EMC Standards Activity

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A New Challenge for EMC: Policy Defined Radio!

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Overview

The EMC Society Standards Development Committee (SDCom) has launched several new study initiatives in the past year in areas of burgeoning interest especially in the area of wireless technology. Many of these initiatives have been reported in the EMC Standards Activities column of the EMC Newsletter. A particular activity that has been brewing for some time now has raised itself to the attention of those interested in better efficiency in using the radio spectrum by a wide variety of uses as well as devices especially above 1 GHz. These uses extend well beyond the popular mobile phone and wide area/local area network populating specific frequency bands. What is of significant interest is that due to the pressure to simultaneously use the same spectrum for many wireless/radio services, there has been research conducted that is demonstrating the potential for time-sharing and other techniques that this paper will be discussing.

Another fascinating consequence of this interest in more efficient radio spectrum use is that the application of EMC is now co-mingling with spectrum allocation which was not main stream even a very few years ago. This mingling is due to the need to limit interference (clearly an EMC issue) for transceivers operating in the same frequency band (classically a spectrum allocation concern whereby radio services were allowed or licensed to operate on a specific frequency and any other transmitter could only operate realizing that any interference received from licensed services is their problem, not that of the licensed service).

This paper then addresses the question of what is being done to increase the classical use of the radio spectrum by multiple services all vying for frequency access. Clearly, if such increases are achieved, the so called “scarce” radio spectrum will have new life for all the potential users as well as those who have to set policy to regulate this use. We will call this “policy defined radio”. A policy defined radio system is one that can monitor its RF environment, identify unused spectrum and “harvest” its use within the limit of a set of operating “policies”. It is the ability of these systems to monitor their environment and coordinate the use of spectrum in space, time and other parameters, that makes these systems deliver revolutionary advances in spectral efficiency. We now introduce the subject with the expectation that many of you reading this will have interest enough to engage in the standards development underway in this area in the EMC Society.

Introduction

Policy Defined Radio, Adaptive Radio, Interference Temperature, Software Defined Radio, Opportunistic Spectrum: what do they all mean? If you deal with wireless, you know that a lot of strange terms are being bandied about. Taken together they represent a new area and new challenges for EMC engineers.

Background

Before we go into detail on the use of these terms, we need to understand the backdrop of why the interest is so intense. First, the radio spectrum is a considered a precious commodity, especially spectrum below 3 GHz. As more and more wireless applications and services are created, the pressure to find more spectrum to house them all increases. The demand for more spectrum will only increase for some time to come. So, as with any rare commodity, we start looking for innovative ways to use the available frequency space more efficiently and share spectrum more effectively. This core requirement to find more efficient ways to use spectrum is driving some very innovative thinking and exploration.

At the FCC, the Blue Ribbon Spectrum Policy Task Force, lead by Dr. Paul Kolodzy, made a basic paradigm shift in the way spectrum should be managed in the future and recommended a number of far reaching recommendations. At the core of those recommendations was that the FCC revise its traditional “command and control” approach to spectrum management for unlicensed and market based spectrum applications and begin to use more variables in its spectrum management. The traditional “command and control” approach still has application for specific problems, e.g. high power systems, and applications with high sensitivity to interference.

In the traditional approach, radio services are managed based on distance and frequency alone. Radio services that are physically close together must be separated in frequency. Those that are widely separated may be allowed to reuse the same frequencies. Under the new recommendations, additional variables would be brought in to allow the spectrum to be used more efficiently. The simplest variable to understand is time. If two radios can coordinate their transmissions they can share the same frequency and the same place of transmission.

At DARPA (Defense Advanced Research Projects Agency—part of the US Department of Defense (DoD)), the NeXt Generation (XG) program is exploring innovative new systems that will allow a minimum of 10 times the number of radios to operate, without interference, in the same frequency space as current systems. DARPA studies show that most spectrum goes unused for up to 95% of the time. By enabling devices to sense their spectrum environment and coordinate their transmissions, more radios can share the same spectrum. Preston Marshall, the XG Program Manager sees breakthroughs in computer science and RF engineering blending together to fundamentally change the way we design radio systems.

Other efforts seek to break the divide between hardware capabilities and its operating characteristics. Software Defined Radios (SDRs) are envisioned to be platforms in which much of the radio functionality is implemented in software rather than hardware. This gives a single radio platform the capability to operate in a variety of operational modes and provide a multitude of communications services. However, these radios would operate under the limits imposed by their software control mechanisms. Thus, the same device may operate very differently in different areas of the world or under different conditions.

Current Spectrum Allocation Practices

Electromagnetic energy propagation at RF frequencies is currently governed by a one-dimensional “real estate” approach to the allocation of frequency bands, where the licensee has specific legal right to transmit within a band. The entire spectrum from 3 kHz to 30 GHz is currently allocated in this fashion. Unfortunately, this “set-it-and-forget-it” management scheme is straining under the immense pressure of exponentially increasing demand by burgeoning numbers of various types of wireless devices. These span commercial and military applications all the way from short range home networks and cordless phones to the global communications grid.

