A Realistic Roadmap for the Introduction of Dynamic Spectrum Management in Military Tactical Radio Communication

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Abstract— **Cognitive radio (CR) technology has to date not been adopted by the military even though more than a decade has passed since its inception. This paper describes how cognitive radio and associated dynamic spectrum management (DSM) procedures can be introduced in military tactical radio communication. CR and DSM address key challenges that face future military tactical radio communication and their successful introduction can reduce or even overcome current spectrum scarcity and deployment difficulty. A DSM roadmap is introduced where military users develop trust in, and experience with, these novel technologies in manageable steps. The first step in this DSM roadmap involves the introduction of a military band dedicated for CRs and subsequent steps gradually increase the spectrum that may be utilized for military cognitive operation. A high-level vision of how existing military spectrum management procedures will change in the future with the introduction of DSM is also presented resulting in a significant reduction in the workload of spectrum management personnel.**

Keywords-cognitive radio; dynamic spectrum management; military tactical communication; roadmap

I. INTRODUCTION

Military tactical networks are being required to support a greater number of services than ever before. In addition, the bandwidth requirements associated with many of the new services are also rapidly increasing. The combination of these two factors means that we are nearing a time when there will be insufficient bandwidth to support the services required for future military operations. Today's military operations are also typically undertaken by multiple nations cooperating in a coalition force. The spectrum and frequency planning activities associated with the deployment of a large multi-national coalition force are extremely complex and unacceptably long and can delay the start of an operation [1].

Both of the aforementioned problems, spectrum scarcity and deployment burden, are to a large degree consequences of the centralized and static nature of current spectrum management [1]. Dynamic Spectrum Management (DSM) is a process where cognitive radios (CR) seek out and use a part of the electromagnetic spectrum in ways that are not predictable, so that it is not generally known which set of frequencies that the radio will use at any given time. The DSM process may be seen as a harmonization of, and dynamic interaction between, both a human element in the form of spectrum regulators and spectrum planners or managers and an autonomous element in the form of one or more cognitive radio networks. DSM represents a fundamental change from existing spectrum management procedures in the way that spectrum is allocated and used for both civilian and military domains.

This paper aims to address two particular aspects of DSM, first:

- how a new and unproven technology such as DSM can be introduced in military tactical radio communication, and second
- how current spectrum management procedures would be affected by such a change.

To address these two aspects, this paper starts in in section 2 with an overview of current spectrum management procedures in the military tactical domain and their inadequacy for future military operations. Section 3 highlights the key challenges for a proposed roadmap describing the gradual and systematic extension of current spectrum management procedures that is presented in section 4. Section 5 relates the proposed roadmap to future spectrum management procedures to clarify possible DSM practices in a future setting where cognitive enabled radios will be the norm in military tactical radio communication. This paper ends in section 6 with major conclusions.

II. CURRENT NATO SPECTRUM MANAGEMENT PROCEDURES AT THE OPERATIONAL LEVEL

The worldwide use of the electromagnetic spectrum is regulated by the International Telecommunication Union (ITU). The ITU sets out the global radio regulations in the form of a global Frequency Allocation Table (FAT) from which each nation defines its own FAT covering many aspects of radio regulation, such as the generic type of radio service that is permitted within each frequency band and whether the band is allocated for military, civil or shared use. In what follows, existing non-cognitive military spectrum management procedures are summarized for coalition operations as defined in ACP 190(C) [2]. ACP 190(C) defines three main phases to each operation: Planning, Deployment (also known as Implementation) and Recovery. The description provided is structured according to these three phases involving the elements introduced in Figure 1.

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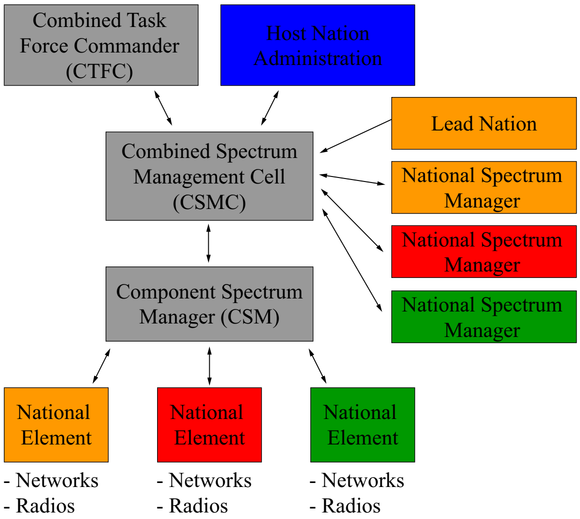

Figure 1. Elements of a coalition deployment and their relationships.

