Demonstration of Shared Spectrum Access of Different User Groups

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Abstract. Spectrum availability is challenged everyday as the consumer consumption of mobile data increases. At the same time, the public safety and military authorities have the need to secure spectrum access for their mandated tasks that may vary temporally and spatially. Current spectrum administration and management schemes do not facilitate such short-term changes in time and space. In this paper, we show that minor adjustments to the Licensed Shared Access (LSA) scheme, and introduction of a spectrum manager function may provide administrations the tools to adjust spectrum assignments in time and space, so that they provide Mobile Network Operators sufficient security of spectrum access to justify investments, and that they allow authorities to access spectrum when their legally mandated tasks so require.

Keywords: Cognitive radio · Homeland defense · Hybrid warfare
Licensed Shared Access · Military · Public safety · Scenarios
Spectrum manager · Spectrum sharing

1 Introduction

This paper demonstrates shared spectrum access between different types of user groups, which include commercial Mobile Network Operator (MNO), Public Protection and Disaster Recovery (PPDR), and Military (MIL). In the demonstration, the priority order between these user groups changes in time. The changes are managed through a User Interface (UI) of a National Regulatory Authority (NRA). In the standardized Dynamic Spectrum Access (DSA) systems, including Television White Space (TVWS) [1], Licensed Shared Access (LSA) [2], and Citizens Broadband Radio Service (CBRS) [3], the priority order is fixed. We demonstrate a scenario, where a frequency band allocated for a MNO can normally be used for practice by PPDR and MIL on secondary

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basis, and during a rescue mission or hybrid war situation, PPDR or MIL can become the primary user locally and temporarily according to a pre-defined sharing agreement.

Conceptually, the spectrum sharing option space is depicted below in Fig. 1. Different options are placed along X-axis as a continuum that begins from *unlicensed*, unregulated, opportunistic common use to the other end, where the ultimate opposite is *licensed* exclusive use mode. In Y-axis, we have either *horizontal sharing* among similar actors and technologies as opposed to vertical sharing among different actors and different technologies. The third dimension is that of the *primary user* versus the *secondary user*.

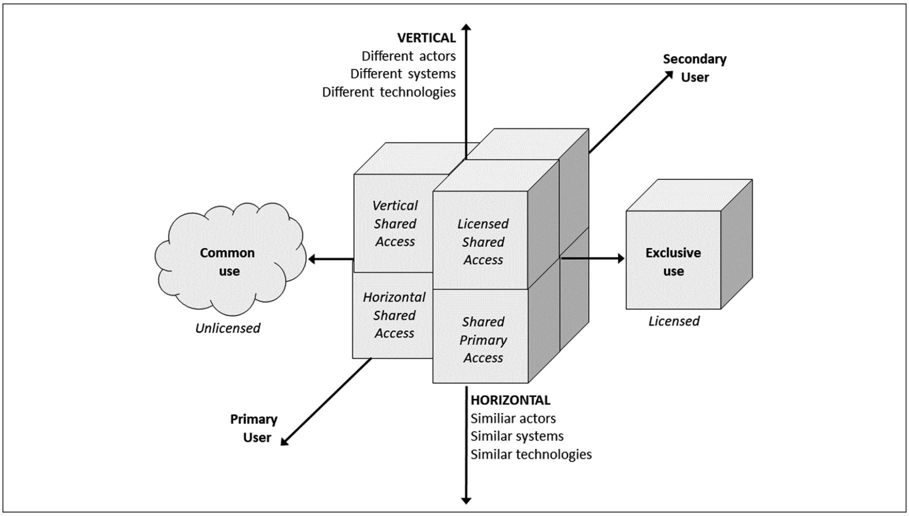

Fig. 1. Spectrum access option space adopted from [1].

Vertical shared access denotes technically regulated sharing between different types of actors or technologies that is exemplified by the unlicensed public use of the TVWS frequencies for broadband wireless data [4]. Horizontal shared access denotes technically regulated sharing between similar users or technologies, an example being wireless local area networking (802.11) within the ISM band. As the notion of primary or secondary user is somewhat ambiguous in this technically regulated sharing domain, the option space depicted to the left of the vertical axis in the Fig. 1 is more constrained. LSA in Fig. 1 denotes shared spectrum access concepts intended for different actors or technologies. Examples of such approaches are the LSA and the CBRS. Shared Primary Access, also known as co-primary sharing, refers to a case where two or more incumbents with equal access rights share their spectrum bands in a common pool. Currently, a generic homeland defence scenario does not provide military any operational incentive to relinquish exclusive access to spectrum. In fact, new spectrum may be needed to support activation of reserve forces or mobilisation. The quality and availability of commercial network and user equipment for LTE and 5G in the future and the possibility to use the same end user equipment both in commercial networks and military or public safety LTE networks may motivate military and public safety for spectrum sharing arrangements.

