# Commerce Spectrum Management Advisory Committee

# Measurement and Sensing in 5 GHz Subcommittee

## 1 August 2016

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## Section I – Executive Summary

A CSMAC subcommittee on 5 GHz Measurements was created and posed with the following set of questions:

> What are the strengths and weaknesses of measurement-based and sensor-based spectrum sharing methods, and how can the weaknesses be overcome? How can this spectrum sensing and spectrum monitoring data be analyzed to identify and address environmental trends pointing towards potential interference situations before harmful interference occurs? Specific bands of interest are U-NII-2B (5350-5470 MHz) and U-NII-4 (5850-5925 MHz).

The approach taken by the subcommittee was to investigate the various measurement systems architectures and techniques and the applicability of such systems to the various spectrum sharing roles. This approach was then specifically applied to the U-NII-2B and U-NII-4 bands, i.e. the spectral focus of the questions posed by the NTIA.

The subcommittee identified four specific roles for measurement-based and sensor-based techniques:

1) prior to sharing which is used to determine both the availability and viability of spectrum for sharing;
2) to enable sharing by providing situational awareness of spectrum occupancy by the primary (and possibly secondary) spectrum user;
3) post sharing to provide both information on potential sharing failures (interference events) and trends of usage of the primary and shared spectrum user; and
4) to provide the necessary data for enforcement of transmission rules.

Based on the substantial efforts already underway in other venues and the past work on the topic in CSMAC itself, the subcommittee decided not to address the enforcement role.

Measurement-based approaches are assumed to be those that include some infrastructure which provide measurements through some means of aggregation and communications to provide spectral situational awareness. Sensor-based approaches are assumed to be sensors integrated with an RF transmitter (primarily the device that is sharing the spectrum) that use little or no communications to obtain local spectral situational awareness. These techniques are to be contrasted with either static sharing approaches such as those that include exclusion zones and databases that are not updated as well as commanded sharing approaches such as those being implemented in the US 3.5 GHz band utilizing a spectrum access system (a.k.a. SAS).

The subcommittee concluded that there were varying strengths and weaknesses of measurement-based and sensor-based spectrum sharing methods. At a high level these strengths and weaknesses can be characterized as follows.

**Strengths**:
- Requires minimal legacy system operator participation,
- Indirectly measures propagation losses and thus enables the largest amount of potential spectrum sharing, and
- Some measurement architectures require no extra equipment and could be lower in cost (e.g. dynamic frequency selection-DFS).

**Weaknesses**

- Measurement system needs to be designed for specific band systems,
- Some measurement architectures require deployed monitors and related infrastructure, which is expensive,
- System potentially determines sensitive legacy system information (i.e. potential security issues), and
- Measurements made co-existing with entrant system have the potential to block detection of harmful interference problems

The subcommittee completed the analysis of the specific bands of interest as well as many of the measurement architectures that are available. The following six recommendations (ordered in priority) are provided to NTIA for possible implementation:

**Recommendation 1 – Measurement Techniques:** *It is recommended that NTIA use different measurement technologies in different bands in order to <u>determine the viability of spectrum sharing</u> for the U-NII-2B (5350-5470 MHz) and U-NII-4 (5850-5925 MHz) bands.*

- The lower band can employ high gain antennas over long periods of time with clear line of sight to airport and space assets in order to determine spectral use.
- The upper band will be more challenging due to the distributed transmission characteristics and will require either distributed spatial measurements or employing some form of signal augmentation techniques.

**Recommendation 2 – Trend Information and Databases:** *It is recommended that NTIA use different measurement technologies in order to <u>enable spectrum sharing</u> for the U-NII-2B (5350-5470 MHz) and U-NII-4 (5850-5925 MHz) bands.*

- The lower band, U-NII-2B can use database techniques for protecting the satellite system, dynamically updated database techniques or sparsely distributed fixed elevated sites for protection of airborne telemetry systems.
- The upper band, U-NII-4, due specifically to the use for DSRC should employ signal augmentation/beaconing or a geo-registered database for protection of potentially deployed systems. Due to the lack of interoperability analysis that has been done between the DSRC systems and possible sharing waveforms, it is difficult to determine the sensitivity of the measurement systems that are needed to insure protection of the DSRC systems.