A. Planning Phase

The primary purpose of the planning phase is to produce the Battlespace Spectrum Management Plan (BSMP). The BSMP is used to inform the coalition force entities of issues relating to the management and planned usage of the spectrum during the operation by providing a mapping between all radio and network systems and frequencies.

In the planning phase, the Combined Task Force Commander (CTFC) assumes overall command for the forthcoming operation as part of a mandate from a higher authority specifying the conditions under which the coalition force will operate. The CTFC establishes a Combined Spectrum Management Cell (CSMC) responsible for coordinating the spectrum requirement of the force, acquiring the necessary spectrum and assigning frequencies for the systems used by the forces within the operational area. The CSMC will normally delegate the authority to manage frequency allotments to one or more Component Spectrum Managers (CSMs), where maritime, land, air, logistics and special forces are typical components. Each component may be composed of multiple National Elements (NEs).

When a coalition is formed, a single nation is given the responsibility to act as the Lead Nation. The Lead Nation is responsible for providing and sustaining frequencies for the force through the spectrum management process and providing technical support to the CSMC. Each nation within the coalition force is obliged to set up its own spectrum management cell with a National Spectrum Manager (NSM) to coordinate spectrum processes for its national forces. Each NSM will identify all radio equipment to be deployed by the NEs, including equipment parameters and operational (geographical) areas, and provide this information to the CSMC. The CSMC combines the spectrum requirements, operational areas and radio equipment characteristics provided by the individual NSMs into the Electronic Order of Battle (EOB). The EOB expresses the overall spectrum requirement for the operation.

Depending on the tools available to the CSMC, it should be possible to model the overall spectrum requirement for the operation that is detailed in the EOB (i.e. frequency planning). This modeling activity makes use of the topographical data associated with the operational area to identify where frequency re-use is possible. It also takes into account any equipment frequency constraints, frequency hopping systems, airborne emitters, preferred frequency allotments and any protected frequencies. The CSMC uses the output of the modeling activity and the EOB to acquire the necessary spectrum to satisfy the operation requirement. Depending on whether or not the operation is conducted with the support of the host nation, the CSMC either establishes contact with the host nation spectrum administrators and submits a frequency request detailing the spectrum requirements or uses electronic surveillance to select the most favorable spectrum without regard for existing local users.

When the available spectrum has either been allocated by the host nation or identified through observation, the CSMC (and CSMs) will produce the frequency assignment tables for all radio equipment associated with the coalition force and incorporate them into the BSMP. These tables include any constraints on the use the frequencies including transmit power, antenna height and location.

B. Deployment Phase

In the deployment phase, each NE implements the BSMP as received from the CSMC via their CSM prior to deployment. Interference may be encountered at any time due to host nation emitters, conflicting allied systems or enemy jamming. Each NE is responsible for investigating the interference that is encountered to try to determine the source and, if the source is local, endeavor to reduce the interference or eliminate it using appropriate action. If local action is impractical or unsuccessful, the interference and resultant loss of capability is reported to the CSM using a specified interference report format and procedure. Each CSM is responsible for the real-time control and management of the spectrum within its area of operation (i.e. the spectrum used by its NEs). The CSM responsibilities include the resolution of any frequency conflicts between its NEs and other interference issues by making appropriate frequency assignment changes or modifying allotments if other efforts to alleviate the interference are ineffective. The CSM will send any spectrum changes to the appropriate NEs where they are implemented.

Whilst the CSMC may delegate responsibility for real-time spectrum management to the CSMs, it retains overall control and will become involved where coordination between components is required. The CSMC's responsibilities include maintaining a close relationship with the host nation so that all interference reports associated with host nation emitters that are received from CSMs are sent to the host nation administration to be resolved. The CSMC will also act to resolve spectrum conflicts between components and other interference issues by making appropriate frequency assignment changes or modifying allotments if other efforts to alleviate the interference are ineffective.