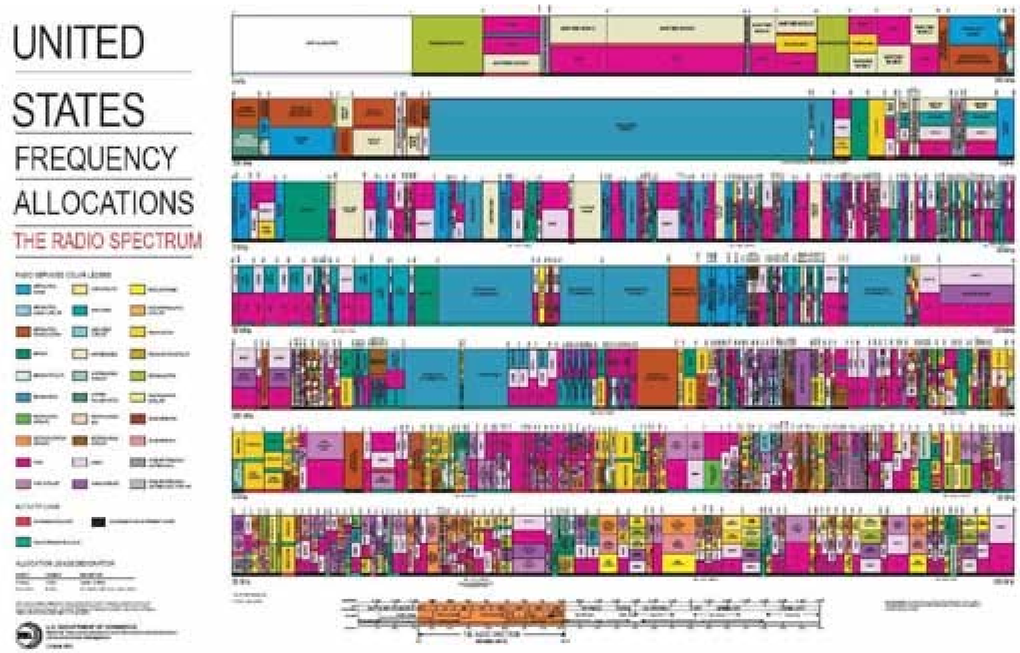

Figure 1. US Frequency Allocation Chart (Courtesy of the US Department of Commerce/National Telecommunications and Information Administration/Office of Spectrum Management, 3/96)

The allocation chart in Figure 1 seems to indicate is that spectrum utilization is densely congested nearly 100 percent of the time and is under constant contention by competing US Government and civilian agencies. The chart specifies the radio services, service priority (e.g., primary or secondary), and whether the service is for non-Government or Government or both (shared). The chart is divided into approximately 800 frequency bands from 0 to 300 GHz. Of the 300 GHz allocated, the Government has exclusive use of 1.4% (4,271 MHz), non-Government users have exclusive use of 5.5% (16,561 MHz), and the remainder, 93.1% (279,168 MHz), is shared between the Government and non-Government users. The vast majority of spectrum use for both the private sector and the Federal government is below 30 GHz. From an allocation point of view in the 0 to 30 GHz range, the Government exclusive allocation is 7% (2,271 MHz), non-Government users have 30% (8,961 MHz), and the remainder 63% (18,768 MHz) is shared.

The current US national-level spectrum allocation policies and practices allege that spectrum is a highly scarce and overburdened resource. Upon closer examination, it can be shown that spectrum scarcity is not the problem, but rather spectrum management inefficiency is the real culprit. Nonetheless, spectrum is still being heralded today as a scarce resource from every direction. Consider, for example, that the current US methods of spectrum management are rooted in policies that date back over 90 years, which at that time centered on the use of old analog broadcasting technologies and fixed, narrowband systems.

However, studies show that spectrum goes unused much of the time. In measurements made by the Shared Spectrum Company, it is shown that even in densely populated areas there exist many opportunities for more effective spectrum sharing. As an example, Gravely Point Park, located next to Ronald Reagan Washington National Airport in Washington, DC, offers one of the densest RF environments in the country. Still, the data shows that a large fraction of spectrum is not used. Measurements in urban and rural areas show even lower utilization than the figures at this site. This fractional use of the spectrum is shown in Figures 2 and 3.

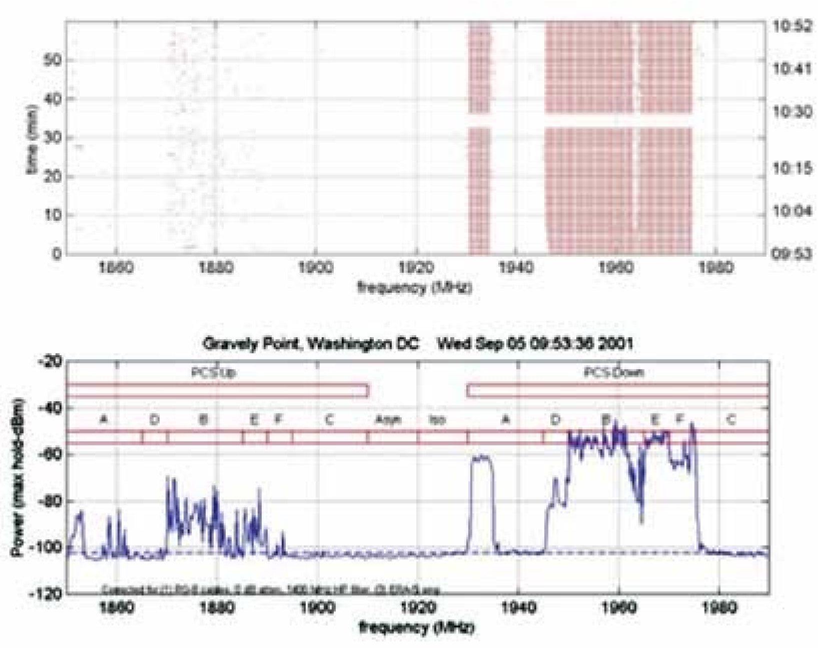

Figure 2. Measurements taken on Wednesday, September 5, 2001 from 9:53 am to

10:52 am depicting spectrum measurements from 1850 MHz to 1990 MHz, which covers the PCS band.

