 3GPP network is performed by UTM management unit, which is used to provide a number of services to support UAS and their operations by following C2 communication [4]:

1. Network-Assisted C2 communication – the UAV controller and UAV register and establish respective unicast C2 communication links to the 3GPP network and communicate with each other via 5G network. Also, both the UAV controller and UAV may be registered to the 3GPP network via different radio access nodes. The 3GPP network needs to support mechanism to handle the reliable routing of C2 communication.
2. UTM-Navigated C2 communication – the UAV has been provided a pre-scheduled flight plan, e.g. array of 4D polygons, for autonomous flying, however UTM still maintains a C2 communication link with the UAV in order to regularly monitor the flight status of the UAV, verify the flight status with up-to-date dynamic restrictions, provide route updates, and navigate the UAV whenever necessary.

Figure 2 illustrates the above C2 communication flows in 3GPP ecosystem [4]. From the point of view of a centralized algorithm for radio resources allocation the more appropriate is UTM-Navigated C2 communication type – it allows for autonomous and dynamic operations with limited input from human-operated UAV controller. Requirements specified by 3GPP for remote identification of UAS assume flow of data between UAS, 3GPP network and UTM, which makes a centralized algorithm implementable inside UTM. Especially the following requirements allow to consider this implementation as feasible [4]:

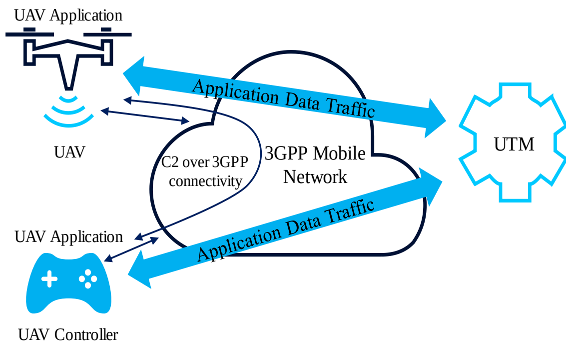

Fig. 2. UAS model in 3GPP ecosystem [4]

- R-5.1-003: The 3GPP system shall enable a UAS to send UTM the UAV data which can contain: unique identity (this may be a 3GPP identity), UE capability of the UAV, make & model, serial number, take-off weight, position, owner identity, owner address, owner contact details, owner certification, take-off location, mission type, route data, operating status.
- R-5.1-006: The 3GPP system shall support capability to extend UAS data being sent to UTM with the evolution of UTM and its support applications in future.
- R-5.1-009: The 3GPP system should enable a mobile network operator (MNO) to augment the data sent to a UTM with the following: network-based positioning information of UAV and UAV controller.
- R-5.1-012: The 3GPP system shall enable a UAS to update a UTM with the live location information of a UAV and its UAV controller.
- R-5.1-013: The 3GPP network should be able to provide supplement location information of UAV and its controller to a UTM.
- R-5.1-015: The 3GPP system shall provide the capability for network to obtain the UAS information regarding its support of 3GPP communication capabilities designed for UAS operation.

In particular, the requirement R-5.1-006 allows for future enhancements in UTM implementations and requests support of necessary data flow between UAS and UTM. Therefore, it can be assumed that any data needed by the algorithm will be available. However, very important data necessary for calculation of mutual interference between all radio nodes is the position of these nodes, and this information is already available e.g. by the requirement R-5.1-012. Other data required by an algorithm, like transmit power, antenna gain and receiver's acceptable interference, can be considered either as *make & model* or *operating status* data of the requirement R-5.1-003, or future defined data of the requirement R-5.1-006.

To conclude: 3GPP-defined UAS system and UTM manager can be considered as a feasible environment for implementation of a centralized algorithm for radio resources distribution between UxNB-served cells and terrestrial cells of 3GPP-based 4G or 5G networks. Next section describes example of such algorithm, based on the Kohonen neural networks theory.

III. DESCRIPTION OF THE ALGORITHM

In the presented study the Kohonen neural network [12] is used to map a layer of input data (i.e. parameters of UxNB-served cells and terrestrial cells) into a layer of output data (i.e. optimal distribution of radio channels) during the process of self-learning and mapping, which takes place inside a layer between the input and the output. Self-learning and mapping ensure that output data is optimal from the point of view of accepted criterion. In this study the criterion is minimal interference between UxNB-served cells and terrestrial cells. Therefore, the algorithm learns possible mutual interference between all cells in the network and map the same radio channel only to cells which are not interferers to each other, e.g. those which have sufficient separation distance.

