Spectrum sharing and management techniques in mobile networks

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Abstract. Radio spectrum has loomed out to be a scarce resource that needs to be carefully considered when designing 5G communication systems. Spectrum sharing is considered unavoidable for 5G systems and this thesis provides a solution for adaptive spectrum sharing under multiple authorization regimes based on a novel architecture framework that enables network elements to proceed in decisions for spectrum acquisition. The decision making process for spectrum acquisition proposed is a novel Adaptive Spectrum Sharing technique that uses Fuzzy Logic controllers to determine the most suitable spectrum sharing option and reinforcement learning to tune the fuzzy logic rules, aiming to find an optimal policy that Mobile Network Operators (MNOs) should follow in order to offer the desirable Quality of Service to their users, while preserving resources (either economical, or radio) when possible. The final contribution of this thesis is a mechanism that ensures fair access to spectrum among the users in scenarios in which conveying spectrum license is not prerequisite.

Keywords: spectrum sharing, spectrum management, fuzzy logic, reinforcement learning, fair resource usage, genetic algorithms.

1 Dissertation Summary

The mobile communications have experienced an exploding growth of the connected devices over the past few years. Quantitative results reported indicate that this phenomenon is not expected to change in the near future and many efforts will be spent in research, standardization and regulation for facilitating the service requirements of 5G networks. The latest reports show that more than 11.5 billion mobile devices will be connected by 2019.

3GPP, motivated by the increased mobile data traffic volume has encouraged the research community to move towards three directions namely: a) spectral efficiency improvement, b) higher network cell density and c) exploitation of underutilized radio spectrum resources. The first solution includes Coordinated Multiple Point (CoMP) transmission using sophisticated MIMO techniques and interference management mechanisms. The second area deals with the addition of extra layer cells in the net-

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work with base stations that cover smaller areas compared to macro and micro Base Stations (BSs). These solutions include femto cells and the use of relay nodes. The third aspect, which is the main focus of this thesis, deals with the extension of spectrum opportunities for mobile broadband access. Nowadays, spectrum resources are allocated to Mobile Network Operators (MNOs) from the National Regulatory Authority (NRA) and through network planning are used in different geographical areas. Re-allocating spectrum resources that are not fully utilized to congested areas is not a trivial procedure that may cause undesirable effects to the network or in other circumstances (e.g. re-farming spectrum initially given to other communication systems) may take months or even years to complete. However, as the capacity needs for mobile broadband access increase it is expected that dynamic, adaptive and fast solutions that deal with spectrum scarcity will arise in the near future. Such solutions will perform flexible spectrum management and enable spectrum sharing among multiple communication systems, since the complementary solutions given by 3GPP (i.e., MIMO antennas and CoMP) will not be sufficient to cover the capacity needs. Towards, flexible spectrum management 5G communication systems should be carefully designed to overcome spectrum scarcity and Mobile Network Operators (MNOs) will need to revisit business models that were not of their prior interest (e.g., Cognitive Radio) or consider adopting new business models that emerge (e.g. Licensed Shared Access) so as to cover the extended capacity needs. Up to now, MNOs have been reluctant investing for extra network technologies that would offer spectrum flexibility and preferred following traditional exclusive access scheme for their dedicated spectrum resources, which led to reduced spectrum utilization. MNOs hesitation towards spectrum sharing has been also reinforced by the fact that spectrum sharing techniques proposed in the literature focus on single authorization regimes, limiting thus the flexibility and the potentials of spectrum sharing among multiple communication systems. Thereafter, new flexible mechanisms that will handle spectrum efficiently and will exploit the benefits of various authorization regimes are required.

Towards this direction, this thesis aims at providing a solution for spectrum sharing under multiple authorization regimes based on a novel architecture framework that enables the network components to proceed in decisions for spectrum acquisition and exchange information that will lead to the realization of the proposed concept. The contributions of this dissertation move towards four directions, namely a novel functional architecture in conjunction with information model and data model for enabling spectrum sharing under multiple authorization regimes, a fuzzy logic based spectrum controller giving the opportunity to mobile networks to choose effectively the most proper sharing scheme taking into account network conditions and spectrum market demands, its corresponding learning mechanism based on reinforcements that enables this scheme to adapt the decision making process over time and finally, a complementary scheme for fair resource usage applied in general authorization regime in which there is no need for spectrum license.