C. Recovery Phase

The recovery phase is a period of transition where each individual NE is responsible for informing the CSM of the time and date when the element will stop using their frequency assignments and handing back frequencies to the CSM for reassignment to another unit. Each CSM is responsible for reviewing and consolidating the spectrum in use by the force component, identifying any NE changes that need to be incorporated into a new BSMP. The CSMC is responsible for reviewing and consolidating the spectrum in use by the force as a whole, incorporate any changes into a new BSMP to meet the requirements of the new force which is passed on to an incoming force or the (newly established) civil administration.

III. Key Challenges for the Introduction of DSM in Military Tactical Environments

The previous section shows that today's military spectrum management procedures are, in the main, centralized and static. For example, the frequency bands allocated for military use within the relevant FAT are typically not modified on a regular basis. The frequency planning procedures that are applied within these military bands are also performed to meet the particular operational requirements of an operation including factors such as size, scope and composition of the deployed force. To a large extent, frequency management activities are typically performed prior to the operation in the planning phase and are often time consuming and complex especially for large coalition operations. Hence, once the assignments are made, they are generally fixed for the duration of the operation. Cognitive radio and DSM technologies offer the potential to significantly enhance the operational effectiveness and management of military tactical radio communications.

However, these new technologies are relatively complex and represent a paradigm shift in capability and operational procedure for military spectrum managers and end-users. Several hurdles must be overcome if cognitive radio technology is to be adopted by the military as the technology is currently not in use even though more than a decade has passed since its inception. Firstly, as with any novel technology, there is general mistrust in its capability and military users tend to be conservative and risk averse towards new and unproven technology. Secondly, if the cognitive radio concept is adopted, it will be introduced into service in a gradual fashion where CRs must be able to safely coexist with existing legacy radio equipment and existing procedures for the foreseeable future. These issues call for a carefully managed and incremental introduction of CR technology over time.

Summarizing, the extension of current spectrum management procedures requires that:

- DSM is introduced in a step-wise fashion gradually increasing military users' experience with and understanding of CR technology and equipment, and where
- DSM procedures co-exist with legacy equipment and current spectrum management procedures taking on a gradually increasing role as more CR technology is coming into service.

Following these two principles, the introduction of CR and DSM in military tactical radio communication should be regarded as a evolution and not a revolution enabling a more flexible and efficient use of the spectrum in future military operations, and to ease the burden of the pre-mission frequency planning procedures.

IV. A Relastic Roadmap for the Introduction of Dynamic Spectrum Management

This section proposes a realistic DSM roadmap that identifies how cognitive radio technology may be introduced into the military communications domain in discrete steps although no specific timeframe is proposed. This DSM roadmap starts from the present day, with no cognitive radios, and with each increment takes a step further into the future with an increasing exposure to DSM in terms of number of devices, spectrum access complexity and freedom in operating spectrum. The DSM roadmap is designed such that military users may develop trust in and experience with the technology in an incremental fashion, and limit risk to existing operational capabilities.

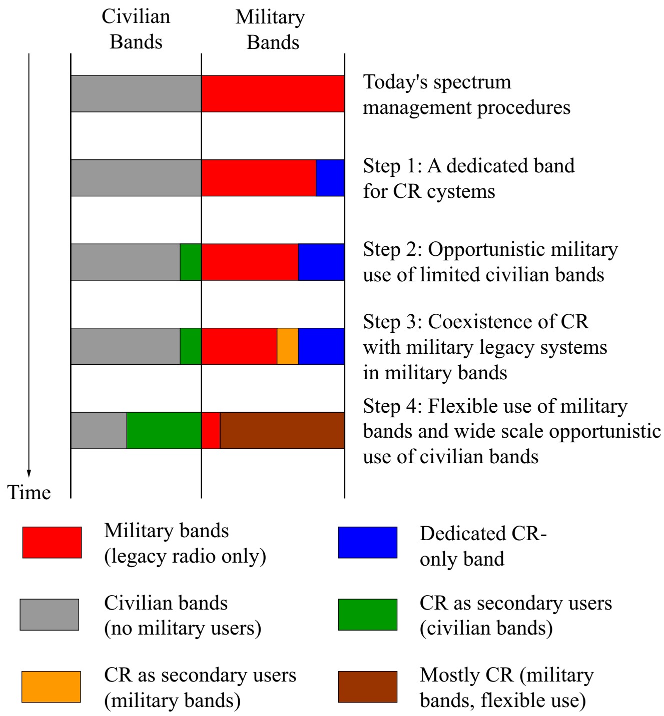

Figure 2. DSM Roadmap representation.

