

Integrating the Policy Dialectic into Dynamic Spectrum Management

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Abstract— In this paper we propose a holistic approach to modeling the management of dynamic spectrum access (DSA). We argue that the range of issues involved requires not just a management scheme, but also a meta-management scheme whereby management processes are monitored, analyzed and improved. In this way different proposals for management can be refined through interaction in a dialectic that reacts to the problems and conflicts of a given management scheme as well as the changes in the technological, social, economic and political environment. We examine Stafford Beer's Viable Systems Model as a possible basis for a framework that encompasses a variety of feedback loops involved in addressing operations, management and meta-management together. We also propose how this model could be mapped onto a concrete policy meta-management system and sketch out issues worthy of further investigation in developing a holistic DSA management framework.

I. INTRODUCTION

Much of the discussion on possible future schemes for more dynamic management of access to the electromagnetic spectrum has focused on the relative merits of market-driven and commons approaches. Both of these approaches differ from the current command and control approach, but their advocates rely largely on analogy to existing, non-spectrum deployments, e.g. land property rights for market driven approaches and internet-based collaborative open source software production for commons. Both these classes of analogues remain unproven and both suffer from clear weaknesses. While the potential benefits of moving away from the command and control system seem largely undisputed, these weaknesses indicate that spectrum regulators and users must enter a period of experimentation to identify the best approach to the management of spectrum. In this paper we argue that the mechanism for conducting experimentation and the evolution that comes from it should be the subject of discussion and agreement. By actively managing the evolution

of dynamic spectrum management, the negative impact of mistakes or of instabilities can be controlled. In other words we propose that schemes for *meta-management* of dynamic spectrum access (DSA) should become an issue in the ongoing debate on schemes for DSA regulation and administration.

Formation of policy always involves a dialectic between stakeholders, and this is an essential part of developing workable but effective policies. Typically, the administrative body responsible for setting policy will make proposals (green papers, white papers), to which stakeholders respond with arguments for changes up to a specific deadline when the policy is enshrined in legislation or government regulations. With complex areas, authorities have allowed partial roll-out of new policy schemes in local trials in order to empirically assess their effectiveness. In some areas, e.g. education, partial deregulation is promoted on the basis that it allows freedom to experiment within nationally applied targets with the aim that best practice can emerge through local innovation. This best practice can be later harvested and offered nationally, perhaps influencing subsequent policy and regulation. Thus the policy-forming dialectic moves from lobbying and argument to quasi-competitive practice. Dynamic spectrum management, enabled by software defined radio, will increase efficiency of spectrum usage. It will also spur technical and business innovation in the use of the spectrum for new applications, as has already been observed by activity in today's industrial, medical and scientific bands.

Structuring policy to enable such dynamism requires a mechanism for quickly and efficiently encoding policies into rules that are enforced by the technical infrastructure. Languages from the policy-based management field of IT administration offer some potential here, and proposals for language specific to dynamic spectrum are emerging, e.g. the U.S DARPA Next Generation Communication (XG) initiative [1]. However, if experimentation and innovation are to be a major element of dynamic spectrum management, such technical encoding of policies will alone be insufficient. They must be integrated into an administrative system that allows for the controlled delegation of authority to form policy and operational regulation to localized regions or specific operators on the basis that conflicts that arise are quickly escalated to the delegating authority, ultimately the national regulator. This should be coupled with an obligation to offer up other data on the effectiveness of innovative policy schemes so that convergence of best practice can be quickly achieved and disseminated. However, this dialectic must be

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continuous, rather than a one off consultation, as new technological innovations or changes to social application usage can quickly disrupt any given policy regime, and so policy and related regulation must be constantly reactive to such change. This paper will discuss how such a dynamic management dialectic can be modeled and analyzed as part of on-going regulatory and secondary spectrum management activities.

II. AGILE DSA MANAGEMENT

To understand how we may make the spectrum regulation process more agile, we first need to discuss in more detail the specific aspects of dynamic spectrum access that have an impact on the rate of change that may be experienced and the problems that change will face.

The two main technological drivers are the promise of software defined radio (SDR) and of cognitive radio (CR). SDR has the potential to break the traditional linkage between the characteristics of an RF transceiver and the spectrum regulation under which it is intended to operate. This may lead to much more general purpose RF transceivers that are able to reconfigure themselves to operate in different bands, under different regulatory regimes and using different encodings. The production of more general-purpose RF transceivers in high volumes has the potential to dramatically reduce the long lead time and high level of investment needed to roll-out a new RF service. Thus regulators will no longer be under the same pressure from RF technology vendors and service operators to maintain the status quo in the allocation of spectrum bands to specific applications so that they can recover the investment made in developing and deploying the new services. CR, with its ability to monitor spectrum usage and intelligently plan wireless communication, allows unused areas of the spectrum to be used opportunistically, but without impacting the needs of occasional priority users, e.g. emergency services, from using those bands when needed. This therefore reduces the impact of claims by these classes of users for exclusive access to certain bands. These technologies thus free the regulator from some of the current economic and social obligations that have previously favored exclusive and static allocation of bands.