Algorithm presented in this paper utilizes Kohonen neural network in the variant of competitive learning [12], where the input data layer includes additional weights which impact the processing inside the layer of self-learning and mapping, called here as 'competitive layer'.

The algorithm has been developed for dynamic and efficient distribution of radio channels between BSs of all involved cells (hereafter refereed as access points - APs). On top of the main part of the algorithm, two additional levels of optimization have been introduced to meet basic requirements for efficient spectrum utilization. Therefore, the algorithm consists of three general stages:

1. <u>Single channel allocation</u>,
2. <u>Multiple channels allocation</u>,
3. <u>Common Primary Channel (CPC) reallocation</u>.

The high-level description of the algorithm can be as follow: Stage 1 aims to allocate one channel to each AP, reusing channel as much as possible when the APs are not interfering with other APs too much. Inside Stage 1 the Outer Optimization Loop and the First Inner Optimization Loop exclude APs that cause interference to other APs, until the remaining APs do not interfere with each other and can use a single channel. Then the Second Inner Optimization Loop tries to add some excluded APs back, if possible, i.e. APs that were excluded for causing interference to other APs (which were also excluded) but can be included again as they cause no interference to the remaining APs. Stage 2 tries to give additional channels to APs that are not interfering with the group of APs the channels were assigned to before. Finally, Stage 3 tries to rearrange the channel assignments to give to all APs of the same MNO the single common channel.

Figure 3 illustrates general block diagram of the algorithm, whereas more detailed descriptions of all stages are presented in the following subsections.

A. *Stage 1: Single Channel Allocation*

Only this stage utilizes adapted Kohonen neural network in the variant of competitive learning [12]. Further stages include enhancements which perform optimization of outcomes from Stage 1.

The aim of adapted Kohonen neural network in the variant of competitive learning is to identify the function of costs, which is represented by the following vector:

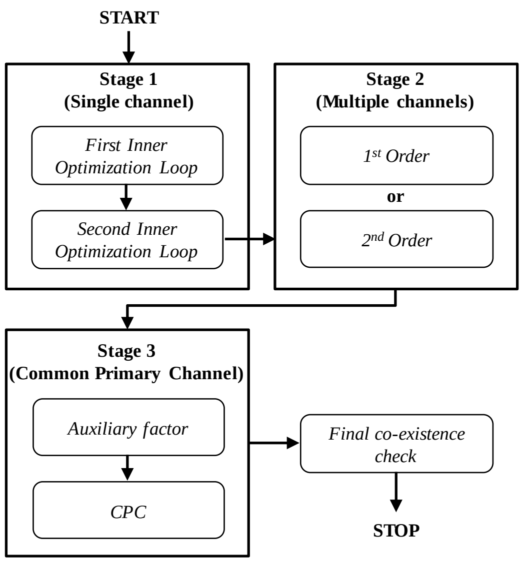

Fig. 3. General block diagram of the algorithm

$$\mathbf{V}=\left\{V_m=\sum_{n}^{M} w_{m,n}\cdot k_{m,n},\right\}_{M\times 1},m,n\in M\ , \qquad (1)$$

where V_m is equal to the sum of interference which given AP m causes to all other APs, whereas M is the number of APs from all cells in the scenario analyzed by the algorithm. Before determination of the vector **V** it is required to obtain the matrix of weights $\mathbf{W}=\{w_{m,n}\}_{M\times M},m,n\in M$, where $w_{m,n}$ is equal to the interference caused by particular AP m towards any other AP n. These interference values can be modified further, if the matrix of comparisons **K** is determined as below:

$$\mathbf{K}=\left\{k_{m,n}=\begin{cases}[0;1] \text{ if } \mathrm{ID}_m=\mathrm{ID}_n\\ 1 \text{ if } \mathrm{ID}_m\neq \mathrm{ID}_n\end{cases}\right\}_{M\times M},m,n\in M\ . \qquad (2)$$

