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NOVEL ANALYTICAL FRAMEWORK FOR HARNESSING COGNITIVE RADIO RESOURCE OPTIMIZATION IN 5G NETWORKS

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ABSTRACT

The issue of spectrum scarcity in wireless networks is becoming prominent and critical with each passing year. Although several promising solutions have been proposed to provide a solution to spectrum scarcity, most of them have many associated tradeoffs. In this context, one of the emerging ideas relates to the utilization of cognitive radios (CR) for future heterogeneous networks (HetNets). More specifically, a joint power allocation and user assignment solution for the multi-user underlay CR-based HetNets has been proposed and evaluated. To counter the limiting factors in these networks, the individual power of transmitting nodes and interference temperature protection constraints of the primary networks have been considered. An efficient solution is designed from the dual decomposition approach, where the optimal user assignment is obtained for the optimized power allocation at each node. The simulation results validate the superiority of the proposed optimization scheme against conventional baseline techniques.

1.0 INTRODUCTION

Energy consumption has become a primary concern in the design and operation of wireless communication systems. Indeed, while for more than a century communication networks have been mainly designed with the aim of optimizing performance metrics such as the data-rate, throughput, latency, etc.[15], in the last decade energy efficiency has emerged as a new prominent figure of merit, due to economic, operational, and environmental concerns. The design of the next generation (5G) of wireless networks [9] [14] will thus necessarily have to consider energy efficiency as one of its key pillars. Indeed, 5G systems will serve an unprecedented number of devices, providing ubiquitous connectivity as well as innovative and rate-demanding services. It is forecast that by 2020 there will be more than 50 billion connected devices [8], i.e. more that 6 connected devices per person, including not only human type communications, but also machine-type communications.

The vision is to have a connected society in which sensors, cars, drones, medical and wearable devices will all use cellular networks to connect with one another, interacting with human end-users to provide a series of innovative services such as smart homes, smart cities, smart cars, tele surgery, and advanced security [7]. Clearly, in order to serve such a massive number of terminals, future networks will have to dramatically increase the provided capacity compared to present standards. It is estimated that the traffic volume in 5G networks will reach tens of Exa bytes (10006 Bytes) per month [8]. This requires the capacity provided by 5G networks to be 1000 times higher than in present cellular systems [3]. Trying to achieve this ambitious goal relying on the paradigms and architectures of present networks is not sustainable, since it will inevitably lead to an energy crunch with serious economic and environmental concerns.

Economic concerns

Current networks are designed to maximize the capacity by scaling up the transmit powers. However, given the dramatic growth of the number of connected devices, such an approach is not sustainable. Using more and more energy to increase the communication capacity will result in unacceptable operating costs [1]. Present wireless communication techniques are thus simply not able to provide the desired capacity increase by merely scaling up the transmit powers. Environmental concerns. Current wireless communication systems [15] are mainly powered by traditional carbon-based energy sources. At present, information and communication technology (ICT) systems are responsible for 5% of the world's CO2 emissions, but this percentage is increasing as rapidly as the number of connected devices [3]. Moreover, it is foreseen that 75% of the ICT sector will be wireless by 2020, thus implying that wireless communications will become the critical sector to address as far as reducing ICT-related CO2 emissions [12] is concerned.

2.0 EXISTING SYSTEM

5G will hardly be a specific RAT, rather it is likely that it will be a collection of RATs including the evolution of the existing ones complemented with novel revolutionary designs [2]. As such, the first and the most economical solution to address the 1000x capacity crunch is the improvement of the existing RATs [8] in terms of SE, EE and latency, as well as supporting flexible RAN sharing among multiple vendors. Specifically, LTE [11] needs to evolve to support massive/3D MIMO to further exploit the spatial degree of freedom (DOF) through advanced multi-user beam forming, to further enhance interference cancellation and interference coordination capabilities in a hyper dense small-cell deployment scenario. WiFi also needs to evolve to better exploit the available unlicensed spectrum [10]. IEEE 802.11ac, the latest evolution of the WiFi technology, can provide broadband wireless pipes with multi-Gbps data rates. It uses wider bandwidth of up to 160 MHz at the less polluted 5 GHz ISM band, employing up to 256 Quadrature Amplitude Modulation (QAM) [11]. It can also support simultaneous transmissions up to four streams using multi-user MIMO technique. The incorporated beam forming technique has boosted the coverage by several orders of magnitude [2], compared to its predecessor (IEEE 802.11n). Finally, major telecom companies such as Qualcomm have recently been working on developing LTE [7] in the unlicensed spectrum as well as integrating 3G/4G/WiFi transceivers into a single multi-mode base station (BS) unit [6]. In this regard, it is envisioned that the future UE will be intelligent enough to select the best interface to connect to the RAN based on the QoS requirements of the running application