The following issues will serve to complicate moves to a more dynamic approach to the management of spectrum access. They therefore need to be considered in the development of a comprehensive model and analytical framework that not only can manage the new dynamism in spectrum allocation, but can also support progressive improvement and adaptation of that management process.

A. Regulatory Experimentation

Many factors will converge to present an extremely challenging and unpredictable landscape for regulators aiming to support dynamic spectrum access. On the one hand there is an inherent degree of uncertainty in delegating the necessary rule making authority required to make secondary markets and common administration viable. On the other hand there is the disruption brought about by new technologies, not only in RF

communications but also in the services that can be offered using digital wireless communication. Internet Protocol by enabling convergence of mobile telephony, TV and broadband WWW access is already producing dramatic changes in what have previously been relatively stable markets. In addition, there seem to be many challenges remaining in establishing a transferable right to access portions of spectrum, many of which are dependent ultimately on economic or legal factors. The advent of open spectrum trading and the increasing drop in the technological cost of entry for new spectrum users may bring additional potential challenges for regulators as players enter the market that have different motivations to the long-term players that form the majority of today's licensed wireless service operators. In particular, there has been much commentary about the equivalent of 'patent trolls' presenting a danger to the effectiveness of spectrum trading based on property-like rights due to the inherent uncertainties in administrating boundaries between adjacent allocations in space and frequency [2].

Therefore, to prevent these large challenges and associated uncertainties from paralyzing progress toward dynamic spectrum access and thereby towards better spectrum utilization, regulators will need to experiment more frequently. Experiments may, for instance involve local trials in spectrum commons administration or the trialing of secondary market arrangements, but with limited geographic or spectrum coverage. What needs to be acknowledged by regulators and players in these experiments is that they are, in part, a knowledge elicitation exercise, and therefore failure of the regulatory apparatus involved may be possible, and perhaps even likely. Such experimentation will need to become more common than currently and will have to involve the delegation of controlled authority to experiment to secondary market providers or regional commons administrators. However, what is required currently is a common framework for conducting such regulatory experiments in a way that the risks can be controlled and the knowledge effectively captured and shared. Agreement on a taxonomy and semantic for key performance indicators, not just at the technical level but also at the economic and social level is needed, so that experimentation can be assessed internationally and the results shared.

B. Co-Existence

Much of the most heated debate to date on possible future regulatory structures has been about the relative merits of market based and commons approaches to dynamic spectrum access. However, both the current command and control mechanism and an observation of society in general would indicate that both approaches have benefits. Market-based approaches are efficient at mobilizing capital for investment in innovation and deployment of new application that use the spectrum. Commons approaches may flourish where the capital and operational costs are not high and can be easily shared. By reducing usage costs they encourage widespread use of the spectrum, potentially realizing higher value more quickly though human network effects (the so-called Metcalf's law). It is therefore likely that market-based and commons

approaches will have to co-exist. The proximity of such co-existence is unclear however. Keeping separate spectrum allocations for the two approaches maintains the inefficiencies of the command and control status quo, and would be highly susceptible to changing political views. However, integrating the allocation of spectrum to commons users in the kind of fine grained spectrum trading mechanism as discussed in [3][4] would require a reliable means for mapping the value gained from commons usage to the more readily assessed financial cost/benefit quantification used when providing spectrum access on a commercial basis. Equally, where commons and market-based users border each other, asymmetries in the administrative and legal resources they possess will make commons users more vulnerable to predatory or trolling behavior by commercial outfits aiming to exploit the difficulties of enforcing spectrum usage rights at boundaries. Any comprehensive approach to managing dynamic spectrum access must therefore accommodate the co-existence of market-based and commons approaches and address the negative impact of asymmetries between neighboring players operating under the different regimes.

C. Transition

Apart from the potential for more efficient utilization of the spectrum, much of the interest in dynamic spectrum access is driven by the upcoming availability of portions of the spectrum released by the move from analogue to digital TV transmission [5]. However, this process also indicates that any modeling framework must take into account the inevitability that transition from command and control to dynamic spectrum access is likely to be piecemeal. The cost of writing off existing technology investment and deploying whatever new radio technologies are required to participate in the DSA domain will vary wildly between user groups and between different national regulatory domains. Therefore any comprehensive modeling framework must accommodate the adjacencies and interaction between full dynamic spectrum players, and those who only need to operate under the conditions of their existing command-and-control spectrum assignments. This can be viewed as a more general version of the co-existence scenario described in the previous section, although its impact will diminish in the long term. In the short to medium terms, however, it will contribute to the asymmetry between DSA players and therefore widen the breadth of organizational interactions that must be accommodated.