Tuukkanen et al. [5] observed that the armed forces' requirements for spectrum access vary greatly over time and location depending on the scenario. The same temporal-spatial variation of spectral needs applies also to public safety in scenarios like large-scale accidents or natural disasters. Therefore, one-off or location specific spectrum occupancy measurements cannot provide credible picture of such needs.

Contemporary standardized Shared Spectrum Access concepts, the LSA [6], LSA evolution [7, 8] and the CBRS [9], are based on the notion of providing secondary user an access to underutilized parts of spectrum. Besides, these concepts have already built-in mechanisms for the incumbent to inform the system on changes in the spectrum needs dynamically. Many nations already have legal provisions that would allow military to have a broader access to spectrum in war time. However, contemporary hybrid warfare homeland defence scenario seriously challenges this notion. Military access to spectrum, which normally is assigned to other use by the administrative application of legal norms, would not meet rapid reaction times needed. Furthermore, military would not be the sole user of spectrum in this scenario, as the scenario involves significant public safety operations amidst fighting units in populated urban combat areas. Future acquisitions and procurement may allow for shared secondary access in peace or normal time yet also allowing for temporally assigned local or regional priority access in disaster recovery or homeland and hybrid scenarios. Capabilities of local and regional prioritization should be pre-planned into the design of dynamic spectrum access systems.

In this paper, we demonstrate tools for dynamic spectrum access to support spectrum management and administration, which could also be expanded to cover the spectral domains of legacy systems. The paper suggests a system model and enabling technologies to support transition from, or an extension of, Licensed Shared Access to incorporate characteristics of Shared Primary Access. For the armed forces, partly also for public safety, already existing inventories of legacy systems have led to fixed, static, and exclusive use approaches to Spectrum Access regardless of location or temporal scope of actual need. We study the applicability and performance of different communication procedures between incumbents and licensees in changing priority sharing arrangement. We also demonstrate that different procedures can co-exist in a single dynamic spectrum sharing system. The key challenge in the work, which is demonstrated in this paper, is how an additional level of complexity, the changing priorities, can be introduced to previously piloted dynamic spectrum access frameworks like TVWS, LSA, or CBRS in a manageable and practical way.

The research questions in this paper are: *which spectrum management controls are applicable for each user group (MNO, PPDR, and MIL) in the selected sharing arrangement; what can be learnt from allowing different controls to be used in a single spectrum management system; how to implement the priority changes, which can be local, regional, national, and temporary; and which elements are important for NRA UI.*

The rest of this paper is organized as follows. The system model, demonstration setup, and method are discussed in Sect. 2. The results are presented in Sect. 3, and finally, conclusions are drawn in Sect. 4.

2 System Model, Demonstration System Setup, and Method

The research method used in this paper is a proof of concept demonstration. We implement a demonstration system of a sharing agreement between different user groups, depicted in Fig. 2. NRA has a user interface to control the priority order between the user groups locally, regionally, nationally, and temporally. MNO and PPDR are demonstrated with off-the-shelf Nokia 2.3 GHz eNodeBs and MIL with Program Making and Special Events (PMSE) wireless camera using DVB-T physical layer for transmission. The PMSE camera is manually operated, and it connects to the Spectrum Manager through a similar reservation system, which is used by the Radio Administration of the Netherlands [10]. The spectrum resource in the LTE TDD 3GPP band 42 (2300–2400 MHz) is managed by a Spectrum Manager. The demonstration uses two discrete 10 MHz channels, which are 2320–2330 MHz and 2330–2340 MHz. If all three user groups want to use the spectrum simultaneously, two highest priority ones get a 10 MHz channel, and the lowest priority one does not get a permission to transmit.