General purpose of the matrix **K** is adaptation of the algorithm according to occurred interference case between AP m and AP n. First general case relates to the identification index (ID) of the MNO. If AP m and AP n belong to the same MNO, i.e. $\mathrm{ID}_m=\mathrm{ID}_n$, it can be assumed that, up to some extent, the MNO can manage interference between its own APs. In that case the value of multiplier $k_{m,n}$ is equal to 0 (interference between APs of the same MNO are fully manageable) or is between 0 and 1 (interference between APs of the same MNO are partially manageable or not manageable). If APs belong to different MNOs, i.e. $\mathrm{ID}_m\neq\mathrm{ID}_n$, multiplier $k_{m,n}$ is equal to 1. Second general case is connected with the priority of APs. If priorities of analyzed APs are different, the multipliers $k_{m,n}$ and $k_{n,m}$ should be equal to 1, which ensures that co-channel allocation will not occur, if at least one AP from the analyzed pair causes harmful interference to the other.

When the vector of costs **V** is determined, the obtained individual interference values can be compared with the vector of conditions $\mathbf{Y}=\{y_n\}_{M\times 1},n\in M$, where y_n represents the maximum interference limit acceptable by AP n. AP m, which has the highest cost among all APs, i.e. $V_m=\max(\mathbf{V})$, and does not fill all conditions of interference limit from the vector **Y**, i.e. $\forall n\in M: y_n<w_{m,n}\cdot k_{m,n}$, is excluded from further optimization. Positions of this AP in the auxiliary vector $\mathbf{x}=\{x_m\}_{M\times 1},m\in M$ is zeroed, assuming that at the beginning of the algorithm all values in the vector **x** are equal to 1.

Detailed description of processing in Stage 1 is as follows:

1. The algorithm goes through the matrix of interferences **W** and for each AP with non-zeroed value in the vector **x** calculates the total interference V_m which this AP causes to all other APs.
2. The algorithm sorts APs (new order) according to descending value of total interference in vector **V** caused by each AP.
3. According to the new order the algorithm checks if given AP causes harmful interference (above the threshold y_n) to any of its neighbors.
4. If harmful interference is caused at least to one of the neighbors, such AP is marked (value of this AP in the vector **x** is zeroed).
5. The algorithm M times repeats steps 3-4, but without APs already marked (First Inner Optimization Loop).
6. The algorithm M times repeats steps 1-5 (because in each repetition the number of APs with non-zeroed value in the vector **x** may be different).
7. The algorithm checks marked APs (with zeroed values in the vector **x**) one by one, if any of these APs can co-exist with all remaining APs (with non-zeroed values in the vector **x**). Marked APs are checked one by one according to descending value of total interference in vector **V**, i.e. during the check of given marked AP, other marked APs are not considered in calculation of total interference.
8. If any of marked APs can co-exist with all remaining unmarked APs, it also becomes unmarked and its value in the vector **x** is equal to 1 again.
9. The algorithm M times repeats steps 7-8 (Second Inner Optimization Loop).
10. The algorithm allocates the same channel to all APs which remain unmarked (have non-zeroed values in the vector **x**) after step 9.
11. The algorithm repeats steps 1-10 until all APs receive channels.

Stage 1 includes additional improvements on top of the basic Kohonen neural network [12], which are marked as the First Inner Optimization Loop and the Second Inner Optimization Loop.

The aim of the first loop is to ensure that each AP is examined not only against the total interference caused to all other APs but also against the interference caused towards individual neighbor. This prevents to stop the basic Kohonen algorithm when the AP, which causes the highest total interference towards all other APs, does not cause the significant interference to any individual AP, but the other AP with lower total interference causes significant interference to some individual APs. This step allows to identify APs which do not cause the highest total interference but are harmful interferers for individual neighbors.

The aim of the second loop is to additionally examine the APs excluded earlier as the strongest interferers. At the input of the second loop the interferers which cause harmful interference towards neighboring APs have zeroed value in the input vector **x** (x_m=0). During the second loop, each AP with x_m=0 is examined, according to descending order of the vector **V**, against all APs which remain with non-zeroed value in the vector **x** (x_m=1). If the harmful interferer meets the conditions in the second loop, it receives the channel allocation already before the start of the next optimization cycle for the next channel. The second loop allows then to allocate a channel to the strongest interferers, even though they did not meet the conditions in the main part of Stage 1, because the number of APs/neighbors in the second loop is different than in the main part of Stage 1. Therefore, the procedure of the Second Inner Optimization Loop helps to minimize the number of separate channels needed to ensure co-existence between all APs in the given area and shorten the algorithm's processing time.