**Recommendation 3 – Measurement Systems Requirements:** *It is recommended that NTIA create a report that defines the measurement system requirements and architectures needed to successfully measure signals for various applications (prior to sharing, during sharing, and trends analysis post sharing). The focus should be to develop technical criteria (sensor to emitter distances, spectrum scanning revisit rate, detector sensitivity, etc.) so that the measurements have a high detection probability*. This report should also define the required RF front-end characteristics needed for the spectrum bands and locations so that cost-effective equipment can be deployed with confidence that useful measurements can be obtained. This report should also describe potential measurement pitfalls and validation tests that should be applied so that imperfect data could be 'quality rated' by the investigators and still be used by third parties as appropriate. The goal is to insure that the lack of signal detection infers that the signal is not present (within the sensor to emitter distances) and not that the measurement approach is defective.

**Recommendation 4 – Measurement Architecture Spreadsheet:** *It is recommended that NTIA complete the investigation of the provided 5 GHz Band Survey and Categorization spreadsheet (see Appendix A) and the different measurement architectures (see Appendix B). The measurement architectures should include evaluation of their utility for various spectrum sharing functions (sharing potential, operationally employed during sharing, post sharing trending analysis and potentially enforcement) and federal services.* This investigation by NTIA should include the remaining 5 GHz bands and their services not specifically addressed by this subcommittee and other federal services utilizing spectrum under 7 GHz in the extension to the Band Survey and Categorization spreadsheet.

**Recommendation 5 – Detection Augmentation Techniques:** ***a)*** *It is recommended that NTIA further investigate techniques that can be employed for federal spectrum users to augment the detectability of their users and the impacts of spectrum sharing on their users.* ***b)*** *It is further recommended that NTIA reach out to work with the FCC to investigate techniques to augment the detectability and mitigation of transmissions from users and services that share federal spectrum.*

- Examples of such technologies would include beaconing or identification of the specific waveforms that are being used. (The report will elaborate on the details behind this recommendation including a larger treatment on the examples referenced and others.)
- These critical investigations must address both security and privacy issues.

**Recommendation 6 – Coordinated Sensing:** *It is recommended that the NTIA adopt the use of coordinated sensing periods in network spectrum sharing systems.* The NTIA should conduct simulation studies to determine the value of coordinated sensing periods within adjacent networks including assessment of this approach's impact on implementation complexity.

In terms of setting priorities for this subcommittee's six (6) recommendations, there are hidden implications the may increase the impact of a recommendation. Please refer to inset box below for the methodology applied for prioritization. Recommendations 2 and 6 request gathering more information. That additional information is essential to determine whether to implement or not implement a specific recommendation.

Underlying many of the subcommittee's recommendations is the need for an accurate "spectrum dashboard" for the 5GHz Band other bands. Without understanding what is in the band today at a detailed level and planned for tomorrow, as well as the technical characteristics of those systems, it is extremely difficult to assess or create sharing opportunities. The subcommittee understands that NTIA and FCC are already working on an enhanced "spectrum dashboard" and updates/extensions to the NTIA Federal Spectrum Compendium. A tool such as this should greatly assist in setting recommendation priorities in the long run and spectrum sharing in general.

Finally, NTIA should consider assessing all the recommendations from the current five (5) CSMAC subcommittees against the above or similar criteria for an overall assessment of relative priority of all the recommendations. Prioritization assistance might be a task that NTIA wishes to assign to the next CSMAC study period.

The remainder of this report is organized into four sections that provide both the background information and a more detailed description of the recommendations: services and technical characteristics of the systems for the specific 5 GHz bands of interest, recommendations for measurement systems for the specific 5 GHz bands of interest, overall strengths and weaknesses of measurement systems architectures, and policy challenges and enhancement possibilities.

