Spectrum Situational Awareness Capability: The Military Need and Potential Implementation Issues

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ABSTRACT

RF based Military systems operate in a crowded, complex and often hostile electromagnetic environment. To succeed in such an environment requires dynamic management of spectrum, including frequency assignment. Such dynamic management needs to be informed by an effective Spectrum Situational Awareness (SSA) capability. This paper describes why the military need a SSA capability, outlining how it might be implemented, details some of the important technical factors that will need to be addressed and why.

The potential benefits of a SSA are many beyond its use by battlespace spectrum managers in planning and support to communications and sensing capability in a congested environment. Others are its use in planning Information and Electronic Warfare operations, and its use for intelligence gathering in its most general sense. We argue that the demands for near real-time and extensive SSA is imperative in the modern congested battlespace, particularly in the urban environment, and will become increasingly so in the future as congestion increases and as operations become more dynamic.

Some concepts for the implementation of an SSA capability are discussed showing how it may be synthesised from existing and planned capability elements, in some cases with limited modification. A number of important technology strands that need to be developed are identified and briefly described. These include the need to develop spectrum imagery techniques possibly in three dimensions, the need for a common format for data exchange, and the needs for visualisation of the data collected. The paper then examines the conclusions and recommendations that arise, including the need for co-operation between potential coalition nations for an SSA capability to be effective.

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1.0 INTRODUCTION

The RF end of the Electromagnetic Spectrum has been used by the military since the early part of the 20th century. In the early days of RF communication Morse Code was used occupying bandwidths of a few Hertz in what are now the Long and Medium Wave bands. By the Second World War, voice communication, teletype and Radar had been introduced, and the useful spectrum extended into VHF and UHF spectrum. This trend in increasing bandwidth need and an increase in the highest frequencies used has continued to the present day.

In parallel with the introduction and changes in the military use of Spectrum, civil use has been changing in a similar fashion. Civil use was initially amateur, but TV and Radio broadcasting, PMR for the emergency services, a variety of Satellite services and scientific use were dominant until the 1980's. Personal communications systems have been a growth area in the last two decades as have digital broadcasting, and the internet leading to a significantly increased demand for spectrum.

Military services are now under pressure from competing civil use and spectrum congestion whilst military demand is increasing. No longer is it possible to introduce new military equipment and services that use spectrum without introducing significantly better spectrum management.

The premise of this paper is that achieving better spectrum management will entail introducing significantly better knowledge of spectrum use than has been available up to now. This paper will examine some of the issues associated with achieving this Spectrum situational awareness, the purposes for which such a capability could be used, the associated benefits and the technology that is needed to enable this capability.

In the context of this conference, spectrum is a significant constraint on many aspects of network deployment into the battlespace. The move to more dynamic network management will require more dynamic spectrum management. Not only will this be essential if the allied battlespace networks are to mutually coexist with acceptable levels of interference; but also essential if the networks are to function with civil, NGO, and even adversary spectrum use. If this was not enough to illustrate the importance of dynamic spectrum management, the increasing potential for the deployment of non kinetic weapons and offensive EW capability will also bring spectrum management requirements to avoid electronic fratricide.

2.0 IMPROVED SPECTRUM MANAGEMENT

The current mechanisms employed for spectrum management are largely mandrolic using a combination of tools and procedures. The tools include databases and spreadsheets for data inspection and entry; email for communications across the spectrum governance community, and systems with significant need for spectrum have frequency assignment elements in their management systems. The procedures are largely paper based and have changed little in the last few decades.

The frequency assignments generated are in the main static. This is particularly so for national assignments but also in the main true in the battlespace.

National assignments include a mixture of permanent allocations and temporary assignments. These temporary assignments are used for test and development purposes and training exercises. Temporary allocations are generally for periods of weeks or months.

In the battlespace the spectrum assignment processes were developed to enable large set piece operations where orbats were pre-planned and there was sufficient spectrum for the capabilities deployed. It should not be assumed that there were never problems in spectrum allocation or in frequency assignment, rather that operational needs were met and that shortcomings in the planning processes were tolerable. Toleration of interference is a subject where the reliance on, and availability of, Spectrum based services is now significantly greater than in the past. The parameters of this reliance on spectrum services are also different with these changes driven by the net centric paradigm. In these situations the need for change in spectrum allocation, and in local frequency assignment was minimal and when required the rate of change was measured in days.

