Introduction to Interference Resolution, Enforcement and Radio Noise

A White Paper

Spectrum / Receiver Performance Working Group*

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Abstract

This White Paper is based upon deliberations of the Spectrum / Receiver Working Group ("S/RWG") of the Federal Communications Commission's Technological Advisory Council ("TAC") that occurred in the 2013 and early 2014 timeframe. It provides insights into and associated recommendations concerning Interference Resolution, Enforcement and Radio Noise issues, one of five study areas addressed by the S/RWG during that period. The broad goal of the deliberations in the Interference Resolution, Enforcement and Radio Noise area was to assist the Commission in developing technical strategies for responding more efficiently and effectively to the fundamental technological, operational and economic/market trends that are challenging its ability to detect, identify, locate, mitigate, report and, when necessary, prosecute those responsible for causing harmful radio interference.

Introduction to Interference Resolution, Enforcement and Radio Noise

I. Background

The purpose of this White Paper is to provide insights into Interference Resolution, Enforcement and Radio Noise issues based upon recent deliberations of the Spectrum / Receiver Working Group ("S/RWG") of the Federal Communications Commission's Technological Advisory Council ("TAC"). The TAC is a formal advisory committee established under the Federal Advisory Committee Act. For 2013, the S/RWG was assigned the mission of (a) providing support as the Commission considers prior TAC recommendations related to the proposed Interference Limits and Harm Claim Threshold policy and (b) making recommendations to the Commission in areas focused on improving access to and making efficient use of the radio spectrum from a systems perspective.

To accomplish its mission, the work of the S/RWG was divided into five study areas with requirements for associated deliverables. One of the five study areas was entitled Interference Resolution and Enforcement. The broad goal of the activities in the Interference Resolution and Enforcement study area was to assist the Commission in developing technical strategies for responding more efficiently and effectively to the fundamental technological, operational and economic/market trends that are challenging its ability to detect, identify, locate, mitigate, report and, when necessary, prosecute those responsible for causing harmful radio interference. The need for developing such strategies was motivated by the recognition that (a) rapidly evolving wireless system architectures, systems and devices, (b) rapid growth in the number of wireless devices and (c) operation of both intentional and unintentional radiators in close proximity has fundamentally changed the nature of interference risks. At the same time, these trends provide technological opportunities to develop more efficient and effective strategies for interference resolution and enforcement. The deliverables for the S/RWG in this area included recommendations regarding interference resolution, enforcement programs and procedures, and methods for interference measurement and mitigation.

The original focus of the S/RWG in this area was primarily on interference resolution and enforcement in spectrum under the sole jurisdiction of the FCC, rather than in spectrum that is shared between non-federal (managed by the FCC) and federal (managed by the National Telecommunications and Information Administration ("NTIA") in the U.S. Department of Commerce) users. At the July 24, 2013 meeting of NTIA's Commerce Spectrum Management Advisory Committee ("CSMAC"), a member of that committee, who also serves on the TAC, raised the issue of enforcement and it was agreed that the topic should be pursued by the CSMAC. Subsequently, the CSMAC approved a broad description for the proposed work. The description anticipated that, in carrying out the approved work, the CSMAC would coordinate with the interference resolution and enforcement activities taking place in the TAC.

In describing the motivation for the new work, the CSMAC highlighted two significant considerations. First, it was agreed that the value of shared federal spectrum to commercial entities depends on their confidence that spectrum managers have applicable rules and resources in place to adequately control the number of interference incidents and will resolve incidents quickly and effectively. Second, and similarly, the willingness of federal agencies to share spectrum on a more extensive and dynamic basis depends upon their confidence that the applicable rules, regulations and contract terms dealing with interference will be effective and enforced in an appropriate time frame. The CSMAC's action adds to the scope and importance of the TAC's work in the area of interference resolution and enforcement.

The work of the S/RWG in 2013 was carried out through weekly teleconferences among the members of the group and FCC Liaisons, regular exchanges of documents in electronic form reflecting those discussions and the on-going analyses, and in-person, quarterly gatherings immediately before each official TAC meeting. This White Paper summarizes the work accomplished by the S/RWG in the Interference Resolution and Enforcement study area. It is divided into five sections: Section II describes the working group's efforts to develop a taxonomy of interference types and Section III describes traditional interference resolution and enforcement tools and processes utilized by the FCC. Section IV describes the challenges faced by the Commission in an increasingly complex radio spectrum environment. Section V describes potential opportunities and strategies for addressing these challenges through the development of policy approaches involving innovative technical tools, processes, and institutional arrangements. Finally, Section VI provides recommendations for immediate actions by the Commission and Section VII sets forth recommendations for the work of the TAC in 2014.