**Prioritizing Recommendations**

Though not a specific Actionable Recommendation, associated with the question posed to the subcommittee is the awareness that, given NTIA's personnel and fiscal resource limitations, it is unlikely that all of the subcommittee's--much less the entire CSMAC's--recommendations could be implemented simultaneously. Undoubtedly, all the recommendations will need to be prioritized in some way and executed in a time sequence, or triaged to eliminate less worthy recommendations. When setting priorities, there are several classical criteria or approaches to consider:

1. Greatest Impact. In general, unless there are timing or logic considerations, recommendations that provide the greater impact should have a higher priority.
2. Logical Order. Some recommendations may need to be completed or at least underway before another can commence or be completed. More directly, pursuing recommendations in the wrong order could lessen the impact of the effort or even elicit the wrong outcome.
3. Implementation Cost. Given resource limitations, an otherwise high priority recommendation may have to be de-prioritized because it is unaffordable in terms of the available funding and/or staffing needs.
4. Temporal Circumstance. In some cases, the opportunity to accomplish a recommendation may be diminished or lost altogether if it is not undertaken at a particular time. Circumstances may dictate action at a particular moment or necessitate delayed action on a recommendation.
5. Implementation timeline. If a recommendation has dependencies and takes a long time to implement, its initiation may be prioritized over projects that otherwise would be of higher priority.
6. Ease of Implementation. A recommendation may warrant a higher priority if it is easy to implement, especially if it does not require substantial resources, does not take long, and has a reasonable pay back.

## Section 2: Services and Technical Characteristics of Systems Operating in the U-NII-2B and U-NII-4 Bands

The subcommittee began its work with a general analysis of the entire 5 GHz band to generate a baseline understanding of the various systems operating in the two bands of interest, as well as the overall 5 GHz band. In order to generate this analysis, research was conducted by the subcommittee members and documented in a spreadsheet provided in Appendix A. The spreadsheet was first used to catalog all the applications/services and to divide them into operational frequency bands by allocation, to discern whether a system was currently operational or planned for future use in the band. This resulted in 42 separate entries across the 5 GHz band. The list of current and future systems was then updated to include technical characteristics for each application. Specifically, research was conducted to determine the power, bandwidth, footprint, antenna height, how often the system transmits (transmit duty cycle) and whether the system can relocate (mobile or nomadic). The characteristics of each system were then used to determine an appropriate bound that in turn was used to separate the systems into generalized classifications. These classifications resulted in the following definitions:

i. Power
  a. Low Power – if EIRP below 100 watts
  b. High Power – if EIRP above 100 watts
ii. Bandwidth
  a. Narrow Band – if bandwidth less than 10 MHz
  b. Wide Band – if bandwidth more than 10 MHz
iii. Footprint
  a. Small Footprint – if less than 1 km radius
  b. Large Footprint – if greater than 1 km radius
iv. Antenna Height
  a. Ground Transmitter – if system on ground
  b. Elevated Transmitter – if system located on elevated tower or in the air
v. System Transmission Occurrence
  a. Continuous
  b. Intermittent
vi. System Relocation
  a. Fixed Transmitter
  b. Mobile Transmitter
  c. Nomadic Transmitter – System transmits while stationary, but can relocate

From this categorization, the subcommittee determined that the various transmitter characteristics would preclude use of a single measurement technology to detect the wide range of incumbent transmission applications. Rather, a variety of different measurement architectures will need to be deployed in order to correctly ascertain the presence or absence of spectrum use in a specific spectral environment.

After its first review with NTIA, the subcommittee was asked to focus more specifically on the U-NII-2B (5350-5470 MHz) and U-NII-4 (5850-5925 MHz) bands, as indicated in the questions posed to the subcommittee. These are respectively highlighted in yellow and orange in Appendix A. The systems currently operating in the U-NII-2B and U-NII-4 bands were comprised of systems with varying traits that reinforced the idea that a single measurement technique would be insufficient. The current U-NII-2B applications are primarily comprised of telemetry and data signals from various platforms, military radars and satellites conducting space-based measurements. The current U-NII-4 band systems include commercial satellite terminal uplinks, land mobile radios and Part 15 devices. Further, there are plans for implementing Dedicated Short Range Communications (DSRC), which is a wireless intelligent transportation system infrastructure, in the U-NII-4 band as well.