D. Enforcement

Most schemes proposed for DSA aim to reduce the burden of enforcement, on the basis that the cost of monitoring for and detecting transgressions would be immense given the distribution of usage in frequency and geography and the potentially large numbers of players involved. There is a general desire, therefore, to develop self-managing schemes where the cost of enforcement is shared as much as possible across all players. In today's unlicensed bands, the cost of enforcement is minimized by using simple frequency and power limit rules and delegating the certification of hardware

to operate in these bounds to an industry supported body, e.g. the WiFi Alliance. As pointed out in [6], the adaptive nature of cognitive and software defined radios in DSA schemes renders device certification impractical due to the ease with which behavior can be change through unmonitored software updates. An alternative approach is indicated by Lehr and Crowcroft in their discussion of wireless commons [7]. They identify the absence of transmit only devices and the adoption of common signaling channels as important pre-requisites of workable schemes to deter free-riding. This could be extended to all forms of radio users by placing on them the obligation to act as witnesses in disputes. Individual radios would be required to monitor RF signals according to a regulator-defined schedule and to provide a certified record of their observations. In parallel, transmitters would be required to always include a user-linked ID in their transmission, most likely in the common signaling channel. Limiting the certification process to these features would be more tractable than attempting to certify the wide range of software radio function that would be constantly generated. The cost of enforcement would be distributed across all users and would be focused on the detection of transgression rather than preventing the potential to transgress. Privacy considerations could be addressed by involving regulatory authorities in the encryption and authentication of ID, so that they could be protected from witnesses.

Software defined radios potentially are able to configure themselves to passively receive outside their usual frequency and time assignments. If regulators can configure such reception directly through a certified mechanism, detection can become very efficient, being driven by user complaints rather than through constant monitoring. The burden of gathering proof, however, is shared rather than falling on the complainant. Easing the cost of identifying a transgressor will serve to deter transgression in the first case, especially if appropriate penalties apply. The runtime burden could be handled by negotiation between the regulators and witnesses in a way commensurate with the suspected depth the transgression being investigated. A high level of transgression would however strengthen the regulator's hand in these negotiations, thereby encouraging the detection scheme to scale with the need for detection. The effectiveness of this scheme would depend on the level to which different bands in a physical region are allocated to entities with no stake in the alleged transgression. High levels of independence would strengthen the credibility of witnesses, though a strongly certified mechanism for delivering encrypted and regulator authenticated witness evidence separate to the radio operator would lessen the need for it.

E. Revocability

Several factors point to the need to abolish any sense of spectrum assignments being made in perpetuity. The rapid advance of wireless communications technology weakens arguments for perpetual assignments based on protection of investment, as does the long terms drop in wireless equipment costs. Coupled with this is the need for experimentation,

which may yield a need to end a particular set of assignments for the general good, including the promotion of the stability of the DSA systems. This may need to be exercised against the wishes of specific assignees. Also, effective enforcement of commons [7] or market rules must wield the sanction of barring a player from the field altogether. Therefore, the ability to revoke spectrum assignment must be retained by regulators at all levels.

F. Transparency

One danger of regulators retaining the right to revoke spectrum assignments is the increased risk perceived by applicants in applying for assignment if they believe there is a possibility that revocation may occur on an arbitrary basis. This may reduce their involvement in the system and their support for transition to DSA over command and control. This risk also applies on a longer time-base for command and control systems, and regulators have addressed this through supporting transparency of their deliberation and decision-making processes. In a DSA environment with multiple secondary regulators, supra-national regulators and devolved administration of common schemes to quasi public bodies, the need for transparent, rules based regulation will be key. However, total transparency may not be viable especially during periods when critical enforcement or future policy decisions are being made. Transparency at this point may encourage attempt to avoid detection if tipped off, or to game a new spectrum allocation regimes before regulatory checks and balances mature.

To summarize therefore, any framework for modeling and analyzing DSA schemes must be holistic in the considerations it involves. It must also be amenable to self-analysis, so that schemes can be improved or tailored to local conditions over time. It must therefore allow experiences with existing schemes to be systematically analyzed with a view to improving new schemes. These meta-management activities, together with the day to day operational management of co-existing schemes must be performed with a level of transparency that is controlled to engender public trust without unduly exposing the systems to innovative attacks. A suitable framework must therefore enable the understanding of the relationship between management and meta-management, of the signals communicated in these relationships and of the potential for a variety of uncooperative behavior.