Regarding the first contribution of this thesis, we have proposed a novel architecture framework, including functional elements incorporated in (either existing or new) network entities, which drive the decision making process of spectrum acquisition and lead to the realization of the proposed spectrum sharing concept. The incorporation of

Spectrum Controller, a logical entity that is responsible for requesting additional spectrum resources to the operator's network and the Spectrum Manager, a logical (and not necessarily centralized) unit that is responsible to gather information on available spectrum and grant access based on the received spectrum requests have been proposed in the context of this thesis. The whole process is regulated by National Regulation Authorities (NRAs) and the framework may be applied upon multiple spectrum sharing scenarios such as the Licensed Shared Access (LSA), the Co-primary spectrum sharing and other light-licensing sharing schemes [1]. A possible instantiation through a Software-Define Network (SDN) has also been introduced. In our proposal we have assumed a fully SDN capable network for configuring both core and access network elements. MobileFlow forwarding engine (MFFE) and MobileFlow controller (MFC) are considered to be the key enablers of the deployment in the configuration of the core network and the Evolved SoftRAN (E-SoftRAN) is the key enabler when configuring the network elements in the access network [2].

The second contribution of this thesis is related to the decision making process that will enable spectrum sharing under multiple authorization regimes. Based on the proposed architecture Spectrum Controller is responsible to perform the decision making process for spectrum acquisition. In this thesis, we propose a novel spectrum sharing technique that uses Fuzzy Logic controllers to determine the most suitable spectrum sharing option. Fuzzy Logic Controllers (also called Fuzzy Inference Systems) consist of three parts, namely the fuzzifier, the inference system, and the defuzzifier. The first part is responsible to map (fuzzify), the input values to the extent that these values belong to a specific state (e.g., low, medium, high using the input membership functions). The input is a numerical value limited to the universe of discourse of the input variable (it could be a real value, integer, natural, etc.) and the output is a fuzzy degree of membership (always in between the [0,1] interval). The second part (inference system) is responsible to apply the fuzzy operators, apply the implication method and aggregate all inputs. More specifically it uses "if … then…" rules to identify the relation of the inputs to the outputs; each rule results to a certain degree for every output. Then, the output degrees for all the rules of the inference phase are being aggregated by using the output membership functions. Finally, the defuzzifier will perform the defuzzification procedure aggregating the outcomes of all the rules and producing a single crisp value. This value captures the decision of the decision maker. In our contribution, Fuzzy Logic Controllers' decisions take into account network conditions, spectral efficiency and the rules preserved in each Fuzzy Logic Controller, which are defined based on the special features of each spectrum sharing option. Several spectrum sharing options exist based on various authorization regimes, which may be divided into two categories, vertical and horizontal spectrum sharing depending on the predefined priority that each communication system has. In vertical sharing concept there is a license-holder, also known as primary user or incumbent, that could grant usage rights to licensees (as in [3]) or the other players (i.e. besides the license-holder) could use the spectrum in opportunistic way [4]. In [5], a rule-regulated distributed and collaborative spectrum sharing approach is proposed. The solution aims at improved system fairness and spectrum utilization and reduced signaling overhead but lacks flexibility. However, solutions that enable spectrum sharing on unlicensed basis fail to give QoS guarantees to the users.

In horizontal sharing the communication systems that use the same spectrum have equal rights of usage. Inter-operator spectrum sharing is a typical paradigm of horizontal sharing that has emerged over the past years [6][7][8]. A partially distributed implementation method using game theory and learning algorithms proposed in [6], focusing on sharing in multiple licensed bands and aiming to reduce network latency and call dropping rate. In [7], a game theoretical framework that enables Dynamic Spectrum Access through a utility function that takes into account network measurements is proposed. In [8], authors proposed a coordination protocol to enhance utilization between mobile operators using auctions. The spectrum sharing protocol is based on one-shot games between operators without using operator-specific information exchange. Game-theoretic approaches though, induce significant computational complexity to the network, rely on predictive behavior from MNOs and occasionally assume the knowledge of information that is not possible to be obtained.