The subcommittee anticipates that the NTIA will continue to examine additional bands for potential sharing opportunities. The subcommittee considers it important to extend the methodology developed for the U-NII-2B and U-NII-4 bands to future bands of interest in order to fully characterize the incumbent systems as well as the measurement techniques available. While time and labor intensive, the analysis undertaken ensures a baseline for all systems. Knowledge of the incumbent systems can support creation of refined bins to group the incumbent systems, which can then be used to characterize sharing opportunities. The general system traits specified in the study of the 5 GHz band lays a foundation for future band analysis that can be adjusted to suit the specifics for that band. The complete categorization of the 5 GHz band is provided in Appendix A.

## Section 3: Measurement Techniques, Trend Information and Databases and Measurement Systems Requirements.

**Recommendation 1 – Measurement Techniques:** *It is recommended that NTIA use different measurement technologies in different bands in order to <u>determine the viability of spectrum sharing</u> for the U-NII-2B (5350-5470 MHz) and U-NII-4 (5850-5925 MHz) bands.*

- The lower band can employ high gain antennas over long periods of time with clear line of sight to airport and space assets in order to determine spectral use.
  The upper band will be more challenging due to the distributed transmission characteristics and will require either distributed spatial measurements or employing some form of signal augmentation technique.

**Recommendation 1 - Discussion:** As noted in Section 1, the Subcommittee focused on measurements supporting three time related application classes, namely 1) prior to sharing – used to determine both the availability and the viability of spectrum for shared use or re-allocation; 2) operation-focused measurements to enable sharing through the provision of situational awareness information; and 3) measurements to assess usage trends and forensics after sharing has been implemented. This section will consider each of these application classes and their associated recommendations.

Given the focus on the 5 GHz band, the subcommittee decided that it would be important to understand the current and proposed uses of the band in order to understand what measurement approaches would be most applicable. The spreadsheet developed in this process is captured in Appendix A of this document. In parallel, the subcommittee initiated the development of a second analysis to identify the various spectrum measurement architectures and to apply them to a range of spectrum usage parameters. Ultimately the 5 GHz applications identified in Appendix A were incorporated into this measurement architecture spreadsheet to provide focus for this effort.

Both tasks represented the investment of considerable time and effort and for the measurement architecture spreadsheet in particular. Therefore, the subcommittee ultimately determined that completing the analysis was beyond the scope of the tasking, and that it was highly unlikely to be completed during the remaining available time of this CSMAC term. This 5 GHz-focused measurement architecture spreadsheet is attached as Appendix B of the report.

Given the specific focus on the U-NII-2B and U-NII-4 bands, the subcommittee directed its efforts to complete the portions of the measurement architecture spreadsheet that related to these bands. This task was mostly completed. Emanating from this work, the first observation made by the subcommittee was the fact that "one size truly doesn't fit all" of the measurement applications. We specifically observed the fact that for the two bands of primary interest, i.e. the U-NII-2B and 4 bands, different approaches were needed to measure spectrum occupancy based on the nature of the services and systems that exist in these two bands.

**Recommendation 2 – Trend Information and Databases:** *It is recommended that NTIA use different measurement technologies in order to <u>enable spectrum sharing</u> for the U-NII-2B (5350-5470 MHz) and U-NII-4 (5850-5925 MHz) bands.*

- The lower band, U-NII-2B can use database techniques for protecting the satellite system, dynamically updated database techniques or sparsely distributed fixed elevated sites for protection of airborne telemetry systems.

- The upper band, U-NII-4, due specifically to use for DSRC, should employ signal augmentation/beginning or a geo-registered database for protection of potentially deployed systems. Due to the lack of interoperability analysis that has been done between the DSRC systems and possible sharing waveforms, it is difficult to determine the sensitivity of the measurement systems that are needed to insure protection of the DSRC systems.