II. Interference Taxonomy

The S/RWG initiated its work on Interference Resolution and Enforcement issues by considering definitions of relevant terms with the goal of creating a taxonomy of interference types. The S/RWG began deliberations on the topic by noting that interference can be categorized into in-band or out-of-band interference; the former can be further divided into co-channel and adjacent channel interference. As an example, a band might be devoted to television broadcasting with further division into channels. Co-channel interference at a receiver results from signal propagation from distant (in the space dimension) transmitting stations operating on the same channel. Adjacent channel interference results from (a) spillover from transmitting stations operating in adjacent (in the frequency dimension) channels within the band, (b) inability of receivers to completely reject transmissions on adjacent channels within the band or (c) combinations of the two. Out-of-band interference relates to the ability of a receiver to reject interference from signals in adjacent bands (not just on adjacent channels) and manifests itself in such detrimental effects as receiver blocking and intermodulation distortion.[1]

[1] Receiver blocking is degradation of receiver sensitivity in the presence of a much stronger, nearby (in the frequency dimension) signal. Sensitivity is a critical receiver design parameter as it relates to the weakest desired signal that a receiver is able to detect. Therefore, higher sensitivity increases the ability to provide wireless coverage over a longer range. Receiver intermodulation distortion is interference that is produced

As a threshold matter, the working group recognized that interference is understood differently by the technical community then it is by the policy/regulatory community. To a communications engineer, for example, the term interference primarily relates to extraneous or unwanted energy that originates from a source external to the signal path and quantitatively degrades the reception of the desired signal.[2] Examples of this include the co-channel and adjacent channel interference described above. In contrast, the policy/regulatory community focuses on the qualitative effect of the unwanted energy. This focus is apparent in the definition of interference that is contained in the Commission's rules:

> 47 CFR § 2.1(c): *Interference*. The effect of unwanted energy due to one or a combination of emissions, radiations, or inductions upon reception in a radiocommunication system, manifested by any performance degradation, misinterpretation, or loss of information which could be extracted in the absence of such unwanted energy. [Emphasis added.]

The current regulatory framework distinguishes between interference and harmful interference. In the Commission's rules, harmful interference is defined as follows:

> 47 CFR § 2.1(c): *Harmful Interference.* Interference which endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service operating in accordance with [the ITU] Radio Regulations.

It is well understood that determining whether interference is harmful or not is technically complex and highly subjective.[3] The complexity and highly subjective nature of this determination and the regulatory uncertainty that it creates provided the major motivation for the S/RWG (and the TAC) to support an interference limit policy known

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when strong, nearby (in the frequency dimension) signals combine to produce additional interfering signals within the channel containing the desired signal. Such mixing is caused by non-linearities in the receiving device. Both blocking and intermodulation interference are associated with the dynamic range of a receiver.

[2] Federal Standard 1037C, *interference*, (1996) ("1. In general, extraneous energy, from natural or man-made sources, that impedes the reception of desired signals").

[3] As an example of the difficulties in determining whether or not interference is harmful, consider a situation wherein a system engineer has designed a wireless link using a transmitter with slightly higher power than initially needed. She might do this for very rational technical reasons such as to allow for inevitable uncertainties in the results obtained when using computer-aided design tools or to allow for the deterioration of devices used in the system over time. Because of the built-in margin, interference with her link might not cause any immediate degradation in link performance (such as bit-error-rate). Therefore, this interference may not be considered harmful. On the other hand, the loss in margin could seriously endanger the future performance of the link and jeopardize the operation of a critical radio service. Therefore, the interference could be considered harmful. Another example of the difficulty in determining whether interference is harmful is when interference occurs despite both parties operating in accordance with the rules governing their respective services. Poorly designed or inexpensive receivers can further complicate the analysis by being overly sensitive to out-of-band interference. The baseline level of interference should also be considered when evaluating claims of harmful interference. For example, is going from an outage rate of 3 minutes per year to 4 minutes per year on a radio link sufficient to label interference "harmful"?

as Harm Claim Thresholds.[4] Despite these efforts to develop a more objective (and easily enforceable) interference limit, two fundamental categories that remain within the taxonomy are harmful and non-harmful interference. The distinction is important because the former is associated with formal enforcement actions.