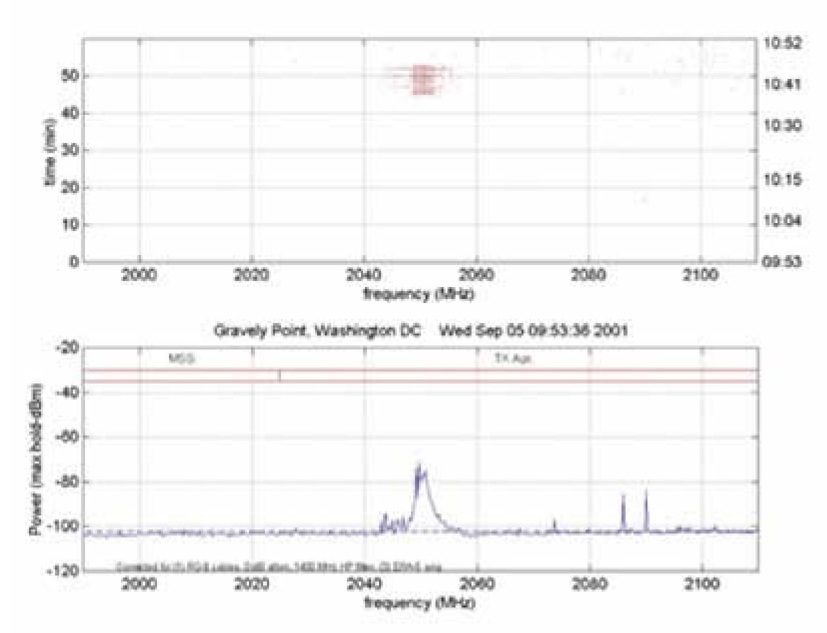

Figure 3. Measurements taken on Wednesday, September 5, 2001 from 9:53 am to 10:52 am depicting spectrum measurements from 1990 MHz to 2100 MHz, which covers the MSS and TX Aux bands.

Note: Figures 2 and 3 are courtesy of the Shared Spectrum Company, www.sharedspectrum.com

So given the finite nature of the RF frequency spectrum, it is desired that more efficient approaches to the management of the resource be explored. These new approaches will certainly influence the way manufacturers design, deploy, and utilize future radios as well as other communication devices in the future. In a sense, we are looking at the joint evolution of policies and radio technologies i.e., the emergence of policy-driven radios and the like.

Relevant Policy-Driven Considerations and Recent Initiatives

There has been a great deal of activity recently in the US pursuing spectrum policy reform in response to emerging broadband, digital communications systems [1-5]. A few of the major developments are as follows:

On 5 June 2003, US President Bush signed an Executive Memorandum creating the Spectrum Policy Initiative to develop recommendations for improving spectrum management policies and procedures for the 21st century. The Department of Commerce chairs the Initiative. The purpose of the Initiative is to promote the development and implementation of a US spectrum policy that will foster economic growth; ensure our national and homeland security; maintain US global leadership in communications technology development and services; and satisfy other vital US needs in areas such as public safety, scientific research, federal transportation infrastructure, and law enforcement. The existing legal and policy framework for spectrum management has not kept pace with the dramatic changes in technology and spectrum use. US Federal Communications Commission (FCC) Chairman Michael K. Powell expressed his strong support for the spectrum policy reform and modernization initiative launched by this Executive Memorandum issued by the President.

A Spectrum Policy Task Force was formed to assist the FCC in identifying and evaluating changes in spectrum policy that will increase the public benefits derived from the use of the radio spectrum. FCC Chairman Powell commissioned the Task Force in June 2002 to develop new policies to advance spectrum reform. Specifically, the Task Force was directed to analyze spectrum allocation, assignment and use, and to develop a plan of action for review by the FCC. The creation of the Task Force initiated the first ever comprehensive and systematic review of spectrum policy at the FCC. The Task Force (i) provides specific recommendations to the FCC for ways in which to evolve the current "command and control" approach to spectrum policy into a more integrated, market-oriented approach that provides greater regulatory certainty, while minimizing regulatory intervention; and (ii) assists the FCC in addressing ubiquitous spectrum issues, including interference protection, spectral efficiency, effective public safety communications, and implications of international spectrum policies.

The FCC's Spectrum Policy Task Force has now taken a lead in pursuing real change in the current national spectrum policy, which in some cases is requiring significant philosophical transformations and changes in the way we think about practical spectrum management. Also, the US National Telecommunications and Information Administration (NTIA) and FCC have a memorandum of understanding (MOU) to work together on evolving spectrum policy. In addition, the US Defense Science Board is making strong recommendations on "shared RF resources" and the US Office of the Secretary of Defense (OSD) is hot on the topic of shifting paradigms related to spectrum sharing. The US National Science Foundation (NSF) is beginning the process of organizing a coalition of academics to build a program on "the future of spectrum." National and international Governments, university researchers, and commercial enterprises all need to consider a new vision that leads to efficient spectrum allocation.

Next, the recent US Defense Science Board Task Force on Wideband RF Modulation, Dynamic Access to Mobile Networks reported two preliminary findings which concluded that: (1) advanced communication techniques coordinating space, time, frequency, and modulation can increase spectrum utilization; and (2) potential interference among military and domestic systems and international treaties challenge the use of wideband RF modulation in systems designed with limited link margins, such as radars, signal interception, satellite, and radio astronomy.

Amid continuing jousting between the DoD and the public sector over the wireless spectrum, the Pentagon has created a position for overseeing spectrum allocation. Defense Secretary Donald Rumsfeld in early 2003 named Steven Price as the Deputy Assistant Secretary of Defense for Spectrum and Command, Control and Communications Policy. Price is responsible for establishing policy and providing direction for DoD frequency spectrum issues.

As part of the FCC's efforts to effectively manage spectrum in the public interest, a Spectrum Policy Executive Committee was established. This Committee is tasked with three major objectives: (1) address broad policy issues affecting spectrum management; (2) implement the initiatives consistent with the principles articulated in the Policy Statement; and (3) coordinate inter-bureau issues. This Committee will bring focus and policy direction in a time of increased demand for spectrum.