As the result of Stage 1 all APs, which were under optimization process, receive a single channel which meets the main condition, i.e. interference in this channel are not higher than the acceptable level in vector **Y**. After this stage the algorithm identifies how many separated radio channels are needed to ensure co-existence between all considered APs. Detailed flow chart of Stage 1 can be found in [13].

B. Stage 2: Multiple Channels Allocation

During this stage all APs are checked for the capability of partial re-using of channels assigned to other APs during Stage

1, and therefore to obtain more radio resources for better spectrum utilization. There are two orders according to which all APs in the area can be examined:

- 1st Order: According to ascending values in the vector **V**. First are examined these APs which have the lowest total interference caused to all other APs. This approach favors APs which are causing low interference and allows them to get more additional channels than APs which cause higher interference, because APs which are examined earlier have higher probability to be allocated additional channel than APs which are examined later during Stage 2. According to this procedure, more channels are allocated to APs of denser network, i.e. belonging to MNO who deploys more APs in the given area than other MNOs. This is under assumption that MNO can minimize interference between own APs and therefore APs of denser network are aggressors to fewer neighbors than APs of less dense network.
- 2nd Order: According to descending values in the vector **V**. First are examined these APs which have the highest total interference caused to all other APs. This approach increases the probability that APs which cause high interference will be allocated more additional channels than in the case of the 1st Order approach. According to this procedure, more channels are allocated to APs of less dense network, i.e. belonging to MNO who deploys less APs in the given area than other MNOs. This is again under assumption that MNO can minimize interference between own APs and therefore APs of less dense network are aggressors to higher number of neighbors than APs of denser network.

Considering the above descriptions of the 1st Order and the 2nd Order, it is up to the central controller policy which approach should be used, as each of them leads to different outcomes. Once the order of APs' examination is chosen, main part of Stage 2 starts. The general rule of Stage 2, which leads to allocation of additional channels, is as follow: Depending on the chosen examination order, AP m is examined against all other APs, from AP 1 up to AP M, and receives additional channel l only when all other APs, which have already allocated channel l, are not interfered by AP m above the acceptable interference level. In the next cycle, AP m+1 must be examined also against additional channel(s) allocated to AP m in the previous cycle, and so forth. As the outcome of Stage 2 some APs can reuse additional channel(s) for better utilization of the available spectrum. These channels are then re-optimized during Stage 3. Detailed flow chart of Stage 2 can be found in [13].

C. Stage 3: CPC Reallocation

During Stage 3 some channels allocated to APs during Stage 1 and Stage 2 are re-allocated in a way which allows to allocate the same CPC to all APs with the same ID, i.e. belonging to the same MNO. Such functionality of the algorithm can be well seen by MNOs – CPC allows for easier mobility and handover of UEs between APs of the same MNO, and at the same time gives to the MNO the confidence that at least one part of the spectrum in the band is available constantly for its operation. During the first step of Stage 3 the algorithm analyses channels allocated during Stage 1 and Stage 2 to determine which particular channel would be the most suitable as the CPC for a given MNO. For that purpose, the auxiliary factor F_j is calculated in the following way:

- For $j=1,\ldots,J$, where J is the number of MNOs, for each MNO find the channel l_j^{max} which has the highest number of allocations x_j^{max} . If more than one channel got the highest number of allocations, select the channel with lower ID. For each MNO calculate the difference Δ_j between x_j^{max} and the number M_j of all APs of given MNO. For each MNO calculate auxiliary factor F_j as a multiplication of Δ_j and M_j. Value of F_j determines the order according to which MNOs are re-optimized. This order has to be determined as re-allocation of channels for one MNO influences re-allocation in the network of other MNO and therefore it has to be started from the optimal point, i.e. re-allocation of channels starts from the MNO with the highest value of F_j factor and continues according to descending value of Fj. If more than one MNO have the same value of F_j, select the one with lower ID. Factor F_j helps also to determine which channel is the optimal CPC.
- Once the order of channels re-allocation and CPC for each MNO are determined, procedure of channels re-allocation starts. Stage 3 is the most complicated part of the algorithm, as it must ensure maintenance of the optimal co-existence between APs and at the same time shuffle the channels in a way which allocates CPC to all APs. Main part of Stage 3 runs according to the determined order of channels re-allocation - first are re-allocated channels of APs which belong to the MNO with the highest values of F_j factor. According to this order, each MNO is checked whether it has CPC allocated in all APs. If not, each AP which does not have CPC is evaluated against all other APs in the area, including also APs of other MNOs. This evaluation determines whether evaluated AP m causes interference to any other AP n. If yes, then that other AP n is checked whether it has channel which is the CPC for AP m being under evaluation. If yes, then the evaluated AP m is checked whether it has the channel which is the CPC for AP n. Depends of these checks, AP m and AP n exchange given channels between them. The evaluation cycle of AP m is repeated against next AP n+1. After that, AP m+1 of given MNO is evaluated. The same procedure is repeated for other MNOs. As the outcome of this procedure, all APs of all MNOs have allocated CPCs.