A. The First Step - A Dedicated Band for CR Systems

As mentioned previously, it is imperative that this first step involves minimal risk to existing legacy operations and allows military end-users the opportunity to build trust in and evaluate CR technology. We propose the introduction of a band exclusively dedicated to CRs within the military allocation. All cognitive devices would operate within this band and all existing legacy systems would operate outside this dedicated band that is governed by current spectrum management procedures. Initially, we would expect only a limited number of CRs within a coalition force and the bandwidth requirement for this CR-only band would be small in comparison to that required to support the legacy systems of the coalition.

1) General Considerations

We propose that the CR-only band would be managed under a managed commons DSA model[1] where all CR users would be considered equal and no traditional spectrum management procedures, such as channel assignment, would be required leading to a reduced pre-operation preparation time. Separate CRNs[2] would be able to coexist within the same band by autonomously and cooperatively or non-cooperatively selecting different operating channels within the band (i.e. channels with the least interference). In the managed commons model case, all CR users/networks share spectrum using an agreed management protocol that encapsulates technology agnostic spectrum access rules. This CR-only band may be utilized by military users at all levels of the military hierarchy. However, it may be best to initially target the technology at the lower priority echelons and for particular applications (see below). If CRs demonstrate success at this lower level, they are more likely to gain acceptance and be more widely adopted across all layers of the military hierarchy.

The choice of a dedicated band for CR systems as a first step in the road-map has some important advantages.

a) No risk for interference with legacy systems

Military end-users are generally conservative and risk averse. The use of a cognitive system in a shared-use spectrum access mode that could degrade a legacy communication system would not be acceptable. The use of a dedicated band for cognitive systems eliminates this risk.

b) Relaxation of system requirements

From a technical point of view, a dedicated band based on the managed commons model will relax system requirements for CR systems. The primary reason for this statement is that the cognitive band will lack primary users, placing less severe constraints on CR sensing and decision making functions to gather and process spectrum information to adapt its behavior. Cognitive systems would thus only need to address interference from other cognitive systems and jammers, which can be expected to be less time-critical compared to more challenging channel evacuation requirements.

c) Familiarity

The concept of a license free band such as the current 2.4 GHz ISM band, is not new for most military end-users and the introduction of a license free military band for CR is likely to be regarded not as a revolution, but as a case where military procedures catch up to the less restrictive procedures used in the civilian world.

d) Compatibility with current NATO spectrum management procedures

In NATO, the civil/military spectrum Capability Panel 3 (CAP3) is responsible for the harmonization of radio frequency use among NATO allies. CAP3 is placed under the new C3B sub-structure (Consultation, Command and Control Board). The military part of the CAP3 panel manages the harmonized military spectrum by allocating bands to applications or services, such as wide-band land systems or satellite broadcast services. As such, the proposed first step would be compatible with established administrative spectrum management procedures where CAP3 would allocate one or multiple bands exclusively for CR systems. However, NATO currently considers CR as a technology rather than as a service or application. CAP3 has therefore refrained from making the proposed allocation necessitating further negotiations and lobbying to overcome this hurdle.

e) Incentives for research and development

One of the main obstacles in the technological development of military CR is the deadlock created by the general lack of confidence in the technology. As long as there is no clear sign from the military end-user showing an interest in the technology and thus establishing a potential market, the military communications industry will be hesitant to invest in the development of military CR systems. On the other hand, as long as there are no military off-the-shelf CR products, which can prove the concept and clearly demonstrate key CR benefits, the military end-user will remain skeptical towards the technology. The creation of a dedicated band for CR systems can end this deadlock and be an incentive for the industry to start investing and developing products, comparable to what happened in the civil 2.4 GHz ISM band.

f) Extensibility

As mentioned previously, an important motivation for this first step is gaining trust. Once the concept of CR proves to work in this dedicated band, the band can be easily extended and integrate more complex spectrum access models with civilian and/or military primary users.