According to FCC Chairman Powell, spectrum policy reform is a crucial initiative. Effective spectrum policy is essential to traditional spectrum-based services, such as mobile phones and Direct Broadcast Satellite. However, the rewards of sound spectrum policies go far beyond traditional stakeholders; they are integral parts of the long-term success of FCC initiatives in Broadband, Competition Policy, Media Regulation, and Homeland Security. Ultimately, like all of our focus areas, spectrum policy must strive to maximize the unique benefits offered by spectrum-based services and devices to the American public.

The development of new wireless technologies promises to accelerate the availability of broadband communications and dramatically change the way that people live, work, and play. The 3G wireless technologies, for example, will provide American consumers with broadband connections to the Internet at any time and any place. Unlicensed wireless services, such as Wireless Fidelity (WiFi), will provide inexpensive wireless connectivity in the home or office and broadband access at many local "hot spots" around town. Breakthroughs in such technologies will drive broadband migration, i.e. an exodus from existing analog platforms to digital architectures. The new networks would be more efficient and provide opportunities for an expanded array of applications and communications services for consumers. In addressing this migration, five specific areas were outlined for FCC attention: (1) Broadband Deployment, (2) Competition Policy, (3) Re-examination of the Foundations of Media Regulation, (4) Homeland Security, and, (5) Spectrum Policy. When we improve the way that spectrum is regulated, increasing access, availability, and efficiency, the other four initiatives are also advanced. For instance, in the case of Homeland Security, spectrum is an essential input in the continuing fight against terrorism, a force multiplier for our military and an everyday necessity for public safety officials. We must continue to work with the Administration's Homeland Defense leadership as well as the public safety and critical infrastructure communities within the FCC's jurisdiction to ensure that adequate spectral resources are available to facilitate reliable and interoperable communications.

Also, electromagnetic interference protection has always been at the core of federal regulators' spectrum missions and also of our own IEEE EMC Society. The Radio Act of 1927 empowered the Federal Radio Commission to address interference concerns. While interference protection remains essential to the FCC, interference rules that are too strict limit users' ability to offer new services and rules that are too lax may harm existing services. The FCC has begun examining whether there are market or technological solutions that can, in the long run, replace or supplement pure regulatory solutions to interference.

The FCC's current interference rules were typically developed based on the expected nature of a single service's technical characteristics in a given band. The rules for most services include limits on power and emissions from transmitters. Each time the old service needs to evolve with the demands of its users, the licensee has to come back to the FCC for relief from the original rules. This process is not only inefficient, but it can stymie innovation.

Due to the complexity of interference issues and the RF environment, interference protection solutions may be largely technology-driven. As an illustration of the shortcomings of our current rules, interference has been viewed as solely "caused" by transmitters. Instead, interference is often more a product of receivers. Yet, our decades-old rules have generally ignored receivers, i.e., the lack of receiver standards. On the other hand, diverse and rapidly changing communications technologies and their interference policy impact must be understood. For instance, emerging communications technologies are becoming more tolerant of interference through sensory and adaptive capabilities in receivers. That is, receivers can "sense" what type of noise or interference or other signals are operating on a given channel and then "adapt" so that they transmit on a clear channel that allows them to be heard. New policies should facilitate and support such innovative technologies that may increase spectral efficiency. The goal should be to build a policy that recognizes the diverse and complex opportunities presented by changes in the role of interference in spectrum policy.

Next, consider "scarcity." Much of the FCC's spectrum policy was driven by the assumption of acute spectral scarcity - the assumption that there is never enough for those who want it. Under this view, spectrum is so scarce that the Government, rather than market forces, must determine who gets to use the spectrum and for what purpose. The spectrum scarcity argument shaped the US Supreme Court's Red Lion decision, which gave the FCC broad discretion to regulate broadcast media on the premise that spectrum is a unique and scarce resource. Indeed, most assumptions that underlie the current spectrum model derive from traditional broadcasting. But just as the presumptions of Red Lion and similar broadcasting regulation based on scarcity have been called into doubt by the proliferation of media sources, so too must we question the continued utility of the pervasive scarcity assumption for spectrum-based services. The FCC has recently conducted a series of tests to assess actual spectrum congestion in certain locales. These tests, which were conducted by the FCC's Enforcement Bureau in cooperation with the Spectrum Policy Task Force, measured use of the spectrum at five major US cities. The results showed that while some bands were heavily used, others either were not used or were used only part of the time. It appeared that these "holes" in bandwidth or time could be used to provide significant increases in communication capacity, without impacting current users, through use of new technologies. Although not definitive as the sample was small, these results call into question the traditional assumptions about congestion. Indeed, it appears that most of spectrum is not in use most of the time.

But even these results, if generally applicable, would be less important if it were not for the birth of new technological tools that allow the public to take advantage of available spectrum resources without diminishing other users' rights. Today's digital migration means that more and more data can be transmitted in less and less bandwidth. Not only is less bandwidth used, but also innovative technologies like software defined radio and adaptive transmitters can bring additional spectrum into the pool of spectrum available for use. Scarcity will not be replaced by abundance; there will still be places and times when services are spectrum constrained. However, scarcity need no longer be the lodestar by which we guide the spectrum ship of state.

Other important considerations include:

Ad Hoc, Rigid Interference Rules Evolve to a New Paradigm for Interference Prediction and Avoidance–Interference Temperature

The time has come to consider an entirely new paradigm for interference protection. One forward-looking approach requires that there be a clear quantitative application of what is acceptable interference for both license holders and the devices that can cause interference. Transmitters would be required to ensure that the interference level, or interference temperature, is not exceeded. Receivers would be required to tolerate an interference level. Rather than simply saying a transmitter cannot exceed a certain power, we instead would utilize receiver standards and new technologies to ensure that communication occurs without interference, and that the spectrum resource is fully utilized. So, for example, perhaps services in rural areas could utilize higher power levels because the adjacent bands are less congested therefore decreasing the need for interference protection. By looking at the spectral environment more comprehensively and dynamically through the more focused measurement of interference temperature at the receiver, we better distribute the responsibilities for spectrum use and achieve greater value for American consumers.