All these solutions focus on a single sharing scheme limiting thus the potentials for spectrum sharing. In addition, the game-theoretic approaches either assume cooperation between MNOs or rely on the good-willingness of an MNO, which though is impractical for real systems. On the other hand, the mechanism proposed in this thesis is a flexible solution for optimizing the spectrum acquisition process by exploiting multiple sharing schemes (i.e. co-primary and LSA schemes)[9][10]. Using Fuzzy Logic to design spectrum sharing algorithm under various authorization regimes is a novel approach, and, to our knowledge, none similar solutions that enable flexible spectrum sharing exist in the literature.

The third contribution of this thesis is related to the fact that permanent manual configuration should be avoided in such system. Thus, we have developed a reinforcement learning technique that allows dynamic adaptation of the decision making process of the fuzzy logic system over time. Reinforcement Learning (RL) is based on learning process that maps situations (also known as states) to actions so as to maximize a numerical value named long term reward [11]. In RL the learner is not instructed to take specific actions, as in most forms of machine learning, but instead is free to explore the environment (i.e., moving among states) by taking the actions that yield the most reward. In some RL cases, actions may affect not only the immediate reward, but also the next state as well and, through that, all subsequent rewards. «Trial and error» search and «delayed reward» are the two characteristics that distinguish reinforcement learning from other machine learning schemes [12].

There are three fundamental classes of methods for solving a reinforcement learning problem, namely Dynamic Programming, Monte Carlo methods, and, Temporal Difference methods. Dynamic Programming solutions are well developed mathematically but require a complete and accurate model of the environment, which is not available in many application scenarios. Monte Carlo methods do not require a model and are very simple, but are not suitable for step-by-step incremental computation. Temporal Difference methods on the other hand, do not require an accurate model of the environment and are suitable for step-by-step incremental computations, but are more complex and depend on the dimension of the search space. In general, Temporal

Difference is simpler and possible to work both in online and offline fashion [13], making it thus the most attractive method in our case. The most representative algorithm of Temporal Difference method is Q-Learning that works by estimating the values of state-action pairs. The value Q(s, a) is defined to be the expected discounted sum of future payoffs obtained by taking action <a> from state <s> and following an optimal policy thereafter. Once these values have been learned, the optimal action from any state is the one with the highest Q-value. The main advantage of Q-learning exploited in our solution is that it is able to compare the expected utility of the available actions without requiring a model of the environment. The introduced technique realizes the concept of Adaptive Spectrum Sharing taking into account the effect that Fuzzy Logic Controllers have upon the network as well as the spectrum market. Then the proposed Q-learning scheme tunes the fuzzy logic rules, aiming to find an optimal policy that MNO should follow in order to offer the desirable Quality of Service to its users, while preserving resources (either economical, or radio) when possible. The proposed Adaptive Spectrum Sharing scheme is applicable in sharing scenarios such as Licensed Shared Access, co-primary sharing, etc., that accessing spectrum is granted through spectrum licenses. However, in license-exempt spectrum access scenarios spectrum sharing relies on spectrum sensing and power control mechanisms to avoid harmful interference. The final contribution of this thesis is a mechanism that ensures fair access to spectrum among mobile users in such scenarios. The proposed mechanism caters for underprivileged users by enhancing their transmission power value, generated by the evolutionary execution of Genetic Algorithm. The algorithm's behavior in cases of an incomplete knowledge model (i.e., some of the users may not know all the information) is also assessed as this is particularly important for real systems in which a full knowledge model is typically an unrealistic assumption.

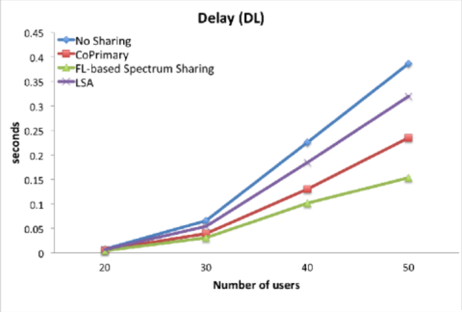
2 Results and Discussion

The previously described contributions, for using fuzzy logic controllers and reinforcement learning for Adaptive Spectrum Sharing have been evaluated in the well-known 5G use case, namely shopping mall, firstly introduced by METIS 2020 project in [16]. On the other hand, the introduced Genetic Algorithm for license-exempt spectrum access scenarios is evaluated in small-scale simulation scenario with limited number of users. The aim is to evaluate the mechanisms' efficiency for identifying appropriately events for spectrum sharing, for adapting the model of the environment and for enabling fair resource usage among unlicensed users. In this section, the results of the application of the developed schemes are being provided and analyzed.