In the following section we review the Viable System Model, which provides a modeling framework that may be able to support many of the requirements above.

III. FUNCTIONS IN AGILE DSA REGULATION

To design a system for the regulation and dynamic management of spectrum access we need to consider a complex set of inter-related behaviors that react to a wide heterogeneous range of technological, physical, economic, social and political environments. As these behaviors and environments react to each other as well as change over time, any suitable framework must explicitly model these dynamic and interactive elements if it is to remain relevant and

effective in the face of change.

The *viable system model* (VSM) was developed by the operations research theorist Stafford Beer. A viable system is one that is able to survive change. The VSM was developed to analyze how human organizations, e.g. corporations and governments, are best able to structure themselves as viable systems in order to adapt to change over time. The model broadly breaks down a system into the Operation of an organization, the Environment in which that operation is conducted and the Management that is exercised over the operation. The VSM places a focus on analyzing the channels that exist between the Environment and Operation and between Operation and Management. The analysis of these channels uses the concept of Variety. This is a measure of the number of states in which a system can occupy. The essential rule applied to by VSM to these relationships is that to be viable a regulating system must possess as least as much variety as the system it regulates. This premise is taken from Ashby Law of Variance [8]. However, an organization's Operation typically has less variety than the broader Environment in which it exists, while organizational Management typically has less variety than the Operation it manages. This problem is addressed by allowing the channels between Environment, Operation and Management to amplify or attenuate the Variety of one system as perceived by another. For instance the channel from Operation to Management will attenuate the variety that needs to be perceived, e.g. summarizing performance metrics.

The VSM breaks down the Operation and Management functions into a set of systems. This breakdown is recursive, such that each element can represent a viable system. The Systems defined are as follows:

- *System 1* represents the primary activities of a viable system, i.e. the functions that justify the system existence. Crucially, these systems are regarded as recursive, i.e. each can be a viable system, made up of the same composition of systems. The viable system will often consist of several System 1 elements working together.
- *System 2* represents the information channels and processes that enable System 1 entities to communicate with each other in achieving the aims of the overall system
- *System 3* represents the structures and controls that define the operational behavior of System 1. It uses System 2 to monitor and co-ordinate the activities of System 1. System 3 is complemented by a further system, System 3*, which monitors the working of System 1 directly, bypassing the coordinating filter of System 2.
- *System 4* represents the outward looking aspect of an organization, monitoring the environment and also assessing potential future changes. It interacts with System 1 via System 3.
- *System 5* represents the policy decisions that balance and steer the organization as a whole, capturing its mission and ethos. Part of this for a viable system is the goals of homeostasis, i.e. reaching a state of equilibrium.

The figure below was provided by Stafford Beer to illustrate the structure of the VSM. It shows the different

communication channels between the Environment (the left-hand area), Management (the large square) and Operations. It also shows the pattern of recursion, where System 1 represents the Management portion of the next level of recursion. It also indicates the feedback loops that enable a system to become viable through self-management. This is primarily performed by System 3, but with feedback provided from System 4 which, coupled with intelligence gathered from the environment and predictions of the future provide meta-management imperatives to System 3. The interaction between System 3 and System 4 is in turn regulated by the overall ethos of the organization.

In considering the application of the VSM to DSA we could surmise that the outermost recursive loop would be structured such that the Management systems are enacted at the international level. International agreements on the aims of DSA could be enshrined by bodies such as the International Telecommunications Union – Radiocommunications (ITU-R), while bodies such as the IEEE and the Wireless World Research Forum could conduct the activities of System 4, guiding the adaptation of the system as technology advances and political and economic changes occur. System 3 at this level may most likely be an enabling activity, supporting the implementation of international standards through certification of technologies and processes by industry sponsored bodies. It could however be the position of an international market in trading spectrum rights. In the main however, we expect most of the management functions to be conducted by national and regional bodies embedded in the next level of recursion. At this next level the management systems would largely be operated by the local regulator, e.g. the Federal Communications Commission, Office of Communications in the UK or the Commission for Communications Regulation (COMREG) in Ireland. However, System 5 and to some extent System 4 would involve elements of national and regional government, e.g. the European Commission, as they seek to exercise oversight and influence over the management of the spectrum, regarding it as a valuable national resources and a crucial part of the infrastructure of modern economies. At this level of recursion System 1 would be made up of particular spectrum users, e.g. the military and cellular operators, as well as newer bodies given sub-regulatory powers, e.g. national spectrum trading markets or metropolitan authorities changed with handing spectrum commons. Within these System 1 instances, management would be exercised within the constraints of the authority passed down from the higher level, but would again operate to an ethos, e.g. maximize trading volume and spectrum value, or social inclusion and fairness of access. Again these systems would have to involve System 3 and System 4 activities in order to stay viable. The System 1 instances at this level would come closer to specific spectrum user organizations, individuals and cognitive radio devices.