**Recommendation 2 - Discussion:** There are two primary concerns for the operational measurements enabling sharing. First we are concerned with the failure to detect the incumbent or protected system which would result in interference to that system caused by a sharing entrant user of the spectrum. Second, we are concerned about false positives resulting in the inefficient use of the spectrum through the prevention of sharing when it could have been allowed without causing interference to the incumbent. As with Recommendation 1, the primary users of the U-NII-2B band are radars and satellite services (e.g. airborne collision avoidance radar and earth exploration satellite service (EESS)) which are both directional and moving. These characteristics tend to make the signals detectable by infrastructure-based systems due to the high altitude nature of the signal sources providing long-range line-of-sight (LOS) conditions to elevated platforms (e.g. towers). In similar fashion device-based measurement or sensor systems may have difficulty in detecting these incumbent applications due to local shadowing and due to the nature of the signal itself – e.g. short pulses for radar and low signal level for satellites. Appendix A and B provide considerable additional details on the nature of the signals and appropriate measurement approaches.

For the U-NII-4 band, the primary incumbents are the dedicated short range communications system (DSRC) allocated for future smart highway systems and commercial satellite communications. The

DSRC application is intended for short range vehicle to vehicle or vehicle to roadside communications. The commercial satellite use is for the high powered uplink from the earth station to the satellite, so terrestrial spectrum use should have minimal impact on this incumbent application.

**Recommendation 3 – Measurement Systems Requirements:** *It is recommended that NTIA create a report that defines the measurement system requirements and architectures needed to successfully measure signals for various applications (prior to sharing, during sharing, and trends analysis post sharing). The focus should be to develop technical criteria (sensor to emitter distances, spectrum scanning revisit rate, detector sensitivity, etc.) so that the measurements have a high detection probability*. This report should also define the required RF front-end characteristics needed for the spectrum bands and locations so that cost-effective equipment can be deployed with confidence that useful measurements can be obtained. This report should also describe potential measurement pitfalls and validation tests that should be applied so that imperfect data could be 'quality rated' by the investigators and still be used by third parties as appropriate. The goal is to insure that the lack of signal detection infers that the signal is not present (within the sensor to emitter distances) and not that the measurement approach is defective.

**Recommendation 3 – Discussion:** One of the significant measurement challenges for all three application areas is to determine whether or not the spectrum measurement has successfully captured the real spectrum usage in a specific location and time. There are endless debates about whether a specific spectrum measurement campaign or test has successfully and thoroughly demonstrated that a spectrum band is available for sharing, that sharing can be successfully allowed operationally without causing harmful interference, and generally whether measurements can be successfully utilized to observe the actual use of spectrum on a regular basis. Most of these disagreements are related to the implication of not detecting a specific signal. These disagreements could be minimized if the signal detection performance issues were quantified.

## Section 4: Strengths/Weaknesses of Measurement Architectures

**Recommendation 4 – Measurement Architecture Spreadsheet:** *It is recommended that NTIA complete the investigation of the 5 GHz Band Survey and Categorization spreadsheet and the different measurement architectures. The measurement architectures should include their utility for various spectrum sharing functions (sharing potential, operationally employed during sharing, post sharing trending analysis and potentially enforcement) and federal services.* This investigation by NTIA should include the remaining 5 GHz bands and their services not specifically addressed by this subcommittee and other federal services utilizing spectrum under 7 GHz in the extension to the Band Survey and Categorization spreadsheet.

**Recommendation 4 – Discussion:** As briefly described in Section 3, one of the major tasks undertaken by the subcommittee was to take a "deep dive" to better understand and subsequently to identify and characterize the various spectrum measurement architectures that are available for deployment. These architectures are composed of appropriate combinations of the following elements:

- Measurement Sites - Fixed, Nomadic or Mobile
- Site Location – Terrestrial, Aerostat
- Bandwidth – Narrow (< 10 MHz) vs. Wide (>/= 10 MHz)
- Measurement Site Density – Low (>250 km$^2$) vs. High (</= 250 km$^2$)
- Data Source – Infrastructure vs. Crowd Sourced.

Fourteen different architectures are separately identified in the Measurement Architecture Spreadsheet found in Appendix B of this report. As illustrative examples of the combinations of elements that are used in existing systems, the Illinois Tech Spectrum Observatory is a Fixed, Terrestrial, Narrow and Broadband, Low Density, Infrastructure based measurement system. DARPA's Radiomap Program is based on the concept of a mostly Mobile, mostly Terrestrial, mostly Narrowband (with the potential for some Wideband capabilities), with mostly a Low (but potentially a High) Site Density. The DARPA approach is effectively a Crowd Sourced measurement system, hence, substantial uncertainly exists in the other parameters).