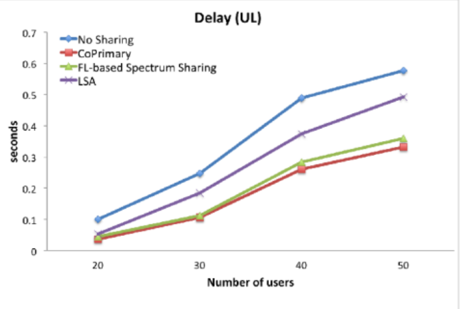
2.1 FL-based spectrum sharing

In order to quantify the benefits of the Fuzzy Logic-based spectrum sharing solution we have performed a series of experiments so as to compare its performance against three other schemes namely, no sharing, Co-primary sharing, and LSA sharing based on the available sharing options. All those schemes and our proposed mechanism have been evaluated using the discrete event network simulator NS-3. Our simulation scenario is based on the shopping mall case proposed in METIS project [16]. The considered topology is a 100x50x10 m floor with 10 rooms (that form a 5x2 grid). Three base stations have been deployed in the area; one macro cell located 200 meters away from the building and two femtocells deployed in the considered area.

In the evaluated scenario, UEs that follow a random mobility have been placed in the simulation area and the average delay and throughput both in downlink and uplink communication over a time window of 100 seconds have been measured. The following figures present a comparison between the Fuzzy Logic-based spectrum sharing solution and the other approaches (i.e., no sharing, only co-primary, and only LSA sharing). In all four simulated cases the UEs initiate consuming services. In the three cases where we assume sharing, when the UEs consume a certain portion of the available bandwidth (i.e., 90% - so as to have some resource blocks still available to serve new incoming service requests till the newly acquired spectrum is available, as well as for capturing the nature of the load trend) the spectrum controller is triggered and proceeds in renting spectrum. In the co-primary and LSA cases the controller rents what he is preconfigured to (i.e., co-primary and LSA spectrum respectively), whereas in the FL-based spectrum sharing it rents what the algorithm dictates. When the operator rents spectrum from LSA users, there is the probability that the incumbent user will reclaim his spectrum. In such case the UEs that are being served using LSA spectrum will have to be served by MNO’s dedicated resource blocks, thus decreasing the throughput and increasing the delay.



(a)



(b)

At this point it should be mentioned that the available economical capacities are the same in all three cases, so the spectrum controller has the same amount of money to consume. Additionally, we assume that the co-primary spectrum has twice the price of the LSA [10][11]. This implies that in the cases of the LSA as well as in the FL-based spectrum sharing the controller may rent extra spectrum, which however, is not guaranteed for the overall time of the sharing. More specifically, in the case of LSA spectrum sharing the operator may acquire twice the co-primary spectrum chunks. Similarly, in the case of the FL-based spectrum sharing if the operator decides to rent only LSA spectrum he may acquire twice the spectrum of the co-primary cases, whereas if he decides to rent only co-primary he may rent exactly as many resource blocks as in the co-primary case. In all the other occasions of the FL-based spectrum sharing scheme the economical capacities are split in the two sharing options.

The results show significant improvement regarding the average delay and throughput when sharing is applied, compared to the no sharing case. Additionally, when comparing the FL-based spectrum sharing to the rest of the sharing schemes we observe that in general the FL-based spectrum sharing and the co-primary sharing perform significantly better than the LSA scheme. This is due to the fact that in the LSA case there is a probability that the incumbent may re-claim his spectrum, thus causing significant delays and throughput reductions. Additionally, for small numbers of UEs the gains from renting spectrum are relative small (since the already available spectrum may cover the user needs), but when the number of UEs increases, the no sharing scheme does not manage to capture the user needs. It is worth mentioning that when the number of UEs increases, the rate of increase in the throughput is reduced even though that the operator rents spectrum, as system's capacity reaches its limitations.
Additionally, it should be highlighted that the developed mechanism outperforms the Co-primary spectrum sharing since it may rent more spectrum when it suits to the users in the vicinity, due to the fact that the controller may split its economic resources to both LSA and co primary spectrum.