Modern operations are in the main of a very different nature. They are likely to include peacekeeping, peace enforcement and are likely to be fast moving. Operations also tend to be performed by ad-hoc coalitions of the willing (with different levels of technological sophistication, and less than full trust between allies-of-the-day) rather than the persistent stable alliances of the past. The move to a net centric paradigm where reliance is placed on abilities to dynamically reorganise for maximum effect, where orbat agility and integrated information management are essential, lead to a need to re-plan local frequency assignments at a faster rate than the deployment changes. At the battlespace level spectrum allocations may also need to change although this will generally be less frequent and more likely to result from the changing phases of the operation.

In the last few years and over the next decade the spectrum needs of equipment will increase by at least a factor of ten to reflect the increased demand for information exchange bandwidth. It is likely that this rate of increase will continue into the next decade. Lessons identified from recent operations shows that the spectrum is currently congested. Analysis of current capability versus programmes in procurement demonstrated that spectrum needs in the battlespace will increase. This illustrates the need to introduce dynamic spectrum management and other changes that will enable more effective and efficient use of spectrum in the future.

Examination of how spectrum is used currently shows that the static nature of planning leads to three main efficiency issues. Firstly frequencies are assigned against occasional or potential use. Secondly Bearers and links in a network are not always utilised to their full capacity. Thirdly transmission attributes relating to AJ/LPI/LPD factors may be selected in the absence of threat. One could suggest an analogy: that spectrum management and frequency assignment still operates under a paradigm equivalent to “circuit-switched”, whereas the aspiration is to move to a dynamic sharing paradigm more like a “packet-switched” network.

Spectrum or frequencies assigned in a static management environment may be required for occasional or even potential use. Examples may be global assignments throughout the battlespace to air assets such that mission flexibility can be obtained. Frequencies can also be assigned for use sporadically over a period of time. The analogy suggested above continues – "if I don’t have a static semi-permanent assignment, how can I be assured that I will be able to communicate when I urgently need to do so?"

In a static network management environment, the links from which the network is constructed need to be sized. This is generally done against worst case capacity needs and these links are thus generally under utilised.

The requirements for network robustness or network covertness in general result in the adoption of inefficient spectrum use. These techniques such as frequency hopping, various applications of spread spectrum, robust modulation schemes and redundancy reduce the efficiency of transmission. It should be noted that in the presence of a spectrum based threat this inefficiency does not equate to ineffective use of spectrum, but in the absence of threats it may well be seen as ineffective as well as inefficient. This highlights the need to develop a more sophisticated measure of “efficiency” that balances redundancy (whilst achieving first-time successful reception) against minimised occupied time-bandwidth product (but needing multiple re-transmissions).

Each of the above examples of inefficient and/or ineffective use of spectrum will need to be addressed if increasing spectrum congestion is to be mitigated. The root cause of these inefficiencies is the static nature of spectrum management. The main factors that will allow change from static spectrum management are the ability to manage spectrum use more dynamically and the information on which to base this dynamic management.

3.0 TECHNIQUES TO IMPROVE SPECTRUM MANAGEMENT

Given that there is agreement that the EM spectrum is congested, that there are efficiency and effectiveness gains to be made, and that the technologies exist or can be developed to achieve these gains then what is the suite of things we need to do? As in most capability areas the things that need to be done will not be a single change, rather they will be a set of evolutionary steps in a number of areas. This section outlines a view of what needs to be done and attempts to construct a roadmap in capability terms.