These architectures are then mapped against the various transmission types that need to be measured. Like the architectures, the transmission types are composed of combinations of more elemental signal characteristics. These transmission types include:

- High Power (> 100 W EIRP) vs. Low Power (</= 100 W EIRP)
- Wideband (>/= 10 MHz) vs. Narrowband (< 10 MHz)
- Large Footprint (>2.5 km$^2$) vs. Small Footprint (</= 2.5 km$^2$)
- Elevated Transmitter (>15 m) vs. Near Ground Transmitter (</= 15 m)
- Continuous vs. Intermittent transmission
- Fixed vs. Nomadic vs. Mobile transmitter.

The number of parameters, and specifically their combination, generates a very large number of possible signal specific transmission characteristics. This is one reason that the measurement of these transmissions is so challenging. The number of measurement scenarios further explodes when adding to use of these measurements for the three categories of potential utilization of the measurements, i.e. pre-sharing viability determination, operational sharing support and post sharing assessments. If one then considers the 14 candidate measurement architectures, the total number of potential transmission characteristics vs. measurement architectures yields a spreadsheet with 56,442 entries. This underscores the point made in Section 3, that when it comes to spectrum measurement "one size definitely does not fit all" potential applications. More to the point, it is very important that the correct spectrum measurement architecture be applied to each measurement task. But, this is not a simple task.

Beyond the detailed technical spectrum measurement capabilities it is important to note that there are other critical factors that must be considered when selecting a spectrum measurement approach. For example, the timeliness of the provision of the information is often a critical factor in spectrum measurement, especially if the system is a component of an operational spectrum sharing system. In this environment it would clearly be unacceptable to wait for hours (or days) to determine that a particular band of spectrum or a channel within the band is available for sharing. On the other end of the continuum, it may take a full year or even multiple years to accumulate the data needed to produce an informed assessment on the potential (pre-sharing) or real (post-sharing) impact that spectrum sharing might have or indeed is having on an incumbent system.

Another non-technical factor is cost, which is always a critical parameter to be considered when deploying a spectrum measurement system. Happily, the cost of deploying relatively powerful spectrum measurement systems has been coming down dramatically over the past decade, especially the past few years. This allows deployment scenarios to be considered that might have been prohibitively expensive in prior years. Beyond deployment, operation and maintenance costs must also be carefully considered when making a spectrum measurement system decision.

An important emerging trend that benefits cost sensitivity is the ability to use existing devices to contribute to the spectrum sensing process. This occurs when an existing device, e.g. a smart phone, police radio, military radio or even a jammer, is provided with a software update that enables the device to sense its environment when it is not performing its normal function (i.e. most of the time for many devices). This allows the device to contribute to the over-all understanding of the spectrum usage in a geographic environment. This technical approach is maturing, including maturation of the system software needed to accumulate the data from these devices, to analyze it, to provide appropriate visualizations of the data, and to take spectrum management actions based on the analysis of the information. This is allowing device-oriented sensor systems and more generally crowd-sourcing of various kinds to be more widely considered as a meaningful and cost effective approach to the spectrum analysis, operational management and post deployment assessments. These device-oriented sensor systems can be used either in combination with infrastructure based measurement systems, or ultimately as a complete standalone system.

Each architecture has significant strengths and significant weaknesses depending on the wireless signal to be measured. Referring to the spreadsheet in Appendix B it can be readily noted through the red, yellow and green characterization that some architectures are technically much better suited (i.e. stronger) for a specific transmission type than others. The inherent limitations (weaknesses) and strengths of the architectures graphically illustrated in the Appendix must be taken into account when attempting to perform any spectrum measurement effort. Too often in the past, a generic measurement solution has been deployed making great claims about the results of the effort only to be later criticized by others because these strengths and weaknesses weren't properly accounted for by the technical team doing the measurements. It is hoped that the 5 GHz spectrum characterization and the spectrum measurement architecture spreadsheets in Appendix A and B will provide a template for helpful tools in the selection of the correct architecture for future measurement efforts. Ideally these tools will be most helpful to the NTIA in helping to eliminate some of the contention associated with various measurement campaigns. To that point, the subcommittee feels that the draft spreadsheets (Appendix A and B) should be completed, expanded and distributed for wide spread use per this Actionable Recommendation.