2.2 Adaptive Spectrum Sharing through reinforcements

Quantitative analysis is used to evaluate the Reinforcement Learning scheme for adaptive spectrum sharing. In our evaluation in order to be able to compare the scheme against the FL-based scheme we have used the NS-3 simulator to model the behavior of the network. Following similar simulation methodology as in the FL-based scheme evaluation we compare the Adaptive Spectrum Sharing scheme against the four cases (i.e., no-sharing, LSA sharing, Co-primary sharing, Fuzzy-logic based) presented afore in the FL-based scheme evaluation. The Reinforcement Learning scheme applied in the Adaptive Spectrum Sharing mechanism is realized via an offline process that performs training sessions which optimize the behavior of the Fuzzy Reasoners taking into account the reinforcements of their actions (i.e. spectrum cost, monitoring measurements). Then the operator uses the trained Fuzzy Reasoners to make its decisions.

The following methodology has been followed for the Reinforcement learning scheme:

- Initialization: At this point the network topology of the operator is deployed in the simulator. The network topology is based on the afore-mentioned shopping mall. Then, the UEs are placed randomly in the simulation area.
- Monitor-Decision-Execution cycle: During this phase several network parameters are monitored and fed to the Fuzzy Logic Reasoners. Based on the decision making engine the MNO decides whether to obtain additional spectrum resources or not. Finally, the additional spectrum resources are obtained and used in the network, before a new MDE cycle is executed.
- Training sessions: Each experiment is subject to our Q learning mechanism for adapting the decision making process based on reinforcements.

The configuration parameters are the same as in the evaluation process of the Fuzzy Logic based spectrum sharing, so as to have comparable results.

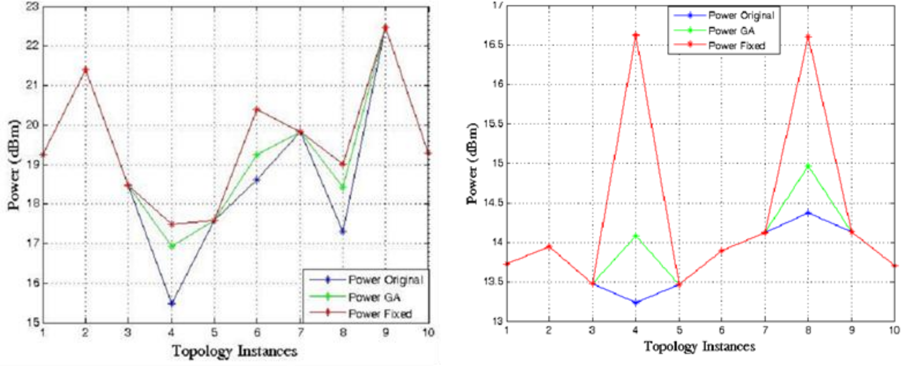
The results reported in thesis show that the Reinforcement Learning improves the average delay and throughput of the FL-based spectrum sharing scheme. The proposed feedback loop optimizes the behavior of the FL-controllers and as the number of UEs increases the benefits of the reinforcement learning are higher. More specifically, the Adaptive Spectrum Sharing scheme demonstrated approximately 20% DL and 30% UL delay reduction compared to FL-based scheme, increasing thus the gains of the proposed spectrum sharing solution against the no-sharing, LSA sharing and the Co-primary sharing schemes. In addition throughput performance of the Adaptive Spectrum Sharing scheme is approximately 5% and 10% increased in DL and UL communication respectively compared to FL-based scheme, and thus is further superior to the no-sharing, LSA sharing and Co-primary sharing schemes.

2.3 Fair resource usage through power control in license-exempt scenarios

The proposed Genetic Algorithm for fair resource usage in license-exempt spectrum access scenarios is evaluated in small-scale MATLAB simulation scenario with limited number of users. The proposed algorithm uses a Cooperative Power Control algorithm [17] as a baseline and is compared to a scheme of fixed power value assignment (maximum valid power level). The main objective is to give "fairer" power values to the underprivileged unlicensed users. This concludes to a more "fair" treatment, but incurs loss in system performance, as principles of the baseline algorithm are violated. The major difference between the two proposed techniques is that in case of GA, underprivileged users get better power values, but not the maximum ones due to the negative impact of interference to other users.