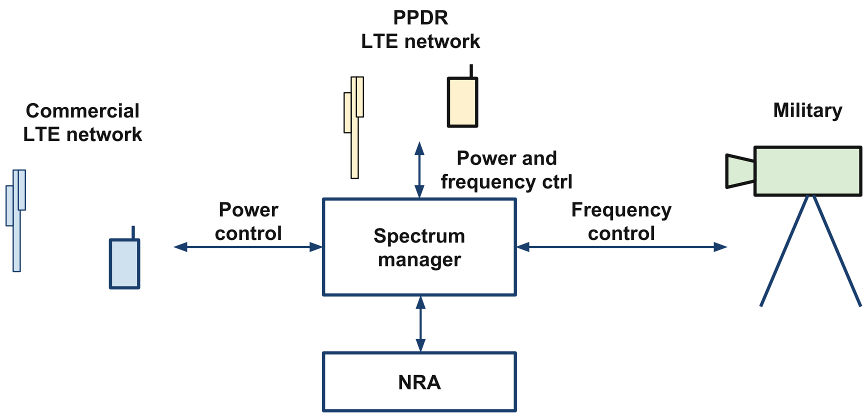

Fig. 2. The demonstration system.

Analyses of scenarios above led to the notional concept of changing the roles of user groups, and that such changes could have temporal and regional variation as depicted in Fig. 3. With three user groups and three priority levels there are 6 states, when all users groups have a different priority level. In case two or more user groups have the same priority level, there are further states in the system. For simplicity, Fig. 3 shows only three different priority orders and the changes between them. The tested concept incorporates changing the priority order. In LSA terminology, each spectrum user can be an incumbent or a licensee [2]. The status as an incumbent or a licensee depends on the temporal and local or regional priority order, which is determined by the alert level of the society. In the shared legacy military or public safety bands, military and public safety may relinquish the protection requirements to allow commercial operations in the specified parts of spectrum in peace time. On the shared bands, which are allocated to commercial operators, the protection requirements are relinquished in times of disaster recovery or homeland defense to allow military or public safety operations in the specified parts of spectrum. Through active, trusted operations of a dynamic spectrum management system, military or public safety authorities can be assigned access to spectrum in times and in locations as the scenario requires. Commercial operators can be assigned access to spectrum in peace time. The communication between the spectrum users is dynamic and automatized as far as possible. Commercial systems can implement dynamic changes in spectrum access in operationally relevant timeframes for military and public safety use (i.e., in minutes or at maximum in hours). Military and public safety systems are allowed more time to enforce changes in spectrum access, e.g., hours or days.

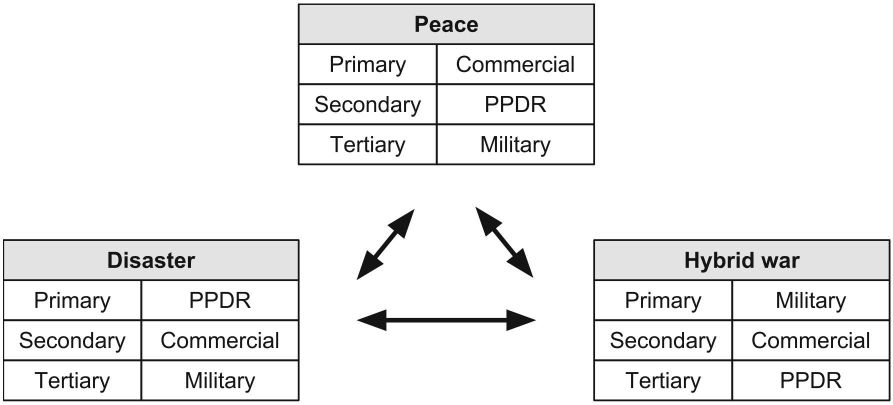

Fig. 3. Concept of changing access rights of different user communities in different scenarios.

The protocols for the communication between the Spectrum Manager and spectrum users are simplified from the ETSI LSA specification [6] using https protocol. In the case that the communication is initiated by the Spectrum Manager (Notification procedures), an intermediate connectivity layer is needed, just like in email app in the mobile phone. In this study, WebSocket was used. TCP/IP is carried over the physical and Medium Access Control (MAC) layers. Between TCP/IP and HTTPS there is a WebSocket in the Notification procedure communication. The LSA-1 protocol is encapsulated in JSON messages and carried over HTTPS.