Scarcity Mitigated by Access to the 4th Dimension: Time

In analyzing the current use of spectrum, the Spectrum Policy Task Force took a unique approach, looking for the first time at the entire spectrum, not just one band at a time. This review prompted a major insight: there is a substantial amount of "white space" out there that is not being used by anybody. The ramifications of the insight are significant. It suggests that while spectrum scarcity is a problem in some bands some of the time, the larger problem is spectrum access, or how to get to and use those many areas of the spectrum that are either underutilized or not used at all. One way to take advantage of this white space is by facilitating access in the time dimension. Since the beginning of spectrum policy, the Government has "parceled" this resource in frequency and in space. The FCC permitted use in a particular band over a particular geographic region often with an expectation of perpetual use. How well could we use this resource if our policies fostered access in frequency, space and time?

Technology has, and now hopefully FCC policy will, facilitate access to spectrum in the time dimension that will lead to more efficient use of the spectrum resource. For example, a software-defined radio may allow licensees to dynamically "rent" certain spectrum bands when they are not in use by other licensees. Perhaps a mobile wireless service provider with software-defined phones will lease a local business's channels during the hours the business is closed. Similarly sensory and adaptive devices may be able to "find" spectrum open space and utilize it until the licensee needs those rights for their own use. In a commercial context, secondary markets can provide a mechanism for licensees to create and provide opportunities for new services in distinct slices of time. By adding another meaningful dimension, spectrum policy can move closer to facilitating consistent availability of spectrum and further diminish the scarcity rationale for intrusive government action.

Command and Control Regulation Transitions to Flexibility

Historically, the FCC often limited flexibility via command and control regulatory restrictions on which services licensees could provide and who could provide them. Any spectrum users that wanted to change the power of their transmitter, the nature of their service, or the size of an antenna had to come to the FCC to ask for permission, wait the corresponding period of time, and only then, if relief was granted, modify the service. Today's marketplace demands that we provide license holders with greater flexibility to respond to consumer wants, market realities and national needs without first having to ask for the FCC's permission. License holders should be granted the maximum flexibility to use or allow others to use the spectrum, within technical constraints, to provide any services demanded by the public. With this flexibility, service providers can be expected to move spectrum quickly to its highest and best use.

Policymakers must establish a spectrum policy framework that increases spectrum access, availability, and efficiency. This framework should ensure that: (a) sufficient spectrum is available in time to meet market needs; (b) spectrum is harmonized worldwide, to the greatest extent possible; (c) spectrum is unencumbered and free of harmful interference; and (d) users have maximum feasible flexibility in how the spectrum is used.

First, to achieve these goals spectrum policies must evolve towards flexible and market-oriented models. Second, interference protection remains essential to effective use of the spectrum. Third, spectrum policies should be balanced, promoting both exclusive spectrum usage rights and creating open access to spectrum "commons." Under the "commons" approach, frequencies are shared on an unlicensed basis, with no right to protection from interference e.g., WiFi. These spectrum-use models, as well as the services they support, can be complementary and both should be supported. "Exclusive use” and “commons” spectrum, however, should be separate to promote the most efficient deployment of both, without the risk of interference to either.

A Brave, New World of “Resource Management”

New Paradigms for Spectrum Occupancy/Allocation

Many will concur that the realm of spectrum allocation is at the threshold of a new age and ripe for policy reform in light of the emergence of today’s broadband digital technologies. This calls for the development of more efficient ways of performing spectrum management that look well beyond traditional fixed allocation methods. Even the term “spectrum management” is becoming somewhat of a misnomer in that we are now beginning to effect the process differently by considering more than just frequency allocation and broadcasting over specified time slots. National policies, standard RF communications and network protocols, and even such factors as geo-location, power requirements, and the use of smart antennas are influencing the way we achieve spectrum harmony to new levels. Instead of “spectrum management” perhaps a more appropriate term would be “resource management.” In reality, spectrum management is more than just the allocation and management of frequencies. It actually becomes a problem of managing the RF “resource space” and applying the appropriate signaling protocols to optimize the communications process in virtually any physical and electromagnetic environment.

The RF “resource space” considered here consists of the multiple “dimensions” of a signal that can be exploited in various ways to achieve the optimum assignment of frequency, bandwidth, power, polarization, coding/modulation, etc. and for a given geo-location in accordance with accepted policies and protocols for that region. Here we coin the P3 law as the basis for the new paradigm shift: physics, policies and protocols. The underlying physics that deals with assigning the RF resource space is closely tied to the policies and protocols that govern a specific application for a given region or location. This is the rationale for the term policy driven radio in the parlance of RF radio communications systems. Encoding these in a software radio for instance, gives rise to the term software defined radio and implementing intelligence within the radio architecture to sense the environment (i.e., “listen before talking”) leads to the term cognitive radio (“Copyright Mitola’s Statisfaction, all rights reserved, used by permission for educational purposes,” www. ourworld.compuserve.com/ homepages/ jmitola.).

New concepts being studied convey the notion of a multi-dimensional resource space in which each dimension allows orthogonality (non conflict) amongst users. Time slicing, frequency division multiplexing, directional antenna arrays, spread spectrum codes, and polarization all independently allow for multiple users to exist without interference. A time-division multiple access scheme allots to N users a separate time slot in a time block and the users confine their respective transmissions to their allocated time slot. In this way, no two users are transmitting at the same time, even though they may be using the same frequency in the same space with the same exact waveform and spread spectrum code. Similarly, a spatially orthogonalized system allows separate users to transmit beam patterns in specific directions that do not overlap. The result is that all users can transmit at the same time, in the same frequency bands, with the same codes, but avoid interference because their transmissions do not overlap in space.