The last step of Stage 3 is called Final Coexistence Check. The aim of this step is to verify if any pair of interfering APs did not receive the same channel(s) during the re-allocation process (Stage 3). If such situation is detected the algorithm removes channel(s), which are the same for interfering APs, from the list of channels of one of the interfering APs. In the result of Final Co-existence Check some APs can have partially reduced number of channels, in comparison to the outcome of Stage 2, however this is the cost of re-allocation and allocation of CPC to all APs. Detailed flow charts of Stage 3 and Final Coexistence Check can be found in [13].

D. Verification of the 3-stage Algorithm by Simulations

Based on the above description of the algorithm a simple simulation scenario has been developed to verify the algorithm's effectiveness, i.e. whether outcomes of the consecutive stages follow agreed assumptions. It has been assumed that the algorithm is used by a central controller to allocate channels between APs of different MNOs. Main simulation parameters used for evaluation of the algorithm are included in Table I. Figure 4 presents example outcome of the full algorithm according to both the 1st and the 2nd Order of Stage 2. Results of each stage of the algorithm are marked by

TABLE I
MAIN SIMULATION PARAMETERS USED FOR EVALUATION OF THE 3-STAGE ALGORITHM

Parameter	Value
Area size	5 km x 5 km
No. of MNOs	3
No. of APs	20 (randomly positioned in the area and assigned to MNOs)
Carrier frequency	3500 MHz
Max EIRP	30 dBm
Interference threshold of AP	-75 dBm
Channel model	Free space
Other	*k*=0 for APs of the same MNO

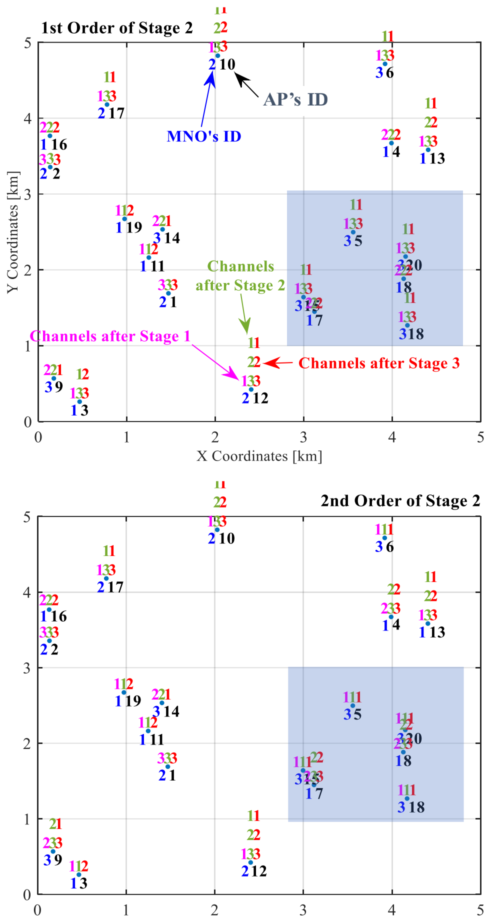

Fig. 4. Results of simulation verification of the consecutive stages of the algorithm

different colors (magenta, green and red respectively for consecutive stages), whereas positions of APs are marked by dark blue points. It can be noticed that three separate radio channels are needed to ensure co-existence in assumed simulation scenario, as '3' is the highest number obtained after Stage 1 (magenta color). As the result of Stage 2 some of APs have received additional one or two channels (green color), which means that better spectrum utilization has been obtained. Difference in the outcome of Stage 2 according to the 1st and the 2nd Order are visible inside the shaded area - in case of the 1st Order more channels are allocated to APs of the MNO 3, which in given area deploys more stations than the MNO 1. Opposite situation occurs in the case of the 2nd Order, when more channels are allocated to APs of the MNO 1. These allocations follow the reasoning described in subsection B. Finally, Stage 3 reshuffled channels allocated during previous stages and ensured that each MNO has CPC allocated to all of its APs (red color), i.e. the MNO 1 received CPC=2, the MNO 2 received CPC=3 and the MNO 3 received CPC=1.