In summary, in light of the advantages described above, the introduction and use of a dedicated band for CR is by far the most appropriate first step in the road-map towards the introduction of cognitive radio in the military. If this first step proves to be successful, the following steps can be implemented to overcome spectrum scarcity and alleviate current deployment burdens.

2) Spectrum Suitability, Rules and Limitations

Spectrum is a scarce resource, both civilian and military, and the introduction of a CR-only band will require sacrifices. In our opinion, the most suitable option is to define multiple smaller bands within different spectrum regions and use them as dedicated CR-bands. It is obvious that the NATO-harmonized bands are the most appropriate. From a technical point of view, and taking into account the possible applications, we think that at least a band of 5 to 10 MHz should be defined in the NATO harmonized UHF band I (225 – 400 MHz). Other possible candidate frequency bands are the military UHF band II (790-960 MHz), the military UHF band III (1350-2690 MHz) and the SHF band (4400-5000 MHz), where cognitive systems for short range wireless networks could be envisaged.

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[1] A DSA model is here used as classification of a high-level Dynamic Spectrum Access (DSA) technique following the terms introduced in [1]-[3].

[2] A CRN is a network where a number of cognitive radios interoperate.

An in-depth study of the rules and limitations for the use of this dedicated band for CR systems is out of the scope of the paper. We will therefore only comment on three aspects of such rules and limitations:

- The types of applications that are allowed and are forbidden to use this band together should be defined. Some example of systems that could be allowed are wideband land systems, line-of-sight microwave links and tactical wireless local area networks whereas pulsed systems like surveillance radars and broadcast stations are likely to be excluded.
- The technical elements of a set of restrictions need to be studied and standardized in a future STANAG. Some possible restrictions are the use of a spectrum mask, a radiated power bound per application and the duty cycle of the systems.
- The need for a pre-defined channelization in the dedicated band should also be studied and if necessary the choice of the channel bandwidth.

B. The Second Step – Opportunistic Military Use of Limited Civilian Bands

A long-term driving factor is the increasing pressure felt by governments and regulatory authorities to reallocate spectrum traditionally reserved for military use to support civilian wireless services. In the event that spectrum allocated for military operations diminishes on this basis, allowing the military to operate in civilian bands as non-interfering secondary users offers a way to increase the total military spectrum pool[3].

In this second step, we propose to extend the military CR footprint by allowing military CR systems to operate as secondary users within limited civilian bands (taking advantage of white spaces in time and space). The terrestrial television and radio UHF/VHF bands are a likely first candidate due to the ideal propagation characteristics for tactical radio systems, the relatively stable channel availability and the maturity of the commercial IEEE 802.22 standard which may be leveraged for military implementations.

Within these television and radio bands, the military CR systems would operate on a non-interfering secondary user basis under a spectrum overlay model. Military CRNs may or may not cooperate with each other and/or with the primary civilian users regarding spectrum access. As noted in step 1, the necessary avoidance of primary user transmissions under the overlay model represents an additional complexity over and above operations under a managed commons model (as in step 1). From a military perspective, a significant advantage of this step in the DSM roadmap is that whilst the military users will have acquired more operating spectrum, no interference risk is introduced for existing military operations using legacy systems[4]. Military CRs would be operating within both the dedicated CR-only band (as peers) and within limited civilian bands (as secondary users). All legacy systems would be operating in remaining military allocations as today. This isolation in frequency maintains the CR and legacy system coexistence assurance provided in step 1. This step also allows military users to evaluate the more complex overlay spectrum access technique with no additional risk to military legacy operations.

C. The Third Step – Coexistence of CR with Military Legacy Systems in Military Bands

In this third step we propose to build on the experience developed in the second step where military CRs were allowed to operate as secondary users within limited civilian bands. We propose that military CR systems would also be allowed to coexist with legacy systems in limited military bands. The legacy systems would be designated as primary users. The CRs would operate on a non-interfering secondary user basis. This will allow military CR systems to take advantage of white spaces in time and space left fallow by military legacy systems.

The proposed third step differs from the previous two steps in the proposed DSM roadmap in that CRs would be allowed to coexist in the same spectrum as legacy systems and thus represents the first step where there is an increase in risk of interference by CRs to existing military operations. However, with the experience of the previous steps in the roadmap and only allowing a limited spectrum overlap (between military legacy and CR systems), this risk may be easily managed.