A spectrum manager can generally control the permission to transmit, transmit power, transmitter center frequency, nominal bandwidth, and in the future, antenna patterns of the devices. The control capabilities may be limited by the sharing arrangement. For example, the original TVWS geolocation database in US was able to change the center frequency but not the power nor the bandwidth. The original LSA is able to control the power level, but not to change the center frequency or bandwidth. The commercial operating environment may also limit the management choices. Considering the demonstration system in this paper, we assume that the spectrum is shared between a MNO, PPDR, and military. The MNO has most likely been assigned the band through an auction or a beauty contest, and the MNO uses the full capacity of the band, when possible. It is not likely that the MNO would change the center frequency to a band of another MNO. The MNO network forms a large area coverage, and we assume here that the PPDR/MIL use is local or regional. Changing the bandwidth and center frequency even within the MNO assigned band, would probably cause unexpected errors at the border of LSA limited network area and unaffected parts of the MNO network. The MNO networks are wide area networks, where each basestation of a MNO has the same center frequency. If a single basestation or a small group of basestations of the MNO wide area network have a different center frequency, the mobile UEs would experience an untypical change in the traditional mobile network coverage. Due to this, at the moment we assume, that the MNO base station control is limited to permission to transmit and maximum allowed power level. PPDR and military are considered here as local networks, and they may have sharing agreements with all operators, whereby the control of PPDR/MIL networks may include also the center frequency and bandwidth changes.

We evaluated the spectrum management controls individually for each user group. Our system consisted of a mixed use of controls, and we evaluated the experiences gained during testing and demonstrations. Furthermore, applied spectrum prioritizations were verified by spectrum measurements using a spectrum analyzer. During the demonstrations, we operated the priorities through the implemented NRA UI. The possibility for local, regional, national, and temporary priority changes was incorporated to the NRA UI as well as to the Spectrum Manager. The key novelty of the system is that the changing priorities were tested with various state changes. These state changes included various arrival sequences and priority orders starting either from an unoccupied spectrum state or from a pre-occupied spectrum. During the demonstration, we monitored the radio signals with a spectrum analyzer, as illustrated in Fig. 4.

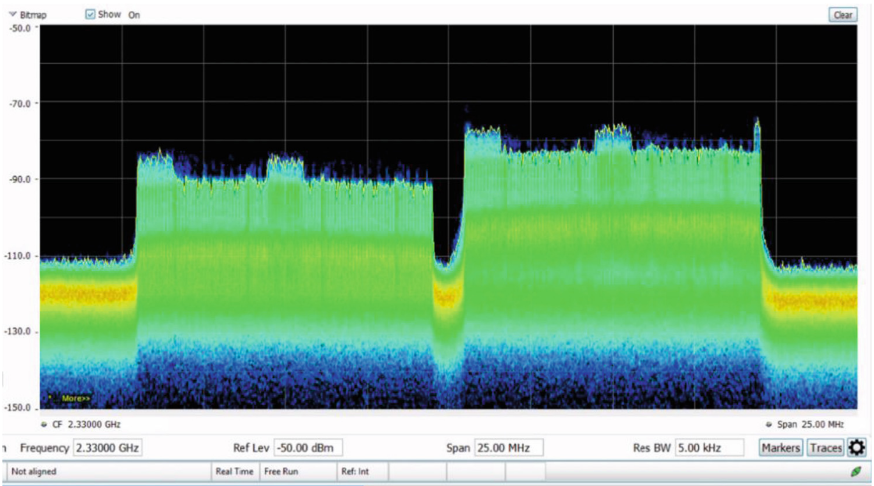

Fig. 4. Spectrum analyzer view of MNO (left signal) and PPDR (right signal) transmitting.

The priority order changes illustrated in Fig. 3 was tested in the demomstration. The conceptual schematic depicting the demonstration is presented in Fig. 5, and which is broken down to use cases, valid priority order, arrivals and spectrum occupancy. For simplicity, we present the highest priority order changes only from commercial MNO to MIL and from MIL to PPDR. In the first case the MNO arrives first, and they are allocated the lower one of the two available spectrum blocks. Next arrives PPDR, and they get the higher spectrum block. Last comes MIL, having the lowest priority. As there is no capacity available for MIL, the access to spectrum is denied. In the second case, MIL has the highest priority. The order of arrival is the same as in the previous case. MNO and PPDR get their spectrum blocks. When MIL with the highest priority arrives, MNO allocation is cleared, and MIL gets the lower spectrum block. The third case continues from the end state of the second case. MNO priority is increased to be higher than that of MIL. Consequently, MIL use is cleared, and the lower spectrum block is allocated to MNO.