Source code of the described algorithm in MATLAB modelling environment, with implemented the above simulation example, can be found in [13].

E. Efficiency of the Algorithm in Realistic Propagation Conditions

To illustrate capability of the algorithm for efficient channels distribution between BSs of realistic cellular network, a simple simulation scenario has been developed. It has been investigated if the algorithm can improve the spectrum utilization in a cellular network with SFR scheme [14]. As illustrated in Fig. 5, SFR allocates different frequencies for downlink (DL) transmission to UEs allocated at the cell edges, to avoid intercell interference. In assumed implementation, 3 radio channels are needed for SFR between 7 cells. This implementation allocates channel according to predetermined order, even if the actual propagation conditions in the place of network deployment allow to avoid intercell interference only due to the path loss. In that deployment scenario the SFR may lead to locally sub-optimal spectrum utilization, but at the same time is simple and does not require additional processing. Therefore, it has been investigated if the algorithm proposed in this paper is able to distribute radio channels between 7 cells in more efficient way than SFR does. The aim of this study was to illustrate the algorithm's efficiency in comparison to baseline SFR scheme. Main simulation assumptions used for this study are presented in Table II.

It has been assumed that DL intercell interference is calculated, i.e. BS is the aggressor for UEs of all neighboring cells. Due to that, the interference threshold for UE's receiver has been determined. Therefore, results of simulation indicate how the available radio channel can be distributed between 7 cells to avoid intercell interference and maximize spectrum utilization in RMa propagation environment. Figure 6 illustrates the geometry of assumed simulation scenario and includes example outcome of the algorithm's calculations. Only Stage 1 and Stage 2 of the algorithm, as described in subsections A and B, respectively, have been used. As can be noticed in the example results of Fig. 6, the algorithm was able to re-use channels 2 and 3 and allocate them to cells 2, 4 and 7 without generation of intercell interference. To obtain the full statistical picture of the algorithm's effectiveness the Monte Carlo simulation method has been used with 1000 drops of algorithm's realizations for assumed scenario. In case of SFR scheme for 100% of scenario realizations the 3 channels are

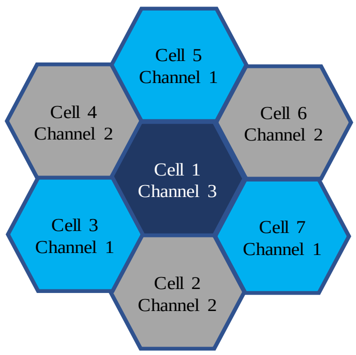

Fig.5. The frequency planning and power allocation for the SFR scheme [14]

TABLE II
MAIN SIMULATION PARAMETERS USED FOR ESTIMATION OF THE ALGORITHM'S PERFORMANCE IN REFERENCE TO SFR SCHEME

Parameter	Value
Propagation environment	3GPP RMa [15]
Height of the BS antenna	50 m
Height of the UE antenna	2 m
Inter-site distance	15000 m
Carrier frequency	1800 MHz
Available bandwidth	60 MHz
No. of MNOs	1
No. of BSs	7
Max EIRP of single BS	43 dBm
Interference threshold of UE	-104 dBm

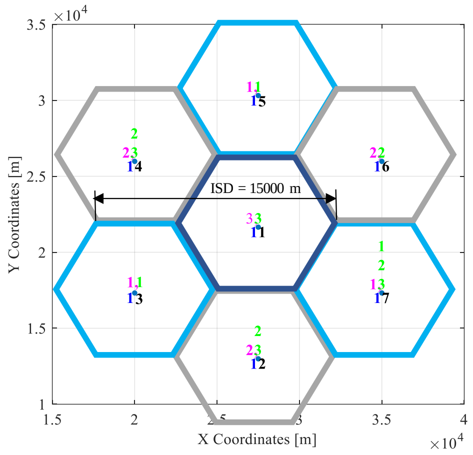

Fig. 6. Geometry of the assumed simulation scenario and example outcome of the algorithm's calculations