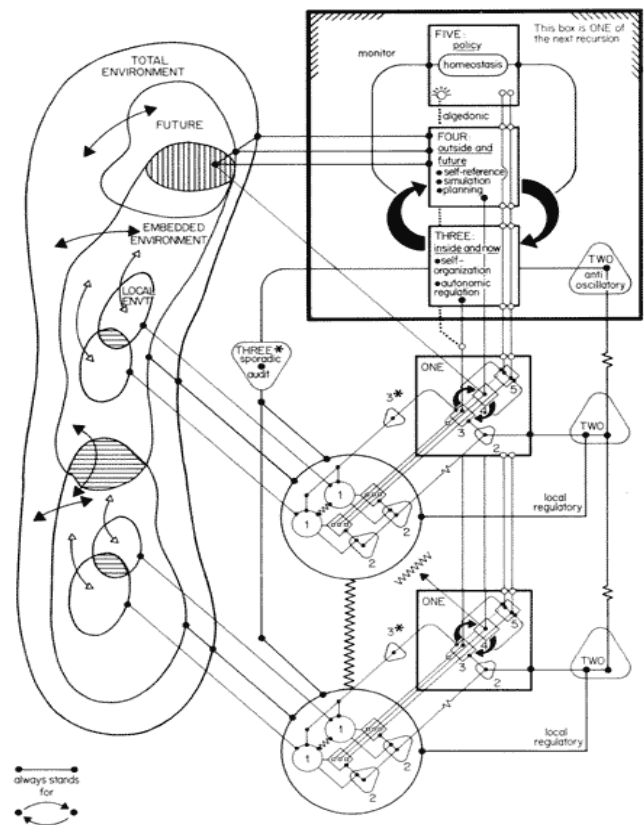


Figure 1: Stafford Beer's Visualization of the VSM

IV. INSTANTIATING A VIABLE DSA SYSTEM MODEL

A crucial element of the VSM approach to modeling organizations is the recursive sub-division of the organization. Viable systems contain viable systems that can be modeled using an identical cybernetic description as the higher (and lower) level systems in the containment hierarchy [9]. Ultimately, however, supporting dynamic session-by-session spectrum management, regulatory and sub-regulatory policies have to be mapped into machine-executable rule that governs the behavior of cognitive radio devices in the field. The U.S DARPA Next Generation Communication (XG) initiative has proposed a management framework for executable policies for cognitive radio by the U.S DARPA Next Generation Communication (XG) initiative [1]. This proposal includes the specification of a specific, executable policy language, the DAPRA XG policy language (XGPL). In a companion technical track paper [10] we propose a specific extension to XGPL based on abstractions from a scheme called Community Based Policy Management (CBPM). The CBPM scheme, as detailed in [11], uses a tree-like hierarchy of communities for structuring the meta-management of executable policies for DSA-aware RF devices [12].

The benefits brought by integrating CBPM with XGPL stem from the organizational modeling that CBPM uses as a basis for enforcing policies. CBPM uses the notion of *community* as the grouping abstraction with the aim of allowing groups within the organization itself to define communities to naturally reflect the changing nature of decision making (i.e. policy setting) authority. This contrasts

with modern role-based access control systems [13][14], such as that used in IBM's Workplace, which typically require the services of external consultants to define roles and their policies. This approach is both expensive and brittle in handling frequent organizational change [15], as will inevitably be the case of a multi-organizational setting such as DSA. Communities towards the top of the hierarchy have the wider membership and more general function, while those toward the bottom have more narrow membership and more specific function. The hierarchy is designed to support organizational change, allowing new sub-communities to be formed and encouraging the delegation of decision making authority as far down the hierarchy as possible.

This structure was in part inspired by observation of how on-line communities operate, where there is no legal seat of authority, but where chains of authority emerge over time. It is our contention that this is a feature of all successful organizations, i.e. that all organizations are subject to continuous organization change from within and without and it is those that manage that change well that succeed and prosper. In this sense we view the set of relationships between regulators, operators, secondary markets and authorities managing spectrum commons as a multi-domain organization. For this reason CBPM has been specifically designed to accurately reflect the structure of decision making authority within an organization. More importantly, however, the scheme is designed to be agile in reacting to changes in an organization's structure.