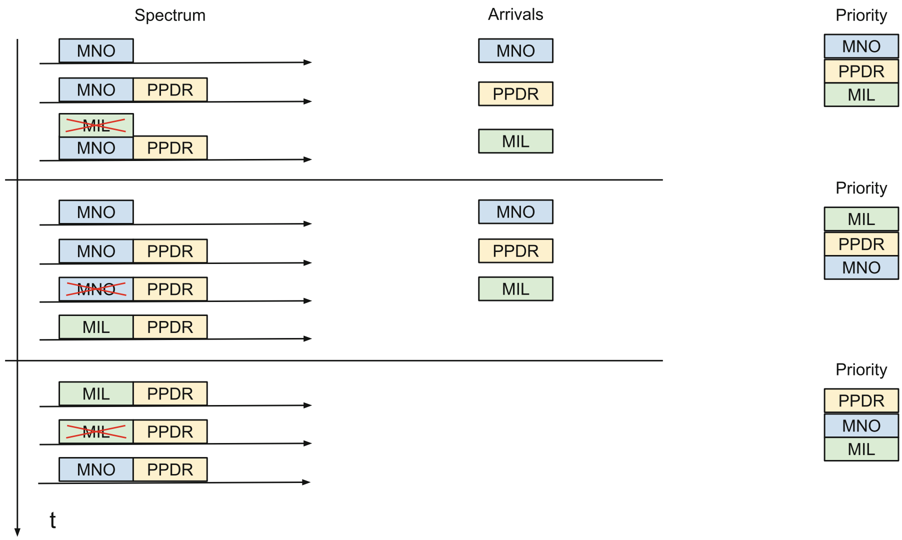

Fig. 5. Changes in the demonstration spectrum use.

3 Results

The main spectrum management controls are the transmit power, and its special case of permission to transmit, transmitter center frequency, and the nominal bandwidth of the transmitter in the demonstration. The MNO center frequency cannot be changed to another operator's frequency block and the change of center frequency within the operator's band would also cause deterioration of the mobility service. Narrowing the bandwidth could in theory be possible, but most likely it would cause unexpected behavior in the network and should be avoided. Thereby we assumed that wide area MNO networks are only controlled by transmission power by the Spectrum Manager.

The center frequency and bandwidth changes of MIL and PPDR are not as restricted as they are in the MNO networks. The mapping of the spectrum management controls and user groups are summarized in Table 1.

Table 1. Mapping spectrum management controls and user groups

Control	MNO	PPDR	MIL
Power level	Possible	Possible	Possible
Center frequency	Restricted	Possible	Possible
Bandwidth	Restricted	Possible	Possible

In the standard dynamic spectrum management, the controlled devices, such as White Space Devices (WSD), LSA Licensee, and Citizen's Broadband Radio Device (CBSD), are homogenous, and they have the same controls available. On the other hand, the systems employed by priority users are heterogenous, and the way how the protection requirements are derived from the priority users varies a lot. The main reason for this is that the incumbents are considered legacy systems. The secondary devices are new, and the same capabilities can be required from them. When the controlled secondary systems are legacy systems, a possibility for heterogenous controls are required. In this demonstration system, we have shown that a plurality of control mechanisms for secondary systems can co-exist and their capabilities can be defined in the rules and algorithms of the Spectrum Manager.

We demonstrated the feasibility to use priority profiles to implement a spectrum management system with changing priorities. The stakeholders of the sharing arrangement negotiate the possibility for priority changes, related spectrum ranges, and the authority to initiate the priority change in advance. By default, the mandate for priority changes is associated with the NRA, but it may also be given to the PPDR organizations. The PPDR has pre-defined rescue plans for a wide range of catastrophes. The plans may include area definitions and rescue times. Both areas and time periods can be included in the priority profiles or they can be left to be defined at the time of need. When a spectrum priority profile is taken into use, it defines the priority of different user groups, the frequency range, geographic area, and the period for the priority profile to be active. A country may have several priority profiles active simultaneously, and the profiles should also have a mutual priority order.