needed to avoid intercell interference, whereas according to obtained simulation results the presented algorithm required only 2 channels in 24% of simulated cases and 3 channels for 68% of cases. In remaining 8% of simulated cases the algorithm required 4 channels. Assuming that 60 MHz of the available bandwidth can be distributed between 2, 3 or 4 radio channels, thanks to Stage 2 of the algorithm, almost 60% of DL transmissions can utilize more than 20 MHz of bandwidth, which includes more than 10% of DL transmissions with 60 MHz bandwidth. Only for 5% of all DL transmissions the available bandwidth is less than 20 MHz. Therefore, 20 MHz of the bandwidth is allocated for remaining 35% of DL transmissions. It should be clarified at this point that 20 MHz is the amount of the spectrum which is available for each cell in case of SFR scheme. Presented algorithm allows then to maximize utilization of the available spectrum by the increase of channel bandwidth in 60% of DL transmissions.

Next section presents outcome of the algorithm in case of radio channels distribution between UxNBs and terrestrial BSs deployed in 3GPP-defined network of 5G system.

IV. SPECTRUM SHARING AND COORDINATION BETWEEN UXNBS AND TERRESTRIAL BSS

Similar simulation scenario as in subsection E of Section III has been used to illustrate capability of the algorithm to distribute radio channels between cells served by UxNBs and cells of terrestrial BSs, deployed in the same network and coverage area. Therefore, UxNBs have been assumed to provide additional coverage or network capacity (e.g. due to emergency situations) in the rural area, where the deployment of terrestrial BSs is not dense and may lead to local coverage or capacity shortage. Simulation parameters for this deployment case are presented in Table III.

Also, in this simulation scenario it has been assumed that DL interference is calculated between all cells, including cells served by terrestrial BSs and UxNBs. Assumption was made that the algorithm can be implemented as new functionality of UTM manager. According to requirements made by 3GPP [4] and listed in Section II, it was assumed that the UTM can obtain from 3GPP mobile network all data required for calculation of interference conditions by the algorithm, like equivalent isotropic radiated power (EIRP) and coordinates of all transmitters, interference threshold of receivers and type of propagation environment. Other necessary information can be subject of individual implementation of UTM and the used algorithm.

Three sub-scenarios have been studied, where the number of randomly distributed UxNBs was 1, 3 and 9, respectively. In all cases the algorithm was trying to find the minimal number of channels required to ensure co-existence between all cells and then re-use those channels in the most efficient way. It has been assumed that without the algorithm the number of channels required on top of 3 channels of SFR scheme would be equal to the number of UxNBs in the analyzed coverage area. Therefore, introduction of 1, 3 and 9 UxNBs in the area served by 7 terrestrial cells would respectively require 4, 6 and 12 separate channels to ensure co-existence between all cells. Figure 7 compares cumulative distribution functions (CDF) of minimal number of channels required in the abovementioned sub-scenarios as an outcome from Stage 1 of the algorithm. In sub-scenario with 1 UxNB the algorithm required less than 4 channels for 65% of statistical realizations and more than 4 channels only for 2% of cases. This means that in majority of simulated realizations the algorithm outperformed the simplified SFR-based scheme. Performance of the algorithm was even higher in remaining two sub-scenario – in case of 3 UxNBs for 99% of statistical realizations the algorithm required less than 6 channels and much less than 12 channels for 100% of realizations in case of sub-scenario with 9 UxNBs. During Stage 2 the algorithm was able to re-use channels pre-allocated during Stage 1 and due to that further increase the efficiency of spectrum utilization, which can be observed in Fig. 8. For at least 85% of DL transmissions in all simulated sub-scenarios the allocated channel bandwidth was higher than obtainable by SFR-based approach, i.e. 15 MHz, 10 MHz and 5 MHz for sub-

TABLE III
MAIN SIMULATION PARAMETERS USED FOR ILLUSTRATION OF THE ALGORITHM'S CAPABILITY TO DISTRIBUTE CHANNELS BETWEEN TERRESTRIAL BS AND UXNBS