The key insight upon which the CBPM model is based is the idea of modeling the organization independently of its decision making structure. The organization is conceived as an inverted pyramid, with each level representing a different functional and structural unit within the organization and the entire organization forming the base of the pyramid, as in figure 2.

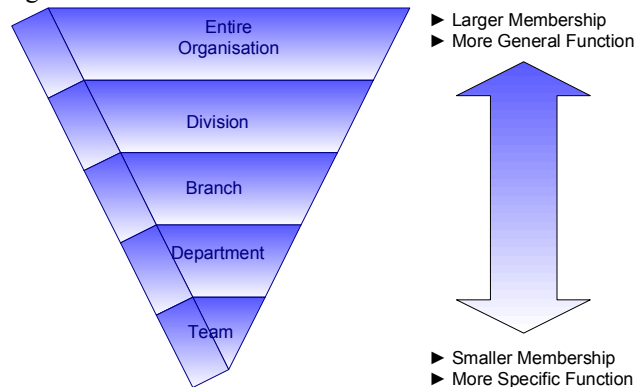


Figure 2 Organization as a Hierarchy of Authority

As we descend the pyramid, each level is more specific in function than the level above and has a subset of its membership. By specific, it is meant that the function of the unit is to carry out a specific function which has been identified as assisting in the attainment of the general goal of the organization. This pyramid is termed the hierarchy of authority. Although the diagram above only shows a single

path through the organization, the multi-domain dynamic spectrum management organization will have multiple branches and include federations between organizations at various levels. The diagram illustrates the hierarchy of authority between organizational units at various levels of generality, rather than being a model of the organization.

This hierarchy of authority is used as the basis of an *authority map* of the organization. Each organizational unit is associated with a decision-making method. An example, of this mapping is shown in figure 3, where the hierarchy of authority in a traditional monolithic organization is mapped to the equivalent groups and individuals who make decisions on behalf of the functional and structural units. It should be noted that policies are considered to be “decisions about choices in the behavior of a system” and are merely a means of specifying decisions that have been made. The notion of decision-making as it is used here is entirely identical to the authoring of policies.



Figure 3 Decision Making Hierarchy

Each level in the pyramid on the right represents the decision-making methods of the organizational units in the pyramid on the left. In moving up the hierarchy of authority, it can be observed that decisions:

- *Have Greater Scope.* Decisions of a regulator at the top of the hierarchy may be binding on the entire membership of the organization, i.e. all RF users, and may relate to any of the organization's resources – they have global scope. Meanwhile, decisions made by a local wireless network administrator normally only apply to the to the users of that network and to the resources that have been allocated to it – they have a scope that is limited to that group.
- *Relate to Higher Level Goals.* Normally, the decisions of the regulator will relate to the high level goals of the multi-domain DSA organization - they will be defining strategies for the entire organization to follow, rather than concerning themselves with the low level workings of the various groups that make up the organization. Similarly, the local administrator's decisions will reflect the particular goals of their network operation activity and they may not be directly derivable from the organization's high-level goals.
- *Are More Expensive.* Decisions at the higher levels of the organization are considered more expensive in general than those further down the hierarchy of authority in two ways. Firstly, it is normally the case

that the higher in the hierarchy one goes, the slower and more time-consuming the decisions are. For example, there may be several months between meetings of the regulator's board and these meetings may have crowded agendas, making their decisions relatively precious. Meanwhile, a local administrator can often take an instantaneous decision without consulting anybody else. Secondly, the cost of mistakes in decisions generally becomes more expensive as one ascends the hierarchy – which is a consequence of the first two points.

- *Can Overrule Decisions at a Lower Level.* Finally, it should be noted that the further up the hierarchy one goes, the greater the weight of the decisions. If the regulator makes a decision on behalf of the entire body of RF users, all of the units further down the hierarchy are bound to follow it. Individual operators or administrators require the explicit permission of the regulator before they can take decisions which conflict with the board's decisions. In the diagram, decisions taken at the higher levels are described as hegemonic while those taken further down are dependant.

It should be noted that these characteristics generally hold, regardless of the decision-making hierarchy that is associated with the organization's hierarchy of authority. For example, if an organization is run according to the principles of direct democracy, where every person who is affected by a decision has a vote in the decision, this can be modeled by configuring communities so that a decision within any unit of the organization requires a referendum of all the members of that unit. Decisions made for local set of wireless users might often be relatively inexpensive, since the group will have few enough members working together to be able to take a vote quickly, and the decisions will still have the same scope and relationship to the goals of the organization as if the organization was managed by a traditional hierarchical bureaucracy. Conversely, in any sizeable organization, it can be expected that the time and effort involved in organizing a referendum of the entire organization will be considerable. However, once a decision has been taken by universal referendum, all of the members of the organization, and all of the units within the organization will be bound to follow it according to the general principles of this organizational model.