D. The Fourth Step - Flexible Use of Military Bands and Wide Scale Opportunistic Use of Civil Bands[5]

The previous steps have identified how CR and DSM technology may be evaluated and implemented in an incremental process. A fundamental component of these steps is the coexistence with existing civilian and military legacy systems as described in steps 2 and 3, respectively. For this final step we assume that most military legacy systems have been retired from service and that cognitive radios are the norm (i.e. a far future setting)[6]. We also assume that military acquisition agencies and end-users have accepted, and are comfortable with, the new technology. These assumptions enable the exciting possibility for a significantly more flexible and effective use of spectrum within the military domain.

In this final step we propose that military spectrum will be managed under a highly flexible and dynamically variable combination of the uncontrolled commons, managed

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[3] Here it is assumed that the military agree to be subservient to civil users (i.e. act as secondary users). This may be the case in training or humanitarian relief operations. In more aggressive operations (such as Defense of National Territory), military forces are unlikely to operate under this premise. They will more likely secure spectrum on an exclusive-use basis either through negotiation with the host nation or by force.

[4] There may be an interference risk to civilian primary users. Of course, the level of acceptability of risk depends on of importance of civilian services being supported in the specific band and the context of the military operation. The risk may be deemed acceptable for TV and broadcast radio bands but not so for civilian air traffic control bands.

[5] The first three steps may not be accompanied by the proposed fourth step as it is entirely possible that the third step is sufficient to overcome challenges with spectrum scarcity and deployment difficulty.

[6] Some portions of the spectrum may always need to be reserved for fixed frequency operations (e.g. GPS and some safety critical applications) and for any remaining legacy radios. However, this may still be managed under the new DSM paradigm with the exclusive-use DSA model type.

commons, dynamic exclusive-use and overlay DSA model types controlled using DSM policies. We also propose the continual and extensive use of civil spectrum bands on a secondary use basis. A CRN will be provided DSM policies which identify where in spectrum it will be allowed to operate and the associated operating conditions, which it must adhere to. Such allocations may include multiple bands each managed under a different DSA model type. The DSM strategy implemented by the CRN management system will autonomously determine the most favorable operating location within the allowed spectrum given the local time-variable environmental conditions.

CRNs operating within bands designated under either of the commons types or the overlay model type (as secondary users) will not require complex traditional frequency planning and should realize more efficient and effective use of the spectrum. However, systems operating under these conditions will not benefit from the preferential (and often sole) spectrum access rights enjoyed under existing military processes, which may have a detrimental impact on existing levels of quality of service (QoS) that need to be managed by planning efforts as well as more dynamic cognitive monitoring and control loops to better reflect the needs of an ongoing operation. These future spectrum management procedures are clarified in the following section.

V. Future Dynamic Spectrum Management Procedures in the Military Tactical Domain

The introduction of CR technology and DSM will involve the modification of existing military spectrum management practices. It is anticipated that these changes will simplify and shorten the spectrum planning activity required prior to an operation. This section addresses these procedural changes using the same three phases of operation as in the current procedure with an emphasis on the planning phase.[7]

A. The DSM Planning Phase

In a CRN future, CRs and CRNs will not, in general, need to be assigned specific operating frequencies. CRs will instead be allowed to dynamically and autonomously select the best available operating spectrum within specific bands according to certain rules. This means that future DSM planning processes will change from current spectrum management procedures as described in the following starting with an overview followed by a detailed example.

1) Overview of DSM Planning Considerations

CRs will not, in general, be assigned specific operating frequencies which is fundamental difference from current spectrum planning that result in the compilation of the BSMP that includes the (static) frequency assignments for all radio and network equipment. CRs will instead be allowed to dynamically and autonomously select the best available operating frequency channel within specific bands according to certain rules formalized by the DSM policies.[8] This means that the contents of the BSMP will fundamentally change in the future and include DSM polices rather than today's mapping between all radio and network systems to frequencies. The EOB can also be expected to undergo changes making DSM policy generation, refinement and distribution the key activities to be undertaken during planning phase of future operations.