Perhaps the most important element of improved spectrum management is the deployment of an effective spectrum management system for use by the Battlespace spectrum managers. Such a capability must have the ability to interact with consumers of spectrum. It should be able to keep track of spectrum use, present this data to an operator and aid the process of adjusting spectrum use to best fit the spectrum available. The system must use communication services available in the battlespace communication systems to

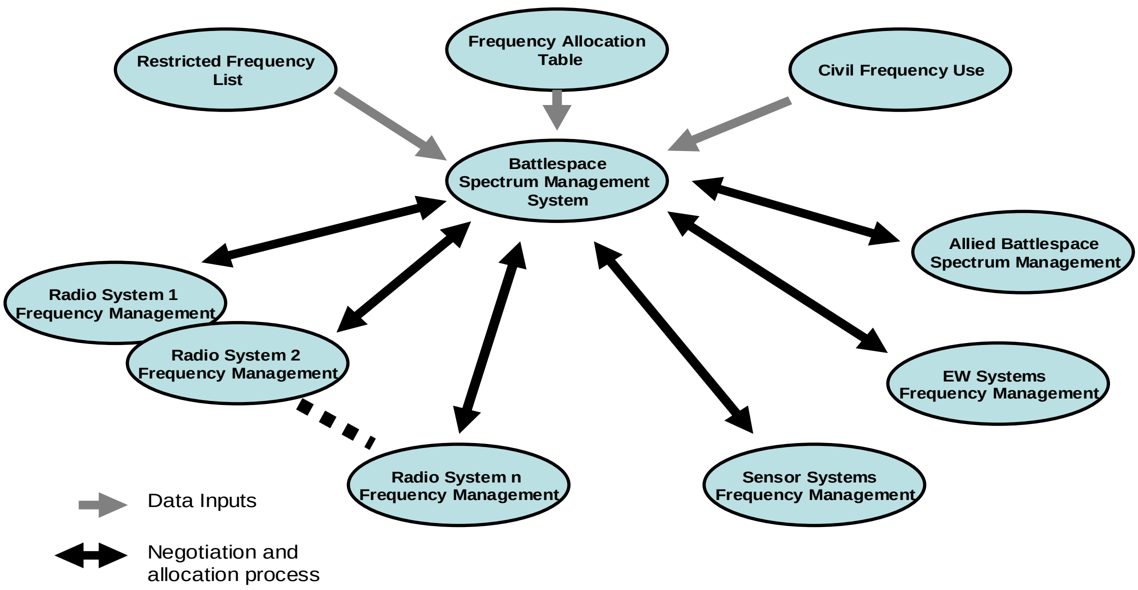

Figure 1: Battlespace Spectrum Management Needs

perform these functions. This will enable spectrum to be allocated to major users and the assignment of frequencies to minor users. Another important ability of this system will be interoperability with other coalition nations' battlespace spectrum management systems. Figure 1 below illustrates this.

Historically, we focussed on a capability for warfighting within a permanent alliance, NATO, which had a permanent frequency management staff, ARFA, and a standardisation process, through STANAGs, to promote interoperability. Today's ad-hoc coalitions have neither the persistent administrative structures nor even the aspiration to technological homogeneity or full mutual trust/releaseability. We need to explore Balance of Investment, etc, issues on whether we concentrate of making our national processes better, or on improving intra-coalition co-ordination, or on strategies for defence against and inevitably coexistence with ever-expanding civil-use spectrum demands - and on whether these different emphases lead to conflicting or convergent goals and directions. In reality we will need to move forward in all these areas but the balance is not obvious.

Important aspects of the battlespace spectrum management system as we look into the future are:

- the ability to react and re-plan with ever decreasing time constants to meet the needs of Net Centricity and operational needs (increased dynamism, agile mission groups);
- the increased tempo of the modern battlespace;
- the general need to support operations other than war;
- the ability to negotiate spectrum requirements with consumers and decide how much spectrum can be allocated to each based on commanders priorities;
- inform the commander of the constraints that exist at any instant or period for which he needs to plan an operation;
- provide the constraints for network planning.

Airborne networking is likely to become much more important in the short to medium term future as NCW/NEC evolves (WNW, TTNT, airborne HCDR, etc as well as legacy Link-16/JTIDS/TADIL-J). EBO will require air assets to be much more tightly integrated with land and naval forces. Two technology challenges pertaining to dynamic spectrum management / SSA are:

- the greatly-enhanced communications and interference ranges for elevated platforms, thwarting frequency re-use over a wide area;
- the very rapid dynamics of the RF footprint as fast jets traverse the battlespace (if SSA/SM cannot keep up, then must it reserve frequency space for air-air and for air-ground communication along the flight-path for the whole mission duration?)