A similar orthogonalization concept applies to frequency and code as well. It even applies to polarization since an antenna with vertical polarization will transmit a signal that does not interfere with another signal from an identical antenna in horizontal polarization mode. This latter example, however, will mostly apply in the context of radar systems, since multiple reflections tend to alter the polarization of the transmitted signal and therefore remove any guarantee of a known polarization at the receiver in a communications context.

Currently there are no known technological approaches to RF transmission that consider all of these dimensions jointly, and certainly none that consider them in the context of a system optimization problem, the results of which are expected to garner several orders of magnitude improvement in RF resource utilization and therefore aggregate information throughput.

Jointly Optimized Transmission Space

A potential solution to the problem of “spectrum management” for emerging radio and communications systems is a jointly optimized transmission space in which frequency spectrum is considered in concert with other parameters such as time, space, code/modulation, polarization, and other signal dimensions. This concept represents a direct departure from the use of the traditional "spectrum" terms and definitions, and hopes to avoid potential confusion with less novel concepts or unsuccessful implementations that may have been previously attempted. This concept is intended to be a unifying visionary solution to today's problem of achieving efficient spectrum allocation particularly in view of new communications devices that are on the horizon.

New approaches for enhancing spectrum utilization and frequency management for large, complex systems of systems have recently been investigated that exploit the above concept to varying degrees of success [6-8]. Some of these approaches enable the effective and efficient joint utilization of all orthogonal electromagnetic transmission resources. The RF resource space can be imagined as an electromagnetically occupied volume bounded in all dimensions (time, space, frequency, code/modulation, polarization, etc.), or a "cube" (in more than three dimensions), as shown in Figure 4. Here, the cube is constantly changing with "cells" of signals that have applied for, received, used, and returned their transmission coordinates. When one wants to transmit, one asks for the coordinates, then transmits and goes off the air. Someone else then fills in or occupies that cell and the new or current user gets another cell the next time through the cycle. Using this approach, it can be shown that unused spectrum changes in time and space as well as other dimensions.

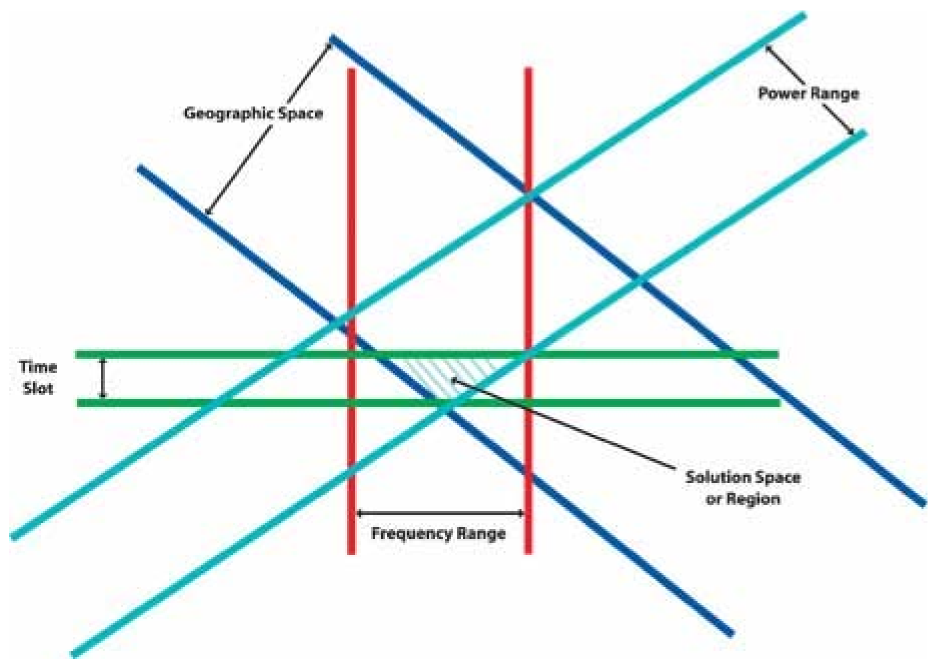

Figure 5. Generalized Approach for Arriving at an Optimized Solution for the RF Resource Space

Next, the approach involves exploiting optimization and orthogonality schemes that allow for multiple users to operate without interference. The approach applies multiobjective joint optimization algorithms in conjunction with novel frequency- and time-domain interference rejection models, and waveform diversity techniques to analyze dimensional "synergy" and "prioritize" the cell dimensions.

An important distinction must be made between the terms multiobjective and joint optimization. First, multiobjective joint optimization refers to a procedure for determining the "best fit" of decision variables (RF resource space dimensions) that satisfy a given cost or objective function in an optimal way. In general, the basis of this approach is the application of mathematical algorithms founded in operations research theory; in this case, to arrive at techniques for improving spectrum efficiency utilizing flexible and adaptive communications technologies. For example, one can optimally assign the various dimensions of an electromagnetic signal in a joint manner to ensure that multiple objectives are met, such as maximizing RF point-to-point connectivity and availability, power control to improve signal-to-interference-plus-noise ratio (SINR) or the interference rejection capacity of a system, and optimizing the mobility of systems in the overall spectrum management scheme while reducing power consumption, latency, and operational cost. Other potential approaches include methods to extend the frequency agility of software-defined radios to provide a wider set of capabilities for dynamic spectrum management as a function of the RF resource space assignments.

There are a number of possible approaches to achieving multiobjective joint optimization. Statistical optimization is one approach. Linear and nonlinear optimization, meta-heuristics, constraint satisfaction, and multidisciplinary optimization are yet others. However, the specifics of these approaches are not covered here. Additional details of these various approaches can be found in [7, 8].

Hence, given a set of dimensions, what can be expected as the dimensions are iteratively varied to arrive at an optimal assignment? Furthermore, how does changing one dimension affect all other dimensions? The application of joint optimization schemes will help answer these questions. Also, given the placement of one or more transmitters in a "spectral environment," how can radio channel assignments and efficient solutions of network design problems be optimized? The knowledge to be gained here will lead to the identification of ways to optimize the RF communications process for real world situations.