## Section 5: Policy Challenges and Enhancement Possibilities

**Recommendation 5 – Detection Augmentation Techniques:** ***a)*** *It is recommended that NTIA further investigate techniques that can be employed for federal spectrum users to augment the detectability of their users and the impacts of spectrum sharing on their users.* **b)** *It is further recommended that NTIA reach out to work with the FCC to investigate techniques to augment the detectability and mitigation of transmissions from users and services that share federal spectrum.*

- Examples of such technologies would include beaconing or identification of the specific waveforms that are being used.
- These critical investigations must address both security and privacy issues.

**Recommendation 5 – Discussion:** The group looked at areas where policy might compensate for measurement weaknesses or shortcomings. Measurements made prior to sharing (such as surveys or even long term monitoring) were discussed by the group, but the group mainly focused on measurements made to enable sharing (real time detection), and measurements made after sharing has been enabled (such as to assess usage trends and to enable forensics).

Though of extreme importance, enforcement issues were not a focus of discussion (being addressed last cycle). However they are recognized to have an impact. For instance, the ability to quickly turn off interfering devices might allow incumbents to tolerate certain weaknesses in detection.

With regard to real-time detection the key weaknesses are measurements that fail to detect the protected system and result in interference; and measurements that produce false positives that prevent sharing when it could be accomplished without causing interference. Measurement problems due to partial or incomplete information about the protected system could be mitigated in part by federal users if they identified the specific waveforms they will be using.

The obvious challenge here is that the incumbent systems are often meant to be covert and the waveforms are therefore generally classified. An alternative that the group returned to multiple times was the option of some sort of beaconing as a key way appropriate federal systems could increase their detectability by new entrant sensors (or even existing systems), without disclosing technical system details. In the instance that the incumbent is a federal user, these beacons could be quite helpful for sharing spectrum with other federal users. Another area where beacons could help is with one way systems, such as receive only sensors, which are currently extremely problematic from a spectrum sensing / interference avoidance perspective. By adding a return beacon of some form detection would be made far easier.

With regard to post sharing measurements, the group focused on techniques to improve the speed and ease of identifying new entrant interferers. One potential policy solution would be a requirement mandating that system/equipment/device vendors identify in advance the waveforms that they will be using. This would speed the classification / identification of interfering sources when they occur (emission designators). Another solution, that would require not just detection but demodulation, would be transmission of "call letters" or other unique identifiers by potential interferers. This could also greatly speed the identification of interferers when they do cause harmful interference.

A key consideration of increased identification is the area of security / privacy issues. As noted above security is of critical importance for many federal government systems. Insuring that the systems are able to perform their mission critical functions in the presence of various potentially harmful interference sources is of great concern. The need to protect these systems will often encumber the approaches to measurement. Indeed, that need can inhibit the goal of sharing itself. In line with this comment, discussions noted that the area of user trades offs of privacy for utility have become more common place and analysis of these tradeoffs more mature. As an example, mobile apps routinely solicit (and receive) user location and other information in order to tailor responses. The NTIA should explore the potential, where appropriate, for user supplied (opt-in) information to be provided that might mitigate sharing concerns.

**Recommendation 6 – Coordinated Sensing:** *It is recommended that the NTIA adopt the use of coordinated sensing periods in network spectrum sharing systems.* The NTIA should conduct simulation studies to determine the value of coordinated sensing periods within adjacent networks including assessment of this approach's impact on relative to the resulting implementation complexity.

**Recommendation 6 – Discussion:** In addition, the group discussed an issue that arises when multiple devices or networks have been found to mask the detection of incumbent systems, due to algorithms in the devices intended to prevent false positives. One way to solve the problem might be procedures that would coordinate the devices in order to create “quiet periods” for measurements.

Finally, the group also discussed, as a general principle, the policy of staged deployments or authorizations in order to limit exposure and gain experience and data. Through this process emerging issues could be identified before they become severe, allowing remedial actions to be taken without undue expense and hardship.