Based on these characteristics of the hierarchy of authority, the following rule of thumb for the distribution of decision making throughout the organization is adopted.

Decisions should be made as far down the hierarchy of authority as is possible

Due to the increasing expensiveness of decision as one ascends the hierarchy, it is desirable to distribute decision making authority to the lowest possible point – it makes much more sense for the details of the workings of a local wireless network to be decided by the team local administrator than by the regulator. In order to fulfil this rule, the CBPM model is designed to be inherently dynamic. Each unit in the organization aims to push decision-making responsibility

downwards wherever possible and units can be dynamically created whenever existing units manage to decompose their own structure and function into sub-functions. The process of pushing decision making down the hierarchy is based on delegation. However, this notion of delegation differs from that used by most PBM systems. Rather than the temporary delegation of rights from one individual to another, this delegation is a semi-permanent transfer of authority between organizational units.



Figure 4 Delegation / Escalation Cycle

Figure 4 illustrates the basic dynamic of the CBPM model. Higher-level units in the hierarchy of authority delegate Parcels of Authority to the lower level units. A parcel of authority refers to a set of resources whose use is constrained in various ways. Through delegation, the grantee unit gains authority to make decisions about the resources that have been granted, but those decisions are bound by the constraints specified in the parcel of authority. Receipt of an authority parcel amounts to being given responsibility to make decisions about the management of certain resources in order to fulfill the goals of the unit. This notion of the distribution of authority in constrained bundles to units which serve as a representation of the stakeholders of the potential decision reflects research into human interactions with policy based systems [16].

In order to respect the principle of least privilege, these parcels of authority should be constructed in such a way so as to minimize the scope of authority to that which is strictly required. The dialectical goals of respecting this principle, while maximizing the amount of responsibility that is pushed downwards, provide one of the motors which drives the evolution of the system. This is a manifestation of the fundamental tension in all management systems between the certainty of centralized control and the convenience of decentralization.

The other factor that serves to shape the dynamic evolution of the system is escalation. Escalation deals with situations where a functional unit needs to make decisions about a resource for which it has not been delegated sufficient authority. It amounts to a lower unit asking a higher unit to delegate it authority, or to take a decision on its behalf with regards to the relevant resource.

In the hierarchy, the authority to author management

policies flows from the top of the hierarchy to its leaf communities. Information flows up the hierarchy concerning policy conflicts and situations where there is a lack of sufficient policy guidance to make decisions in particular contexts. It is these two flows up and down the hierarchy of communities that forms a dialectic that can be harnessed to improve the operation of the systems.

The CBPM therefore provides a good framework for modeling the recursive sub-division of the organization present in VSM. Each community in the CBPM hierarchy can be considered to be a Viable system. The community hierarchy, supports an algorithm for identifying the point in the hierarchy where policies that permitted a policy conflict detect lower in the hierarchy. This algorithm unites the various viable systems at different levels of the organization, into a coherent whole, i.e. a viable meta-management system. The policies defined within each community provide the operational details of each VSM. The richness of the policy language used is analogous to the VSM concept of variety – certain policy languages can capture highly expressive conditions that depend on complex relationships of environmental variables, and map these into policy decisions. Technically, the CBPM system performs the role of system 3 in the VSM. It automatically enforces the policies established by system 5 of the model – the organization’s decision makers – and it defines the interface between this system and the lower systems – by defining the policies which govern the policy authoring process. Thus, the CBPM can be used as the basis for modeling organizations according to the VSM approach. System 1 of the VSM can be mapped to CBPM resource authority trees, while the policies authored about these resources are the CBPM’s definition of system 2. The CBPM policy enforcement service itself becomes system 3 of the VSM, while the VSM’s system 4, is equivalent to the semantic richness of the policy language, and in particular, the richness of the environmental information available to it.

As described in a companion paper in the technical session [10], this hierarchy of communities can be used to model a regulatory systems, with sub-communities representing direct users, or sub-regulators such as secondary markets or regional/municipal commons communities.

V. CONCLUSION AND FUTURE WORK

In this paper we have discussed the need to address the management of DSA in a holistic manner, including meta-management issues. We have reviewed several problem areas that require both management and meta-management solutions. We have then considered Stafford Beer’s Viable System Model as a potential framework for modeling and analyzing the complex DSA management scheme that would be required. We then discussed how such a scheme could begin to be grounded in an implementation of the Community-based Policy Management scheme, a meta-policy management framework that possesses a hierarchical community structure that aligns well with the VSM.