Consider the application of optimization schemes to the present problem of achieving spectrum efficiency in terms of sets of intersecting parallel lines that are nearly orthogonalized with respect to each other as Figure 5 roughly illustrates.

The labeling of the parallel lines is somewhat arbitrary in this illustration. True or perfect mutual orthogonalization among the dimensions is not necessarily implied or enforced here for practical purposes. Each set of parallel lines represents a range for a given RF resource space dimension e.g., frequency range, time span, geographic space (say, for mobile transceivers), range of code/modulation diversity, and so on.

The shaded region formed by the intersection of the lines in Figure 5 represents the joint optimum solution to the multi-dimensional RF resource space problem. Of course, this is an oversimplification of the approach in that the actual process of achieving the desired result is much more involved and can be quite computationally rigorous depending on the mathematical algorithms and computational methods utilized.

The results of recent studies on this topic [7, 8] have shown that potentially several orders of magnitude improvement in RF resource utilization and therefore, aggregate information throughput can be garnered through this approach. This is further described next in the context of computer modeling and simulation.

Results of EMI Analysis and Prediction

Computer modelling has been performed to assess the efficacy of selected optimization measures for mitigating the potential for EMI and enhancing RF communications throughput and the potential for frequency reuse. First, a legacy system model was constructed consisting of a group of 100 RF antenna systems each with identical transmitter and receiver operating characteristics and omni directional antenna patterns. All the antennas were tuned to 2.4 GHz in the model. Electromagnetic coupling was computed for all possible pairs of interactions over each time slice. A successful transmission was assumed when a message packet was sent and received between an intended pair of nodes. This was accomplished on the basis of a single node-pair intentionally communicating with each other during a given time slice in the legacy system case. In the legacy system, only one pair of transmit-receive antennas could operate interference free (simultaneous transmissions were not considered viable as this could lead to significant interference in the legacy case). The total number of time slots over all possible time slots based on single-pair interactions for the legacy system was computed to be 9,900.

The next step was to introduce several additional RF resource space dimensions into the problem; namely, power range, beamwidth, smart antenna beam directionality and limited frequency agility. The results of analyzing changes in these other dimensions of the problem were then compared to the legacy system in order to compute the effective improvement in data throughput and frequency reuse.

In the augmented problem, the 3-dB beamwidths for each antenna were specified to be 12.5 degrees each with a Gaussian beam distribution in azimuth and elevation along their (coincident) boresight direction. The transmit and receive beams were aligned with respect to each other and then coupling interactions were recomputed for antenna pairs over each possible time slice. In this case, multiple antennas were allowed to transmit and receive simultaneously. Intended pairs (RF links) were established in the presence of ambient interference due to unintentional signals from other antennas in the model. In addition, power control was employed to set the transmit power levels to threshold the intended receiver based on a predefined +10 dB SINR value. Information was then accumulated on the number of interference-free RF links and time slots in order to arrive at a throughput enhancement figure of merit.

By comparing the number of interference-free time slots involving simultaneous transmissions to the total number of time slots in the legacy case, approximately a 22X+ improvement in frequency reuse over the legacy system was predicted (or more than 450 simultaneous transmissions can take place). This was based primarily on employing beam diversity, power control, and other geo-spatial diversity techniques. When frequency diversity is considered in addition to other control schemes, further improvement by nearly 38X+ over the legacy system was predicted. If modulation diversity as well as other waveform diversity schemes were to be employed, the improvement could be extended to nearly two orders of magnitude above the legacy system.

As you can see from the above detailed explanation of the many issues, there needs to be a well thought out plan on proceeding in a manner that can be adopted/adapted by manufacturers of radio equipment, users of associated services, and those that regulate the use of the RF spectrum. This then leads us to how the EMC Society fits into the picture and what we as EMC and radio engineers can bring to the table. The next section describes that link and where we are in developing standards that would apply to increase the RF spectrum usage and availability.

New Standards Initiative

The IEEE EMC Society Standards Development Committee (SDCom) and IEEE Communications Society (ComSoc) Standards Development Committee have been exploring how best to develop the standards for this new area of spectrum usage innovation. It is clear that what is being explored is a future for radio services where we don't eliminate interference so much as we manage coexistence between radio services - again perhaps a different concept for EMC engineers to solve. The standards to support these future systems will need the expertise of communications, EMC, and computer engineers.

So in December 2004, the IEEE Communications Society and IEEE EMC Society signed a Memorandum of Agreement (MoA) to cooperate in the development of standards in this area. Within this area both Societies will cooperate and provide support for the development of the foundational standards needed to support future radio services.

Already the first joint projects are being launched and in November 2005 the first conference dedicated to this topic will be held. We now describe these projects with again the hope that the reader who is interested in this topic might contact the authors to see where there can be a contribution to the work.

First Project

The Project Authorization Request (PAR) has already been approved by the IEEE EMC Society SDCom and the IEEE Communications SDCom and is before the IEEE Standards Board New Standards Committee (NesCom) for review. Anticipating the IEEE Standards Board approval based on a positive recommendation from NesCom, this new joint working group will create a standard that:

- defines terminology, concepts, vision, and roadmap for adaptive radio (AR), policy-based radio (PBR), cognitive radio (CR), software defined radio (SDR), reconfigurable radio (RR) and related technologies,
- describes concepts for spectrum management that utilize these new radio technologies,
- defines interference/compatibility issues that must be addressed.

There is significant interest in AR/PBR/CR/SDR/RR worldwide. Progress in these technologies is somewhat hampered by inconsistent use of terminology which has led to duplicative and inconsistent development of the technology foundations. Nevertheless, these technologies are viewed internationally as having the potential for a more efficient use of the spectrum because of the potential for the radio to sense its operating environment to determine what frequency, power, modulation, etc. to use. In order to progress these technologies, a technical guide or equivalent is needed that outlines the terminology, shows the relationship of the various radio concepts being promoted, and how these technologies impact spectrum management.