3.0 PROPOSED SYSTEM

Cognitive Radio Network that is supported by 5G based communication. Our proposed work in CRN is designed to improve the utilization of spectrum along with secure data transmission. The complete framework consists of Primary Base Station (PBS), Spectrum Agents (SA"s), Certificate Authority (CA) [11], Fusion Center (FC), Primary Users (PUs), Secondary Users (SUs), and Malicious Users (MUs) [15]. In our work, FC performs an important part in receiving multiple signals and transmitting multiple output signals. A novel Fusion Center Rotation (FCR) method is designed for reducing the overhead among the SA"s [1]. This FCR method covers only a particular area until the timestamp „tix" reaches the threshold value. If the FC covers an area of „ar1" at a time „ti1", then it receives signals only from the SA"s that are present in that coverage area „ar1"[3]. Hence this method reduces overhead among SA"s. Each SU sends the request to its SA to sense the channel whether the intended white space is present or absent in the primary user signal.

Then the SA senses the PBS spectrum and forwards its local decision to the FC when the FC‟s rotation reaches its coverage. To assure that the specific SU and SA is a normal user, all the legitimate SUs and SAs are certified by CA [14]. Spectrum sensed SAs send the local decision to FC including with the certificate and so if a malicious user is involved in sensing, it is detected by FC and its request is discarded.

4.0 TECHNIQUES USED

NOMA

The key feature of NOMA is that multiple users will be allocated at different power levels, depending on their channel conditions, where it is worth pointing out that the communication with these users is happening at the same time, code and frequency channels [9]. Therefore, the signal model at User 1 can be viewed as a special case of multiple access channels (MAC) [8], to which the successive detection strategy, i.e., detecting User 2's message first and then removing it from the mixture, is optimal in terms of achieving the MAC capacity [18]. User 2 simply treats User 1's message as noise and detects its own message directly.

SCMA

SCMA is a multi-dimensional codebook-based non-orthogonal multiple access technique. The key component is SCMA encoder which joins modulation and spreading. It maps user's data bits to a K-dimensional complex sparse code word selected from the given codebook, where K is the length of an SCMA code word [3]. In other words, user's data bits are spread on K resources after SCMA encoder. An SCMA encoder contains J separate layers [2], where J = K N and N is the non-zero dimensions of the sparse code word. J layers are multiplexed over K a resource, which generates overloading with factor J/K. A user can be assigned one or more different code words.

5.0 IMPLEMENTING METHODS

Spectrum sensing: The spectrum sensing plays an important role in obtaining awareness of the radio environments and detecting unused licensed frequency bands of PUs. Several spectrum detection methods [11] have been studied, which are shown and categorized in Figure. Cooperative detection methods can obtain better performance than non-cooperative detection methods at the cost of processing complexity. In 5G systems [2], the wideband signal up to 1 GHz will be a challenge for the conventional detection methods. Cooperative detection, especially

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cooperative multi-band detection will play an important role [3].

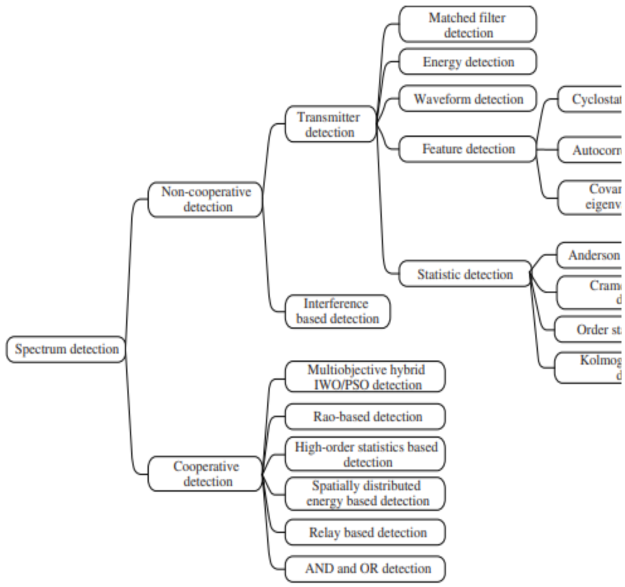

Figure Spectrum detection methods

Spectrum mobility: As the available licensed frequency bands are time-variant with the movement of PUs, SUs need to dynamically adjust frequency resources. When available frequency bands of PUs are detected, SUs can access licensed frequency bands to gain better quality of service (QoS). When licensed PUs are activated, SUs have to evacuate the channel to guarantee PUs' QoS [11]. This means that the SUs communication would suffer interruption frequently. Spectrum mobility is a key feature to enable continuous SUs data transmission.