The proposed implementation examines a typical network environment with 5 or 10 unlicensed mobile UEs cooperating in order to transmit with an acceptable power value. The Tx power ranges between 10 and 23 dBm and the distances between the unlicensed users is a random number in the [50, 550] meters range. The users set their Tx power levels to maximize the utility function of [17] until the algorithm converges to a steady state for a given topology. The whole procedure lasts for 10 time steps that reflect the mobility of the users in consecutive time frames. For every successive step, our fairness GA-based policy mechanism is triggered, in order to examine whether underprivileged users exist. If so, the GA algorithm is activated, so as to enforce fairness. In order to identify whether an unlicensed user is underprivileged, a time window of previous Tx powers is examined. to detect underprivileged users. The fixed power value schema (FX) lets underprivileged users to transmit with maximum power values usually resulting to a non-cooperative state, where all users are negatively affected. On the other hand, in the proposed fairness scheme the Tx power of the underprivileged users is re-calculated based on the fitness function of the Genetic Algorithm [14].

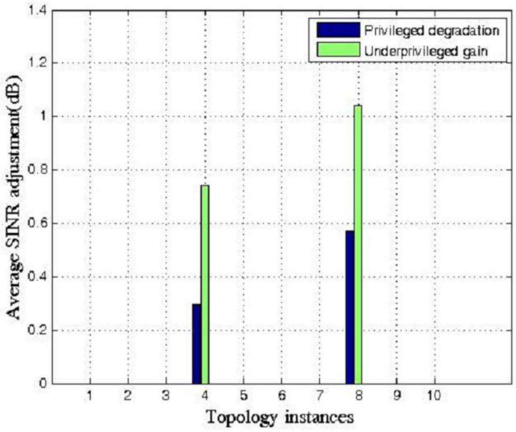
The results shown in the following figures illustrate the average Tx power values of the 5 and 10 UEs respectively, for each of the 10 time steps and highlight the purpose of the fairness scheme, that is to support the underprivileged users and minimize the negative impact to the network. Indeed, in the proposed scheme the underprivileged users get enhanced power values; however, this is done in a controlled way, so that the impact in the overall performance of the network is limited (marginal reduction of the average network SINR by approximately 0.3 dB). This is a reasonable trade-off for enhancing the overall fairness, especially considering that the SINR of the underprivileged users and the related QoS is increased.



(a) (b)

Furthermore, the proposed solution leads also to enhanced SINR at the receiver for the underprivileged users and the increment of the number of users does not impact the fairness policy. The system remains resilient as more opportunistic users try to transmit and SINR gains remain sufficient [14].

Since the utility function of [17] strikes the optimal balance from a system utilization perspective between the selfish need for transmission at the highest power level and the social conformance of reducing the interference to other neighboring users, altering the Tx Power to the constantly underprivileged users will also have a negative impact to the rest of the users in the environment. Thus, we have measured the consequences of the fairness policy upon the opportunistic users that are not underprivileged compared against the gains of the underprivileged users. The following figure shows a comparative analysis of the average SINR gains of the underprivileged users against the average SINR degradation that the other users will experience. The results show that the gains of the underprivileged users are significantly more compared to the SINR degradation of the rest of the users.



Finally, as mentioned previously many fairness schemes are challenging in their application to real world systems due to the full knowledge requirement and the stringent synchronization constraints among the wireless nodes that this requirement imposes. In our case the genetic algorithm can operate efficiently with a significantly relaxed knowledge model and synchronization scheme. For our evaluation of this highly desirable property we have conducted 1000 experiments assuming the same environment as before; the fundamental difference is that the system suffers a 10-20% message loss, thus leading to undesired effects for the nodes, as they will not have a complete knowledge of the environment. Our results in [14] show that in cases of an incomplete knowledge model the GA (in the scenario of 10 users) is triggered again exactly 2 times (as in the case with full knowledge) with probability equal to 42%. The results also show that cases of not triggering the GA when needed (false negatives) are not possible, but there are some false positive cases where the algorithm is triggered more times than actually needed.