Our future work will involve the examination of further

analytical tools that can be integrated with a CBPM tool-set to support difficult areas of analysis that arise from adoption of the VSM. One such difficulty is analyzing the attenuation and amplification of variance in the channels between systems. Here we have begun to investigate the application of semiotic theory for organizations [17] as a way of analyzing the richness of signals and also the loss in semantics as they pass through a particular system. For instance, the impact of attenuation on a signal given by a particular anti-trust policy set at a national level as it passes through levels of CBPM communities with the aim to guide the behavior of individual organizations. Another area of further work involves the analysis of potential gaming strategies as part of VSM System 4’s forward-looking activities. Promise Theory is a recently emerged technique to modeling a system as autonomous entities, with policies forming promises between entities [18]. In a particular circumstance, an entity may chose to break a promise, thereby declaring their refusal to conform to the policy from which the promise was derived. Promise Theory uses games theory techniques to predict the stability of a particular set of policies by predicting the circumstance under which promise/payoffs tradeoff encourages them to break a promise. We are examining how the integration of Promise Theory with a dynamic what-if analysis of a CBPM set-up may enable regulators at various levels to identify possible gaming attacks that may render a given system of regulatory rules unstable.

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REFERENCES

- [1] DAPRA XG Working Group, “The XG Vision Request for Comments”. Version 2.0, prepared by BBN Technologies, Cambridge MA, USA, January 2004
- [2] Hatfield, D.N., Property Rights In Spectrum: Taking the Next Steps, in proc of the IEEE DySPAN 2005, Baltimore, USA, Nov 2005, pp 45-56
- [3] Forde, T., Doyle, L., “Exclusivity, Externalities and Easements: Dynamic Spectrum access and Local Coasean Bargaining”, DySpan 2007
- [4] Doyle, L., Forde, T., Argyroudis, P., Nolan, K., O’Sullivan, D., “Towards a Fluid Spectrum Market for Exclusive Usage Rights”, DySpan 2007
- [5] “Redistribution control of digital television broadcast”, 47, C.F.R. pt 73.9001, Federal Communications Commission
- [6] Giacomoni, J., Sicker, D.C. “Difficulties in Providing certification and Assurance for Software Defined Radio”, in proc of the IEEE DySPAN 2005, Baltimore, USA, Nov 2005, pp 526-538
- [7] Lehr, W., Crowcroft, J, Managing Shared Access to a Spectrum Commons, proc of the IEEE DySPAN 2005, Baltimore, USA, Nov 2005
- [8] Ashby, W.R., “An Introduction to Cybernetics” (Chapman and Hall, 1956)
- [9] Beer S., "The Heart of Enterprise". 2nd ed., John Wiley and Sons Ltd., Great Britain, 1979
- [10] Feeney, K., Lewis, D., Grouping Abstraction and Authority Control in Policy-based Spectrum Management”, submitted to technical track of DySpan 2007.
- [11] Lewis, D. Feeney, K. Foley, K. Doyle, L. Forde, T. Argyroudis, P. Keeney, J. O’Sullivan, D., Managing Policies for Dynamic Spectrum Access, 1st International IFIP TC6 Conference on Autonomic Networking (AN2006), Paris, France, September, 2006, LNCS 4195, Springer, 2006, pp285 - 297

- [12] DARPA XG Working Group "DARPA XG Policy Language Framework, Request for Comments", version 1.0, prepared by BBN Technologies, Cambridge MA, USA, April 16 2004
- [13] Sandhu, R.S., Coyne, E.J., Feinstein, H.L., Youman, C.E, "Role-Based Access Control Models," Computer, vol. 29, no. 2, pp. 38-47, Feb., 1996.
- [14] Lupu, E. C.. A Role-Based Framework for Distributed Systems Management. PhD Thesis, Department of Computing, Imperial College. London, U. K., July 1998.
- [15] Jude, M., Policy-based Management: Beyond the Hype. In Business Communications Review, available from <http://www.bcr.com/bcsmag/2001/03/p52.asp>, March 2001. pp 52-56
- [16] Barrett, R. People and Policies: Transforming the Human-Computer Partnership, 5th IEEE International Workshop on Policies and Distributed Systems and Networks, IEEE, 2004
- [17] De Souza, C., S., Preece, J. (2004) A framework for analyzing and understanding online communities. Interacting with Computers, The Interdisciplinary Journal of Human-Computer Interaction.
- [18] Burgess, M., "An Approach to Understanding Policy Based on Autonomy and Voluntary Cooperation" 16th IFIP/IEEE International Workshop on Distributed Systems (Operations and Management, DSOM 2005) (Barcelona, Spain, October 24-26, 2005, Lecture Notes on Computer Science, 3775:pp 97--108, 2005