In 5G systems, it requires higher spectrum handoff success rate and lower handoff delay. Non-handoff, pure reactive handoff, pure proactive handoff and hybrid handoff strategies have been considered. Furthermore, the concept of CR will be extended to new scenarios, such as dynamic spectrum access between inter-RATs or multi-layers [16].

Security: CR is vulnerable to attacks due to frequency sharing [13]. Various attacks and security threats have been discussed.

- Malicious PUs emulation attack: attackers play as PUs to transmit strong signals in order to interference SUs' detection;
- Unintentional PUs attack: PUs with defects always transmits strong signals for communication cause SUs' detection errors;
- Malicious SUs emulation attack: attackers act as SUs to report false sensing information to mislead spectrum decision;
- Unintentional SUs attack: SUs with defects report inaccurate sensing information;
- Selfish SUs attack: SUs report false sensing information to maximize their aggregate spectrum utilization.

6.0 METHODOLOGY

ANMO-SDR Architecture

ANMO-SDR follows a hybrid architecture paradigm, according to which, self-

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organization and self-optimization procedures are running locally on the MN considering local scope tasks, while, accordingly, the tasks with wider scope (global network view) are being managed by the SDN controller, a central managing authority on the network side (i.e., at the core network).

The proposed hybrid architecture extends the design directions of GANA [29,30], which provided the fundamental principles and guidelines towards ANM objectives, without providing any specific solution or implementation. More precisely, GANA introduced ANM components for different abstraction levels of functionality [6], which follow the principles of hierarchical, peering, and sibling relations among others. ANMO-SDR promotes self-management, as well as self- and environment-awareness (in comparison to GANA), giving to the MN the ability to control its own context.

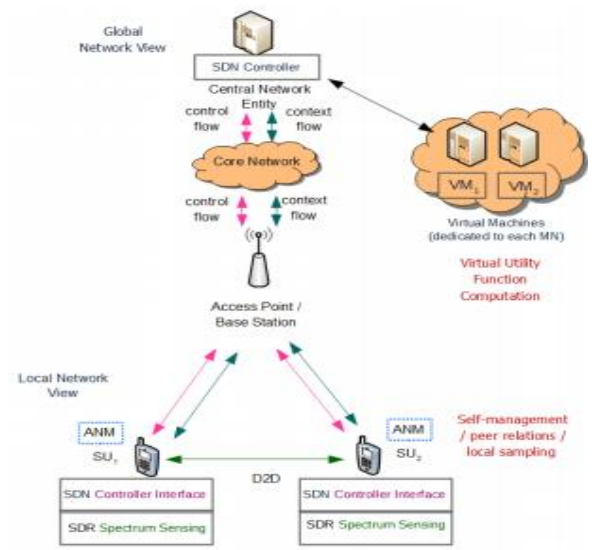

Figure Hybrid ANMO-SDR architecture

Thus, it enables the MN to determine the appropriate time to execute respective actions, promoting local optimum, enabling it to assign the best available channel according to the desired operational goals (self-optimization).

Cross-Layer Optimization

The proposed framework focuses on the three lower layers of the protocol stack, namely the Physical (PHY), Medium Access Control (MAC) and Network (NET) layers [7], which are extended to include a vertical cross-layer interconnection. The entire stack is realized individually in each MN. More precisely, the physical layer is enhanced with SDR features such as spectrum sensing. The cross-layer functionality related with the involved entities and the respective ACL are presented in Figure. Complying with the SDN concept, the proposed framework

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allows the decoupling of the control and data plane [7], where the latter implements only the data forwarding related operations and does not perform any type of control. As far as non-control functionalities are concerned, the three layers remain essentially unaltered compared to the traditional protocol stack. Specifically, the data plane [6] of each MN (i.e., SU) is responsible for providing the ambient information of each individual layer to build the self- and environment-awareness, through the Information Collection component.