A further consideration is that a possible move to “ATO-less” reactive air operations would remove one useful planning information source.

Dynamic Battlespace Spectrum Management Systems will be dependent on the information that is available to enable them to function in the highly dynamic environments of the future. At present this information whilst sometimes available is not delivered to the right place and doctrine tends to mean that capabilities that could supply information are not designed to do so. In some cases security requirements may not allow direct connection also providing a significant constraint.

Looking further into the future RF equipment may be able to sense its environment and decide how best to use the available spectrum, cognitive radio. Whilst cognitive radio, when it is deployed, will enable some military capabilities to manage their own frequency and spectrum use (within constraints), it is unlikely that this will ever apply to all spectrum use Their are continuing concerns with cognitive radio that will need to be addressed prior to widespread deployment. These include vulnerability to various deliberate bespoke attacks; that the introduction of distributed semi-intelligent, partially-informed automated decision-making into the battlespace may have undesirable emergent properties. (An analogy is TCP, a distributed algorithm which reacts to its local perception of the transmission path, but misinterprets errors and/or large delay-bandwidth product as indications of congestion and reacts inappropriately.) Cognitive radio as currently envisaged, although not as originally conceived, seem to deal with only one aspect of spectrum management, that of the frequencies that can be used. Other issues such as protection of receivers, choice of waveforms, and network considerations associated with congested spectrum are not currently being addressed with any vigour, but could have military benefit. Like ‘autonomy’, ‘cognitive’ does not have clear-cut boundaries – when does something become merely ‘adaptive’? Should 'cognisance' be confined to the radio [layer0/1] – or shared with the router, etc to make cognitive networks? Anther factor that needs to be considered is that that transmitters only OCCUPY spectrum, it is receivers that CONSUME spectrum and transmitters are detectable, receivers not so.

It is suggested that another element of Spectrum Capability is required for effective spectrum management. This we have termed Spectrum Situational Awareness (SSA). This capability will collect, collate and process the spectrum usage data we believe is required for more dynamic spectrum management and various other purposes in the Battlespace. It is required to support the transition to Cognitive capability at the very least. It is also suggested that it may be required to deal with the impact of cognitive RF technology particularly as we believe that it is unlikely and probably undesirable, that all RF equipment will be cognitive in the at any point in the future.

The timeline and key changes in battle space spectrum management are shown diagrammatically in Figure 2 below.

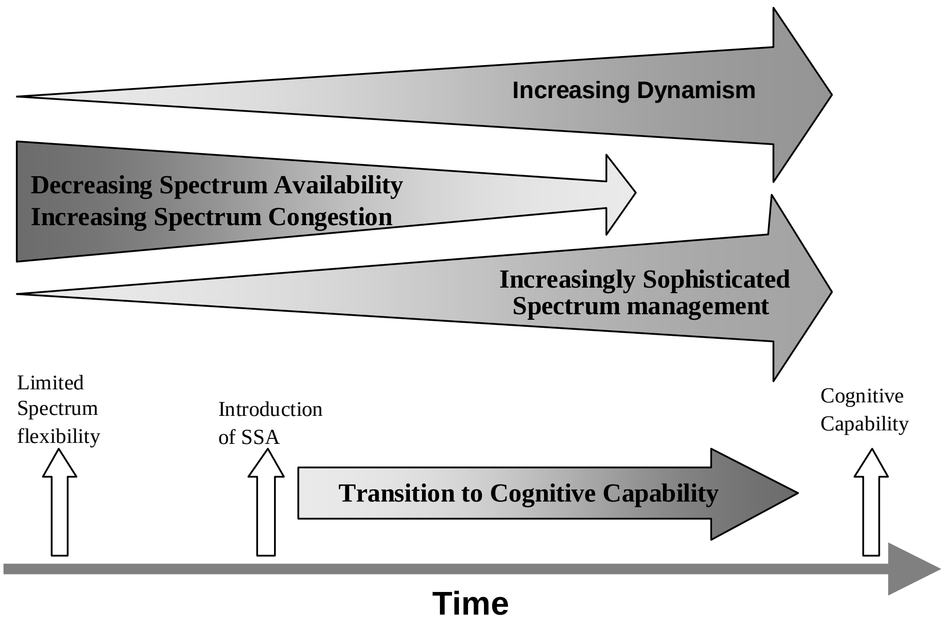

Figure 2: Transition to a Dynamic Environment

4.0 STATEMENT OF NEED FOR SPECTRUM SITUATIONAL AWARENESS

The concept of Spectrum Situational Awareness arises from the information needs for Battlespace spectrum management and also from the need for a tool to aid operational planning. The latter is a contributory factor in keeping this capability separated from the BSMS. The other reason for this separation is the security considerations.