3 Conclusions

Innovative approaches are required for covering the augmented requirements of the future networks to reduce spectrum resources shortage. Considering that other frequency bands remain underutilized due to limited data transmissions of their rightful users the exploitation of such bands becomes very attractive. Up to now, exploitation of TVWS with cognitive radio approaches has been under consideration, though the drawbacks (i.e., complex solutions, interference may be caused to the mobile user, etc.) of such solutions make their realization questionable and discourage their application. On the other hand, the rise of new approaches, such as co-primary spectrum sharing and Licensed Shared Access, which protect both spectrum license holders and spectrum licensees are expected to enable flexible spectrum management.

In this thesis the vision of future mobile networks in which the MNOs share spectrum resources either with other MNOs (co-primary sharing scheme), or with Incumbent Users (LSA sharing scheme) has been thoroughly presented by describing the key characteristics of each approach. The analysis could be summarized in the two main differences between these two spectrum sharing approaches. Both of the differences are related to actors involved in the sharing procedure. The first one is related to the incumbent users that shall not be burdened with complex calculations, which implies that in the LSA case the presence of a translation and coordination entity is required. The second main difference is related to the fact that in the LSA concept potentially several spectrum licensees (i.e., MNOs) may exist, which will not be necessarily coordinated; this may introduce interference among them (the incumbent user is protected from interference), whereas in the co-primary spectrum sharing the spectrum buyer will not experience interference for the time period of the renting. In our work we have presented a common architectural framework for coupling the co-primary and the LSA sharing schemes. For meeting the requirement of reduced complexity in the incumbent users we propose the introduction of a translation engine, with the prerequisite that the data will be formed in Spectrum Availability structure indicating available spectrum over time, frequency and geographical domains.

The proposed architecture is accompanied by a fuzzy logic based spectrum sharing algorithm for enabling the operators to decide which spectrum authorization option is more suitable given the network conditions. In our analysis, fuzzy reasoners for the LSA and Co-primary sharing schemes have been presented. However, the proposed algorithm could be easily extended to other sharing schemes (e.g., light-licensing). The algorithm has been evaluated against single sharing schemes and also against the typical operation (i.e., without spectrum sharing) of a mobile network in a well-known 5G communication scenario (i.e., shopping mall) related to Ultra Dense Networks. The algorithm influences the decision making process through fuzzy evaluation of the network conditions and the results of the evaluation show significant improvement in achieved throughput and average delay both in uplink and in downlink communication.

However, the way the proposed Fuzzy-Logic based spectrum sharing algorithm evaluated network condition is rather static and thus, it has been further extended with adaptation mechanism (i.e. reinforcement learning technique) to tune the decision making process and realize the concept of Adaptive Spectrum Sharing. Adaptive Spectrum Sharing is the ability of the network to model its environment, assess it and interpret it so as to decide whether spectrum resources (beyond the licensed spectrum of the MNO) will be needed in the near future. Then, evaluate whether the taken decision was beneficiary for the network and tune the decision making process (i.e., adapt the behavior of the Fuzzy Logic Controllers) so as to improve future decisions.

The Adaptive Spectrum Sharing mechanism is then complemented with a fair resource usage mechanism applied in cases of spectrum sharing under general authorization regime. In such scenarios, users are accessing spectrum without having a dedicated license a priori and are obliged to tune their operation in order to avoid harmful interference to the licensed users operating in the same frequency band. This may be done either through spectrum sensing techniques, or via querying a GeoLocation Database before accessing spectrum. However, mutual interference among unlicensed users in such scenarios is not part of any regulatory process and thus, mechanisms that allow fair resource usage are needed. In this thesis we proposed a fair power control mechanism using Genetic Algorithms. The proposed solution has been applied upon a cooperative power control algorithm and the results showed significantly improved SINR for the underprivileged users compared to the original algorithm with minimal impact in the SINR of the privileged users. Furthermore, in comparison to the case of a simplified fairness policy, which assigns underprivileged cognitive users with the maximum valid power level, the proposed scheme offers considerable power gains to the network. Finally, it has been shown that the proposed algorithm can operate efficiently even in cases of partial knowledge models and imperfect message exchange/synchronization between the users, a property that is highly desirable for application in real world system.

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