7.0 RESULTS

The implementation of the resource management software and the configuration of the SDR resources were realized with GNU Radio, a free and open-source software development toolkit that provides signal processing blocks to implement software radios. In IRIS, the secondary network consists of four nodes organized in a full-mesh topology, i.e., every node has a direct connection to every other node in the network. The operation of the proposed autonomic cross-layer framework is first evaluated in the absence of PUs, assessing in that way the achieved localized and distributed spectrum sharing among SUs.

Table Experimental Scenarios

S. No	Test bed	PU	No. of SUs	No. of Channels	Sweeps	Transmissions	Collisions
1	IRIS No	4	4	5	50	47	3
2	IRIS No	4	4	5	50	47	4
3	IRIS No	4	4	3	30	47	5
4	IRIS No	4	4	5	50	36	1
5	IRIS Yes	4	4	4	40	47	3
6	IRIS Yes	4	4	5	50	47	0
7	ORBIT No	8	4	6	60	57	4

Subsequently, the focus is shifted to the demonstration of the transparent to the primary system operation of the secondary network. Hence, a PU is added to the topology. Finally, the capability of the proposed mechanism to efficiently react to variations of the wireless environment is examined in respect to PU mobility (channel evacuation and idle time, PU reappearance, change of the occupied spectrum, etc.). Similarly, the secondary network in ORBIT consists of eight

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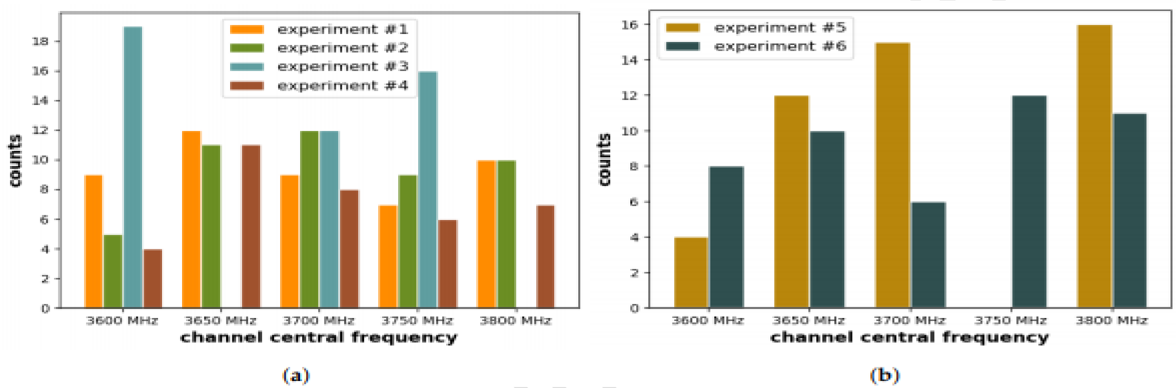
nodes organized in a full-mesh topology, allowing us to verify the operational behavior of the mechanism in a larger, more realistic layout.

More specifically, this scenario involves the presence of multiple SUs in a constrained space, potentially coexisting with PUs. Such a case may correspond to a peer-to-peer network where SUs exchange files, or a sensor network where devices exchange localized information by opportunistically accessing the licensed spectrum. Regarding Gibbs sampling, all sites update their state sequentially within a sweep, one at each epoch according to the selected visiting scheme (the ascending numerical order of IDs). An annealing schedule of the form T(w) = c0 ln(1+w) is adopted, where T(w) is the temperature of the w th sweep and c0 is set to 2.0.



Graph Channels utilized for transmissions in a 4-node full-mesh topology in IRIS: (a) PU absence. (b) PU presence

The secondary network is assumed characterized by best-effort traffic, therefore the parameters of the sigmoid function are chosen as A = 2, B = −1, C = 2 and d = 0. Likewise, the parameters of the potential functions are set to {λ1, λ2, λ3} = {4, 2, 2} for IRIS and {λ1, λ2, λ3} = {2, 3, 5} for ORBIT. In both cases, the spectrum nominally assigned to PUs and opportunistically accessed by SUs is in the area of 3550–3800 MHz. The channel bandwidth (both control and data) is equal to 10 MHz and the control channel has a central frequency of 3400 MHz. Furthermore, we assume that the interference radius is equal to the transmission radius, hence the neighborhood of each SU extends within a maximum distance of Rt + Ri = 2 · Rt . Finally, δ1 and δ2 are both equal to 500. The experimental scenarios executed are summarized in Table.