A future DSM hierarchy would in the planning phase define and refine the DSM policies for the underlying CRNs in preparation for deployment. Each decision making entity in the hierarchy is expected to use a computer-based DSM policy generation and management tool for this purpose. The host nation administration will define the highest level DSM policies. These mainly specify the frequency allocations and conditions of their use, which may be used by the CR systems of the coalition force in the forthcoming operation. These DSM policies may be updated and refined by each lower layer in the SM hierarchy prior to being downloaded into the policy repositories in the individual CRN management. DSM policy refinements made by the individual NESMs and CSMs are reported back up the SM hierarchy to the CSMC. These feedback paths ensure that the CSMC is completely aware of how the spectrum will be utilized during the mission. The CSMC would here not be permitted to change the DSA model type of a band unless the band has been allocated to it by the host nation on an exclusive-use basis. This is true for all decision making entities in the SM hierarchy, which must respect the DSA model decisions made by the hierarchical level immediately above it.

The CSMC will update the DSM policies provided to it by the host nation to reflect the decisions made. Where host nation allocations are split into sub-bands, the DSM policy associated with each sub-band inherits the access conditions of the parent allocation, together with any additional or replacement conditions specified by the CSMC. The relevant DSM policies are then distributed to the CSMs. Note that the particular decisions made by the CSMC depend on the requirements of the individual national elements supplied to it by the NSMs.

2) A DSM Planning Example

As an example to illustrate the DSM planning phase, we consider a military operation involving two battle groups, BG A and BG B, from two different nations. The host nation administration provides the military force with two frequency bands, one in the VHF band from 47–50 MHz and one in the UHF I band from 318–328 MHz, both on an exclusive use basis. The administration also allows the military force to make use of the civilian terrestrial television band (470–830 MHz) on a secondary use basis. Figure 3 illustrates the allocations defined by the spectrum management hierarchy (line 1).

The CSMC decides how the host nation allocation should be used by the military force on a high level (line 2 in Figure 3). Whilst the focus here is for the BG A operation, the CSMC must also consider the spectrum needs for BG B, that is operating in another region of the same area of responsibility.

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[7] In the proposed roadmap, CR systems and legacy radio systems may coexist. It is proposed that legacy radio systems will continue to be managed using the principles described in section 2 whereas future CR systems managed as described in this section. The overall management procedure will therefore be a blend between static and dynamic processes.

[8] DSM policies are here used as a mechanism to guide, control and bound the autonomous behavior of CRs.

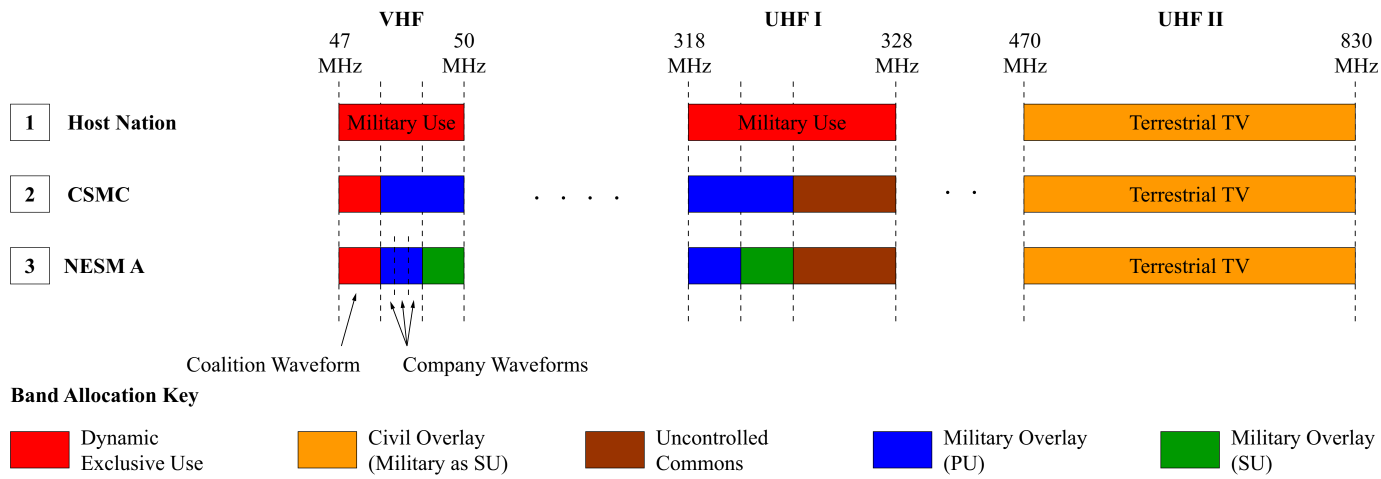

Figure 3. Spectrum plan as output from DSM planning processes at different levels in the spectrum management hierarchy. Primary and secondary users are designated as PU and SU, respectively.