Clearly, the use of these advanced radio technologies must be based on a thorough interference and electromagnetic compatibility assessment. Thus, the agreement by the EMC Society and ComSoc for joint sponsorship of this standards development effort is a very logical path to rapidly advance the

radio technology while ensuring that interference and compatibility issues are fully defined, understood and addressed.
The chair of this new work group is:

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Individuals having interest in adaptive radio, cognitive radio, policy-based radio, and advanced spectrum management are encouraged to contact the chair.

Second Project
The second project, currently being considered by the IEEE EMC Society SDCom would give guidelines on how to analyze the potential for coexistence, or conversely interference between radio services. This project will provide guidance on how to determine the potential of out-of-band, in-band, co-channel or adjacent channel interference. The project will also identify the many variables that must be considered and recommend values for items such as indoor and outdoor propagation loss and many other factors that enter into a thorough analysis.
Once finished, this project will not only provide guidance on how to analyze interference, but by identifying the many variables and their relative contribution, will guide the work of radio system architects as they seem to optimize system coexistence.
The proposed WG Chair is:

Stephen Berger
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These and future projects will provide the foundation and tools necessary to harvest and utilize spectrum with far greater efficiency than current systems. For the EMC engineer, it creates a very interesting new career direction for some. Instead of avoiding interference, these engineers will hone the skills necessary to manage interference and optimize future radio services. They will be working in new ways with those in from the communications and computer sciences and inevitably new specialties will emerge.

Conclusions and Call for Action
This article has introduced the reader to an exciting new area for EMC engineers to contribute. As you know, all IEEE standards committee meetings are open to the public and of course, due to the international nature of our membership, to others outside of the US. Participation is largely by electronic means, as we all know the problems with travel restrictions. The SDCom has set aside a limited budget to handle teleconferences on its active projects to further facilitate getting the job done. We further have tools that we use to craft standards. We call your attention to the following web site where you can get a very good view of what it takes to complete a standards project and what the SDCom recommends being followed if the project team prefers to do its development "on-line". (See http://standards.ieee.org/resources/development/index.html as an example of standards development tools for on-line approaches.)
So the EMC Society SDCom urges those of you who have interest in these projects to get in touch with the chairs identified above or with one of the authors. Andy can be reached on a.l.drozd@ieee.org and Don can be reached on d.heirman@ieee.org. The chair or secretary of the SDCom are also points of contact. The chair is Stephen Berger, stephen.berger@ieee.org and the secretary is Mike Hart, mjhart@quantumchange.com. We look forward to hearing from you and "let the action begin!"

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About the Authors

Andrew Drozd is President and Chief Scientist of ANDRO Computational Solutions, an engineering company that specializes in research and development related to the application of computer modeling and simulation technologies for analyzing complex systems-level electromagnetic environment effects (E3) problems. He has recently been involved in projects for the Government to investigate new methods of achieving efficient spectrum management using Transmission Hyperspace technologies. He is President-elect (2005) and a Board of Directors Member of the IEEE EMC Society. He is also an active Member of the EMC Society's Standards Development Committee (SDCom) and is the Working Group Chair of current IEEE Standards Projects 1597.1 and 1597.2 towards the development of a standard and recommended practice for computational electromagnetic (CEM) model validation. Mr. Drozd is a Certified EMC Engineer of the National Association of Radio and Telecommunications Engineers (NARTE). Mr. Drozd is a Fellow of the IEEE for the development of knowledge-based codes for modeling and simulation of complex systems for EMC. He has published over 140 professional papers, journal articles, and textbook chapters on topics related to EMC. He may be reached at 315-334-1163, a.l.drozd@ieee.org.

Stephen Berger is president of TEM Consulting, an engineering services and consulting firm specializing in the development of engineering standards, regulatory compliance, electromagnetic compatibility and disability access. He is president of the National Association of Radio and Telecommunications Engineers (NARTE) and chairs the IEEE EMC Standards Development Committee. Mr. Berger currently leads the IEEE Standards initiative developing standards supporting high spectral efficiency radio systems. He has participated in the development of numerous engineering standards and has served on three US federal advisory committees. He has 10 patents, granted or pending, and has published numerous professional papers. Mr. Berger may be reached at 512-864-3365, stephen.berger@ieee.org.

Donald Heirman is president of Don HEIRMAN Consultants, a training, standards, and educational electromagnetic compatibility (EMC) consultation corporation. Previously he was with Bell Laboratories for over 30 years in many EMC roles including Manager of Lucent Technologies (Bell Labs) Global Product Compliance Laboratory, which he founded and where he was in charge of the Corporation's major EMC and regulatory test facility and its participation in ANSI accredited standards committee and international EMC standardization. He chairs, or is a principal contributor to, US and international EMC standards organizations including ANSI ASC C63 (committee vice chairman and subcommittee chair) and the International Electrotechnical

Commission's (IEC) Special International Committee on Radio Interference (CISPR) where he is its subcommittee chairman responsible for CISPR Publication 16. Mr. Heirman is a Fellow of the IEEE and a member of its EMC Society Board of Directors (and its Vice President for Standards). He is past president of the National Cooperation for Laboratory Accreditation (NACLA). He is also president of the IEEE Standards Association (SA), member of the SA Board of Governors and member of the IEEE's Board of Directors and Executive Committee. He is a member of the IEC's Advisory Committee on EMC (ACEC) and the Technical Management Committee of the US National Committee of the IEC. Mr. Heirman is also an adjunct professor/senior research scientist at the University of Oklahoma and is the Associate Director for Wireless EMC at the University's Center for the Study of Wireless EMC. He has presented numerous workshops, tutorials, and technical papers internationally and is listed in several Who's Who publications. He is a retired Commander in the US Navy Reserves. His contact information may be found on page 3 of this Newsletter. **EMC**

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