In this study, we develop a UI for NRA to create, manage, and operate the priority changes in a dynamic spectrum management system. The UI has a map interface to define the areas, as illustrated in Fig. 6. Separately defined region or municipality areas can also be used. The location definitions can be named and stored for later use. The spectrum priority order and the frequency range are stored and named. Finally, a period with begin and end time (or permanently) are bound together with the area, frequency range, and priority order definitions. The defined and active priority orders are presented as a list where the position in the list defines the priority order between the priority profiles.

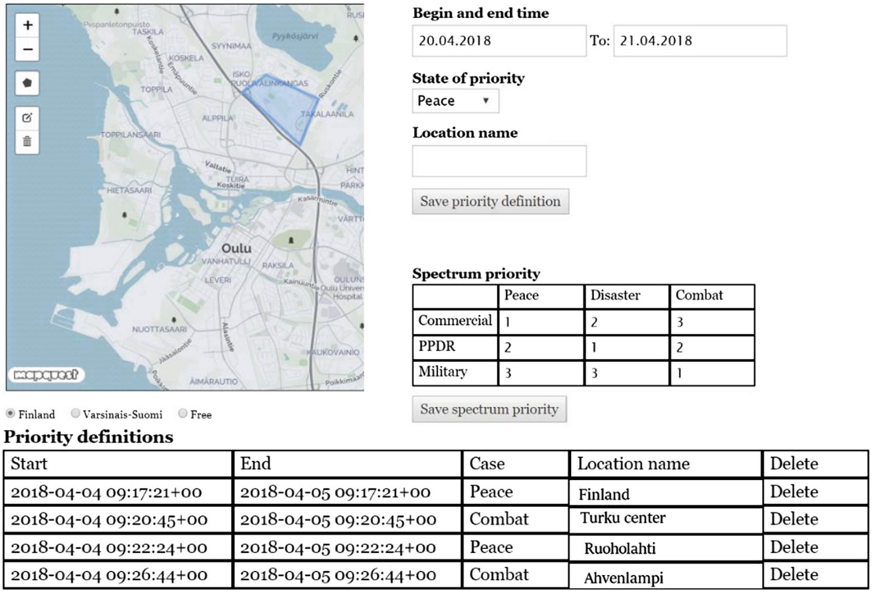

Fig. 6. User interface of the NRA to control changing priorities.

4 Conclusions

The standard dynamic spectrum management systems have fixed user groups as priority and secondary users and do not allow the priority order to be changed. Especially, PPDR and military users may have training and similar non-critical use, which could be carried out with secondary spectrum access. For obvious reasons, the critical use of PPDR and military should be prioritized when appropriate. In CBRS, this could be enabled by having the military and public safety as incumbent users and MNO as Priority Access License (PAL) user. The military and PPDR could enter the system also as General Authorized Access (GAA) users. Only at the time of critical missions, they would utilize their incumbent status. This arrangement would work for two different spectrum users in CBRS. When the system contains three or more different user groups, which should be able to change their relative priorities, a spectrum priority management system, introduced in this paper, would be required.

The introduced system and demonstration has various types of controlled systems and the capabilities to control them. In the standard systems, the incumbents are heterogenous, but the controlled devices are relatively unified. The demonstration shows that a dynamic spectrum management system can control simultaneously various types of devices and they may have differing capabilities and restrictions in spectrum use.

In this demonstration, we showed how the priority order can be defined locally, regionally, and temporally in addition to the nation-wide priority order. Furthermore, MNO and PPDR type of spectrum users can flexibly adapt to power level, center frequency, and bandwidth control. Only the power level of the eNodeBs of a nationwide MNO network should by default be controlled by the Spectrum Manager. If the commercial LTE network is a local private LTE network, there is freedom for center frequency and bandwidth changes within the private LTE frequency block. The pre-defined spectrum priority profiles support well the pre-planned disaster recovery of PPDR and military contingencies. Carrying out the negotiations between the sharing parties in advance, and allowing the electronic control of the spectrum management, improves the response times and communication capabilities at the time of critical missions. The NRA UI demonstrates how the priority profiles can be created and managed.

Interest towards dynamic spectrum access has increased. This demonstration shows that new capabilities could be introduced to the future spectrum management systems: changing priority order, geographically limited changes in priority order, and simultaneous control of heterogenous networks. As future work, we recommend to study how different procedures (request, notification, and reservation) impact the evacuation time, extending the mixture of different controls in this paper to include also the procedural dimension. We would also welcome studies about the impact of local center frequency change and local bandwidth change in a nation-wide MNO network.

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