The CSMC assigns primary status to NESM A for BG A communications for the 48–49 MHz and 318–320.5 MHz bands. These preferential assignments are intended for the higher priority waveforms associated with BG A. The CSMC also assigns primary status to NESM B for BG B communications for the 49–50 MHz and 320.5–323 MHz bands. We assume that a coalition waveform is used for communication between elements in the two battle groups does not support DSM and is assigned exclusive-use access for the 47–48 MHz band. The CSMC assigns the 323–328 MHz VHF band as uncontrolled commons spectrum to be shared by all BG A and BG B cognitive systems (intended for squad or platoon level waveforms). The terrestrial television band is assigned to be used equally by all systems in the military force on a secondary basis.

Line 3 in Figure 3 illustrates the planning decisions made by NESM A as the next level below the CSMC in the SM hierarchy (the decisions made by NESM B are not shown as they are of no further interest in this example). NESM A decides that it has three different company waveforms that are high priority and are thus given primary status in separate bands as shown. Underlying squad and platoon level waveforms are not provided dedicated allocations – they are required to find their own operating spectrum.

B. *The DSM Deployment Phase*

At the beginning of the deployment phase, all CRs should have downloaded the appropriate DSM policies and be able to initiate communication activities within their possible allocations, under the specific conditions defined in the planning process. During deployment all CRNs will regularly send performance and spectrum status reports back up to the relevant NESM provided resources are allocated for this purpose. The NESMs will send aggregate status reports to the relevant CSM, status reports that are further aggregated to the CSMC. These status reports allow spectrum managers at all levels of the SM hierarchy to continuously evaluate spectrum usage and network performance within their allocations throughout an operation. Spectrum managers at all levels will have the ability to update and disseminate DSM policies at any time to ensure the coalition force communication needs are continuously met.

Each CRN will be responsible for dynamically and autonomously selecting the best available operating frequency within its specific allocations defined by the active DSM policies and be transparent to the end-user. With this capability, many interference issues may be handled directly by the CRNs themselves through the execution of the selected DSM strategy and spectrum mobility, with no involvement of any spectrum management personnel. Each NESM, in conjunction with a network manager, will be responsible for monitoring the status reports provided by their CRN management systems. During deployment, an NESM may make act to optimize the performance of the underlying CRNs by updating the active DSM policies associated with any allocations provided to it on an exclusive-use basis by the relevant CSM.

C. *The DSM Recovery Phase*

During the recovery phase, spectrum managers at all levels of the SM hierarchy will be responsible for reporting to their immediate superior manager that their units no longer require their spectrum allocations. The associated DSM polices may be modified to better reflect the needs of the remainder of the coalition force.

The CSMC will be responsible for consolidating the master DSM policy database such that it may be used by an incoming / replacement force.

VI. CONCLUSIONS

Military DSM is and requires a fundamental shift in capability and spectrum management procedures. This paper has attempted to clarify the need for an incremental approach for implementing DSM into the military domain. We have outlined a DSM roadmap for this purpose. Through this roadmap we have described how novel CR technology with non-cognitive legacy radio systems can co-exist over the transitionary period towards an all CR future. This roadmap has also addressed how military users may develop trust in, and experience with, this novel technology in manageable steps. The first step in this DSM roadmap involves the introduction of a military band dedicated for CRs. It has been proposed that this band is managed under the managed commons models using multiple smaller bands within different NATO-harmonized spectrum regions.

We have also presented a high-level vision of how existing military spectrum management procedures will change in the future with the introduction of DSM using ACP 190(C) as a baseline reference. With the application of secondary use and uncontrolled use of spectrum, we foresee a significant reduction in the workload of spectrum management personnel. We have focused on both the important planning and deployment phases of military operations. The decisions made by the spectrum management entities, both before and during an operation, will principally revolve around dynamically creating, updating, activating, deactivating and deleting DSM policies.

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