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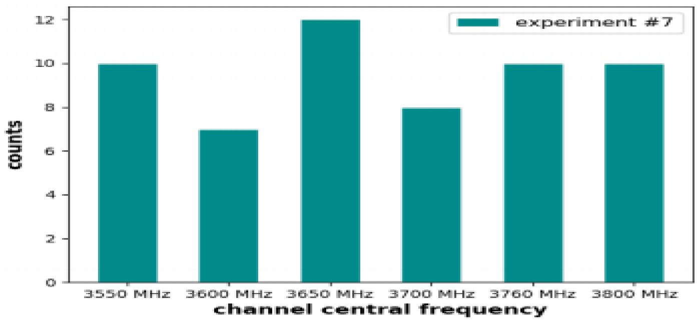
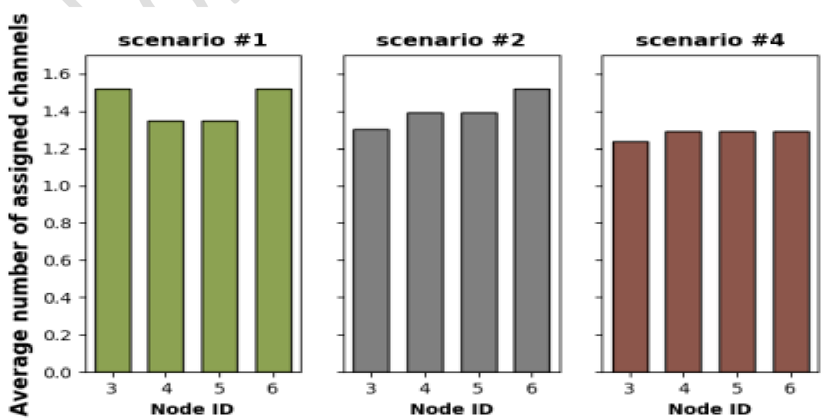


Graph Channels utilized for transmissions in a 8-node full-mesh topology in ORBIT.

Each experimental scenario is independent and has its own configuration file that defines the transmission rounds to be conducted and other operational parameters, like the total number of channels along with their respective central frequencies.

The framework assumes time-slotted operation, with every time-slot further split into smaller frames for the execution of different (cognitive) functions. Every transmission round can be viewed as a separate iteration of the resource management routine. The latter describes the complete operation of a SU during one time-slot. In all scenarios there are three kinds of data transmissions: 1-hop, 2-hop and 3-hop transmissions. The implementation of the proposed RCA mechanism presents enhanced reconfiguration capability as it adapts efficiently to different scenarios, accomplishing a key performance objective of the proposed approach. More specifically, the algorithm presents fast convergence, as it is indicated by the number of sweeps, taking into consideration the number of MNs and the number of channels used in the experimental scenarios, as depicted in Table.



Graph average number of assigned channels per secondary user

The latter was indicated by the simulation results provided and now it has been experimentally verified. Additionally, it has been shown that a relatively small number of collisions occurred,