A Spectrum Situational Awareness capability is a means of collecting disparate information about spectrum use and processing this information to produce a fused spectrum picture. Much information is available in the battlespace about spectrum use and users but much of this information is not used for spectrum management. A vast amount more is available from other sources and this is, in general, not used either.

The need for SSA is predicated on the need to achieve more effective, more efficient and more dynamic spectrum management and frequency assignment. The data required for this purpose will be the RF characteristics of equipment in use; these data associated with the platforms in use and the deployed orbat, and the locations of each of these orbat elements, platforms and other users. In addition to blue spectrum use effective SSA will also need to obtain information on civil and adversary spectrum usage. Again this will require RF characteristics, location and purpose data. As we move into the future, effective spectrum use will entail collecting and using this data within a framework where the accuracy requirements associated with the data will become tougher. The refresh requirements for the data will also become shorter. It is also essential that this is accomplished in a manner that does not generate an IER that will significantly worsen the spectrum congestion.

5.0 SPECTRUM INFORMATION SOURCES

The information required to build a spectrum situational awareness picture is a fusion of data from many sources. Spectrum usage data is available in the battlespace from a number of military capabilities but also available from civil information resources.

Spectrum management systems in the battlespace can supply data associated with allocated spectrum for coalition forces. This data will enable the spectrum associated with each orbat element and platform to be recorded. In current systems this will also be associated with some limited location information depending on the user. In the case of a Tactical HQ this location information may be well known and static. In other cases the location may only be known in very general terms.

Operational pictures, such as the Joint Operational Picture, Common Air Picture, Blue Force Tracking etc, will be able to supply more accurate and nearer real time location data. This data can then be fused with the spectrum management data to produce a much more accurate picture of spectrum usage. This fused data should allow the more effective use of spectrum in that the specific coverage for Transmitters and Receivers can be more accurately estimated allowing better spectrum re-use. Improved spectrum use can also be realised in a temporal sense.

Battlespace capabilities in the electronic surveillance domain are designed to monitor and record RF emissions and in the tactical domain have geolocation capabilities. This ability to provide spectrum usage maps of the battlespace can be exploited to contribute to the SSA capability. In general it can provide confirmation of the coalition spectrum usage but more importantly can provide data on civilian and adversary use. The limitation of this element of SSA is that ES capabilities will only be available for use for SSA on an opportunity basis, due to their deployment on their primary mission. Current thinking suggests that they will be able to make a significant contribution to SSA but are unlikely to be specifically tasked for spectrum management purposes.

Specific Spectrum monitoring and policing systems are likely to be required in some areas of the battlespace. The use of such systems at present is limited to specific deconfliction and interference resolution purposes in support of spectrum management. In future one would expect such systems to be deployed in direct support of spectrum management in the battlespace. Such systems would be deployed to areas with particular spectrum congestion problems or areas where spectrum management is difficult for technical reasons. An example of the former might be the areas surrounding Tactical or coalition Headquarters in the battlespace or in the rear area where ES resources are not generally targeted. An example of the latter may be deployment in urban areas. Spectrum monitoring systems deployed on UAVs have also been suggested for deployment with significantly enhanced coverage.

The last potential source of relevant data identified in this paper is general intelligence. The disposition of radio transmitters for civil purposes is generally available from unclassified sources such as the internet. Other sources of data are also likely to be available from a variety of published and media sources. Generally a lot of background spectrum usage information could be available. In addition to this data on spectrum use for neighbouring countries may be needed and this may well be made available if they are allies.