Parameter	Value
Propagation environment	3GPP RMa [15]
Height of the terrestrial BS antenna	50 m
Altitude of UxNB	150 m
Height of the UE antenna	2 m
Inter-site distance	15000 m
2D position of UxNBs	Random
Carrier frequency	1800 MHz
Available bandwidth	60 MHz
No. of MNOs	1
No. of terrestrial BSs	7
No. of UxNBs	1, 3, 9
Max EIRP of terrestrial BS	43 dBm
Max EIRP of UxNB	23 dBm
Interference threshold of UE	-104 dBm

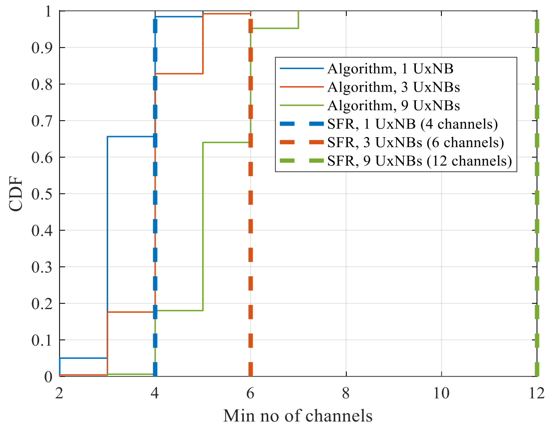

Fig. 7. Simulation results of minimal number of channels obtained for the algorithm and SFR scheme in terrestrial and aerial 3GPP RMa deployment

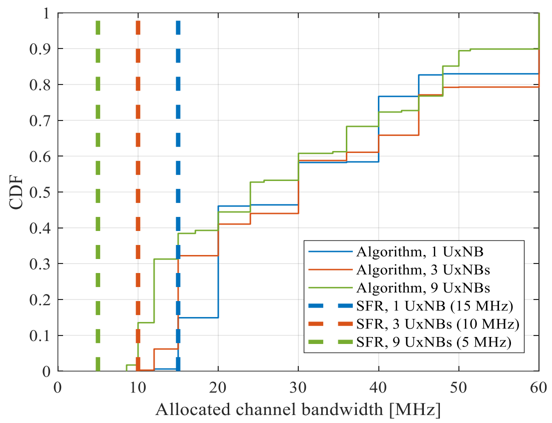

Fig. 8. Simulation results of allocated channel bandwidth obtained for the algorithm and SFR scheme in terrestrial and aerial 3GPP RMa deployment

scenarios with 1 UxNB, 3 UxNBs and 9 UxNBs, respectively. Only for less than 1% of realizations in sub-scenario with 1 UxNBs the algorithm allocated less than 15 MHz. It can be also noticed that with the increasing number of deployed UxNBs, the algorithm is able to outperform the SFR-based approach better. This is due to the limited number of transmitters in the analyzed deployment area, which allows to re-use radio channels between cells and still avoid intercell interferences. However, further increase of the number of UxNBs will lead to severe intercell interference and will decrease performance of the algorithm, which at some point may be similar to the performance of the SFR-based approach.

V. Conclusion

This paper includes high level feasibility study for implementation of a centralized algorithm for dynamic and efficient spectrum sharing between UxNBs and terrestrial BSs deployed in 3GPP-based cellular network of 4G or 5G systems. It has been presented that the latest releases of 3GPP specifications include definition of UTM manager and its functionalities. According to these requirements the UTM is able to monitor and control activities of UxNBs through 3GPP systems and at the same time can share relevant data about 4G or 5G networks, inside which the UxBNs are deployed. Based on the information from 3GPP specifications, it has been assumed that UTM manager is feasible to implement centralized algorithm as part of its functionalities. Proposal of the algorithm has been made, which is based on the principles of Kohonen neural networks theory. It has been shown that the algorithm is able to allocate minimum required radio resources to all radio nodes participating in optimization process and at the same time it helps to maximize spectrum utilization. By simple simulation scenarios it has been presented that spectrum available for transmissions inside 4G or 5G networks can be efficiently distributed between UxNBs and terrestrial BSs. In comparison to basic SFR scheme the centralized algorithm can allocate radio channels more efficiently. For assumed RMa deployment scenarios it has been observed that at least 85% of simulated DL transmissions are gaining more channel bandwidth if the presented algorithm is used instead of SFR-based approach. These preliminary results allow to consider the concept of centralized spectrum sharing between UxNBs and terrestrial BS inside 3GPP network as a valuable direction in studies on cognitive UAV networks, especially in the context of growing interest in UAV communication and work progress of 3GPP.

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