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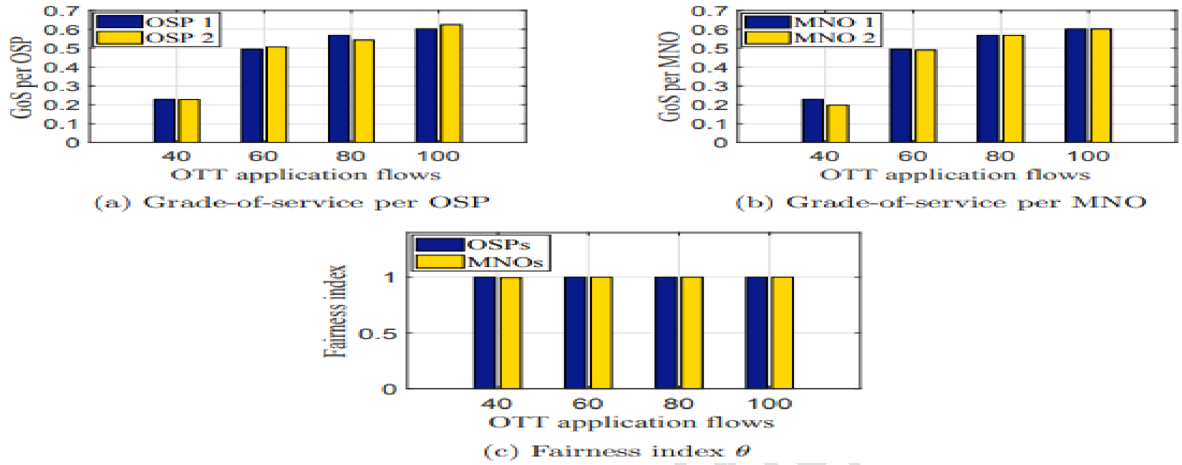
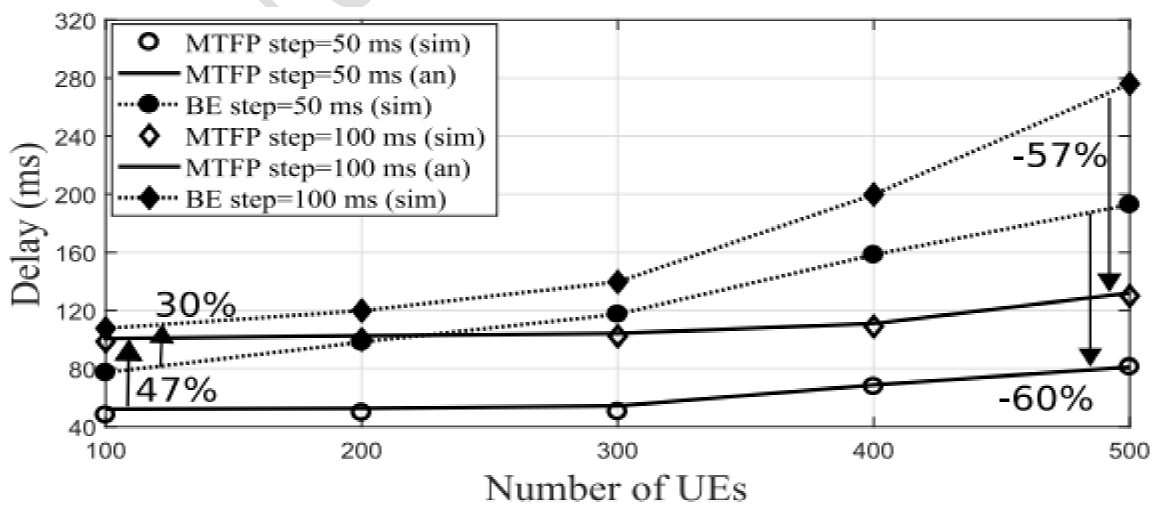
considering all experimental scenarios, confirming the efficiency of the proposed approach. As it was expected, in resource constrained scenarios (according to the number of channels used and the number of MNs) we noticed a small increase in the number of collisions, but again at an acceptable degree.



Graph Fairness in GoS vs. number of OTT application flows

Effect of different numbers of UEs

We study the effect of number of UEs that are connected to the considered shared LTE-A network on the delay experienced by the flows, using the MTFP and BE approaches. A number of U = {100, 200, . . 500} UEs and two different VS allocation steps, i.e., 50 and100 ms, are considered, simulating different CN congestion levels. As illustrated in Fig, the increase of the number of UEs leads to higher experienced delay, since more flows are generated and compete for resources.



Graph Delay vs. number of UEs

In contrast, the BE approach results in up to 137% and 112% higher delay for step values of 50 and 100 ms (U = 500), respectively, as it does not take into account the OSPs' performance goals and allocates randomly the RBs to the flows. Moreover, for both schemes, the delay is higher when the step value increases, reaching values up to 47% and 30% higher for MTFP and BE (U = 100), respectively. As the information exchange takes longer to be completed, each round lasts longer and the impact of lost rounds on the experienced delay is higher, increasing the average delay experienced by the flows.

CONCLUSION

The emerging wireless applications with stringent QoS requirements continue to demand more spectrum resources. Spectrum sharing is the key solution to deal with the problem of spectrum scarcity. We have proposed a network selection mechanism and formulated an optimization problem for network selection to minimize the interference to primary networks and cost paid by SUs. We then solved the optimization problem with the PSO and modified GA in order to find near-optimal solution. We have also designed two scenarios for performance evaluation with different system settings, SU data rate demands, and price preferences. Then the performance of proposed mechanism for network selection was evaluated under these scenarios. The simulation results showed that the modified GA outperforms the PSO and achieves a higher fitness value with less iterations in terms of both interference reduction and SU price requirement.

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