6.0 CONCEPT OF EMPLOYMENT OF SSA SYSTEMS

The concept of SSA is that it provides a picture of spectrum use that will be useful in spectrum management processes and that this usefulness will increase as spectrum congestion increases. The role of an SSA capability in spectrum management is to identify RF emitters and receivers in the battlespace; identify changes and movements in RF equipment, and aid in the optimisation of spectrum use. With sufficient information this will enable more efficient and effective reuse of spectrum to be achieved. As the tempo of change in the battlespace increases with the introduction of NEC/NCW, SSA will be an essential enabling tool.

In addition to aiding the management of spectrum it is expected that SSA will also be able to support operational planning. Traditionally operations have been planned with little cognisance paid to spectrum use. In future with increasing spectrum congestion operational planning may demand choice of ORBAT elements that able to be used effectively in the spectrum available. These spectrum considerations could be significant constraints on operational planning particularly where conservative assumptions must be made in the absence of information. More effective use can be made of operational assets where SSA can provide the detailed data needed to plan their spectrum use.

SSA will also be required in future for the planning of information and electronic warfare operations. These operations are reliant on spectrum for their success. Some forms of media operations use spectrum, as do some forms of EW operations. As spectrum becomes more congested the need to plan such operations with an element of spectrum management will become essential. To achieve this, the disposition of Red, Blue and Civil (white) spectrum elements will need to be known to avoid spectrum fratricide and to avoid disruption of essential civil services. This is of maximum importance in operations other than war such as Peace Keeping and Peace Enforcement where the battle for “hearts and minds” and the preservation of NGO services are of immense significance. Electronic surveillance systems could be cross-cued from SSA. This would enable more effective use of expensive and limited ES assets.

Dynamic network planning in the battlespace also includes dynamic spectrum management if it is to be successful. Planning a network that will operate successfully and with maximum effectiveness will involve making effective and efficient use of spectrum and doing so with a degree of dynamism that can only be achieved with SSA. The ability to plan and re-plan spectrum use dynamically to reflect changing network demand and topology will be an essential element of both network and spectrum capability and enabling this is a prime use of SSA. SSA also needs to capture a ‘behaviour’ characteristic of each specific emitter in the picture describing its likely response to any spectrum-management actions that we might perform. For example, a blue cognitive radio may try to avoid you, a white TV transmitter will stay exactly where it is (both in frequency and location), whereas a red follower-jammer will do exactly that. Reduced spectrum availability will also need to be reflected into information management processes, thus allowing appropriate routing, compression and QoS attributes to be selected. Without SSA, at least in the transition phase indicated in figure 2, this will prove very difficult and the re-planning time constant will be extended.

Whether, ultimately, we combine this SSA capability into Battlespace management capability is not entirely clear at this point. Whilst this would be possible from a technical view point, it is unclear whether this would allow the wider uses to be put in place and whether security architecture constraints would limit the potential connectivity to the various data sources. For this reason this paper suggests that the two elements are kept separate. This is however a question that needs answering. The answer may be different depending on the context – national (i.e. UK SSA – UK BSMS integration), coalition, alliance, framework nation or not, etc. This question also needs to be precisely defined. The CAPBILITIES need to be linked or coupled together even if the EQUIPMENTS/SYSTEMS are not intimately connected.

7.0 ENABLING TECHNOLOGIES FOR SSA

In general terms the technology for SSA capability is either available, is being developed or being researched. It is however, not being developed with this particular use in mind. The biggest gap is in the integration and demonstration of SSA capability as a synthesis of the relevant technologies. This integration needs to be done in such a way that the dynamic requirements of the changing battlespace can be met.

The key technology elements are:

- Common spectrum data exchange processes
- Wideband digital receivers and associated processing elements
- Rapid Geolocation Algorithms
- Co-channel signal separation Algorithms
- Spectrum allocation negotiation engines
- Multi-format data fusion engines
- Data mining (Internet and intranet)
- Effective visualisation
- Protocols to allow spectrum capabilities to interface with network management systems
- Dynamic QoS management
- Policy based network management
- Multi Level Security

It is not the purpose of this paper to expand this list of technology elements as each is a subject in its own right. Suffice to say that SSA capability will probably need to draw on each of these areas. SSA is about the synthesis of a new and necessary capability from existing research and development work. This should not be taken as meaning that this will not take effort, rather that some or most of the parts will not need to be developed from scratch. This said, a few essential elements are discussed.

Wideband digital receivers are being developed in the Electronic surveillance domain. The RF front end, the externals processing and the radio type determination elements of ES receivers are of particular importance to spectrum monitoring capability. This said it may well be that the bandwidths and processing capacity of these elements will need to be enhanced as the systems need to deal with the complete range of signals over a wide frequency range.

Spectrum Data exchange between national systems, alliance systems and coalition partner systems is probably the most important element of SSA that would need to be standardised and is a key enabler. This will be needed for spectrum management capability whether or not SSA systems are to be developed. In the spectrum management future envisaged in this paper this data exchange will also need to be compatible with EW and ES systems. An XML schema for this data exchange has been developed and will shortly be released by NATO as SMADEF-XML. This will form the basis of any data exchange schema for SSA albeit with some modification or extension

8.0 CONCLUSIONS

In conclusion the following represent some of the important issues that need to be considered further as we move to the modern dynamic, NEC enabled and evolving battlespace.

The future dynamic network to support Network Centric operations and the move to effects based planning and operations will require dynamic management at the physical layer. A substantial part of the management at the physical layer is the management of spectrum. Management of spectrum will need tools, processes and procedures that can respond to changes in communications needs with increasing frequency. This will demand significant changes in the way Spectrum is managed.

One can conclude that the spectrum management processes today are analogous to network management in a circuit-switched era whereas we should be aiming to move to a regime analogous to that of a packet switched network. This will entail the allocation of spectrum to meet short term needs, the reallocation of spectrum to reflect changes in priorities, and effective use of spectrum consuming assets.

Spectrum is currently congested and new capabilities will almost certainly make this situation worse. This congestion in itself will demand more dynamic management of spectrum to improve the efficiency with which it is used, making more effective use of this scarce resource.

This paper identifies Spectrum Situational Awareness as an essential capability if we are to achieve a goal of dynamic spectrum management. As with all operational needs an essential element of management is the need for good operational intelligence, no less so in the spectrum domain. Effective management of any scarce resource demands a good “picture” of how that resource is being use at any instant, without which it is difficult to effect change. Rapid changes in operational priorities, an essential part of net centricity and an effects based approach to warfare, will certainly result in the need for equally rapid changes in spectrum use.

Implementing a spectrum situational awareness capability will require the synthesis of the spectrum picture from relevant information. A substantial part of that information already exists or is gathered in the battlespace for a variety of purposes. Other parts of the information set required are not currently available. This results in a need to modify some existing capabilities and the development of new equipment for deployment.

Spectrum management is an international issue, there is only one spectrum and it is used by all groups in the battlespace. Effective spectrum management and as part of this, Spectrum Situational Awareness will require the sharing of spectrum usage data if it is to be both efficient and effective.

This paper has, in the main, concentrated on the concepts that will define effective spectrum management and advocates the need for Spectrum Situational Awareness. There are however some key technological issues that need to be highlighted. The introduction of cognitive radio will go some way to helping achieve dynamic spectrum management, but will bring with it a set of new issues that need to be addressed. Cognitive radio will also need to co-exist with traditional radio for the foreseeable future so will need awareness of these systems to prevent total chaos. (Note: Transmitters only occupy spectrum, Receivers consume spectrum but are not detectable.)

The other key enabler for Spectrum management is the exchange of data between RF systems and spectrum management tools. If effective spectrum management is to be maintained then all coalition partners must be able to exchange their usage information. Achieving this demands a common data exchange schema that all parties adopt. The use of the SMADEF –XML standard to achieve this is probably the most sensible course. It has been suggested that adoption of common tools would also meet this need, but this is not considered an optimal solution. This results from different nations having different needs, e.g. operating as a framework nation will need significantly more capable spectrum management tools than a nation contributing a small force element to a coalition. The need is to enable spectrum management co-operation rather than having a tightly integrated set of tools.

In summary we need to enhance spectrum management and frequency assignment capability within nations and within coalitions to reflect increasing spectrum demand, to reflect the move to a more dynamic battlespace and to enable the introduction of net-centric communications capability. This will include the introduction of better, networked, spectrum management tools, which will by necessity include spectrum situational awareness capability.

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