In addition to the distinction between harmful and non-harmful interference, another useful classification of interference is whether or not the interference is produced by intentional or unintentional radiators of electromagnetic (RF) energy. Loosely speaking, unintentional radiators are devices that intentionally generate RF energy for use *within* the device but allow some of that energy to be radiated or "leaked" outside the device.[5] An example of unintentional radiation is the RF energy emitted by a digital timing component (clock) within a laptop or tablet computer. Intentional radiators are devices that are designed to generate and emit RF energy. An example of an intentional radiator is unlicensed wireless baby monitors operating under Part 15 of the Commission's rules.

Another basic distinction associated with interference relates to RF noise. A general definition of RF noise is any undesired disturbances on a channel or path between a transmitter and receiver; it is regarded as a subset or type of interference. For the purposes of this White Paper, a more restricted definition may be useful for reasons that will become clear below: RF noise is interference that does not come from an identifiable intentional radiator.[6] With this definition, three categories of RF noise emerge:

1. Natural noise such as that produced by lightning (atmospheric noise or "static") or by celestial objects (cosmic noise).

2. Man-made noise produced by unintentional or incidental radiation (as defined above) from such things as switching power supplies, certain types of light fixtures, and computer clocks.

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[4] *See* FCC Technological Advisory Council, *Interference Limits Policy The use of harm claim thresholds to improve the interference tolerance of wireless systems* (Feb. 2013), *available at* http://transition.fcc.gov/bureaus/oet/tac/tacdocs/WhitePaperTACInterferenceLimitsv1.0.pdf (last visited May 25, 2014). *Also see* de Vries, J. P., *Optimizing receiver performance using harm claim thresholds*, Telecommunications Policy (2013), *available at* http://dx.doi.org/10.1016/j.telpol.2013.04.008 (last visited May 25, 2014).

[5] In addition to interference that is produced by an intentional or unintentional radiator, interference can also be produced by undesired signals that are conducted from one device to another over, for example, wiring that is used for other purposes -- e.g., to deliver electric power. Conducted interference (as opposed to radiated) interference is not addressed in this White Paper..

[6] These definitions and distinctions are consistent with those adopted at a recent Silicon Flatiron's Conference entitled "Radio Spectrum Pollution: Facing the Challenge of a Threatened Resource." *See* Silicon Flatirons, John Cook, et al., *Radio Spectrum Pollution: Facing the Challenge of a Threatened Resource* (Jan. 2014) *available at* http://www.silicon-flatirons.org/documents/conferences/2013-11-14%20Spectrum/2013SpectrumConferenceReport.pdf (last visited May 25, 2014).

3. Aggregate man-made noise from a host of individual intentional radiators such as out-of-band emissions, harmonics and other spurious signals emitted by many licensed and unlicensed devices.

The RF noise floor is an important topic that warrants further explanation. The three categories of RF noise listed above all originate from outside the receiver itself. In addition to these three categories of external noise, receivers also generate internal RF noise of their own ("instrumentation" or "thermal" noise). This is a fourth source of RF noise. This internal noise may be inconsequential (depending upon a host of factors) but it can never be completely eliminated.[7] In communications, the noise floor is the measure of the signal created from the sum of these four noise sources plus the interference coming from identifiable intentional radiators. It includes all signals other than the desired one. The noise floor is a critical parameter in communication system design because the capacity (as measured in bits-per-second) of a channel or path depends upon (a) the bandwidth of the channel and (b) the strength of the desired signal relative to the strength of these sources of noise and interference.

Aggregated, unidentifiable interference from multiple sources tends to be noise-like in character and difficult to distinguish from natural sources of RF noise and from the noise produced internally in the receiver. This can cause a net increase in the noise floor and adverse consequences for wireless system performance and, more broadly, for efficient and effective use of the spectrum resource.

Devices falling into the intentional radiator category include unauthorized devices, authorized devices not meeting their associated requirements (e.g., in terms of their spurious emissions), and authorized devices meeting those requirements. Still another distinction is between unintentional interference of the types described above and intentional interference (including jamming and spoofing). The last category can be further divided into intentional interference that is malicious and intentional interference without malicious intent. An example of the latter could be an employer who jams cellular signals to prevent employees from making distracting wireless calls while engaging in hazardous activities.

The interference categories described above are neither sufficient nor analyzed deeply enough to create a complete classification scheme or taxonomy for different types of interference. By design, the categories are intended to be mutually exclusive and the complete taxonomy would provide a systematic way of classifying interference situations both before and after the fact. Before the fact, classification descriptions could be used in the analysis of different interference scenarios and to facilitate the development of specific recommendations regarding interference resolution, enforcement programs and procedures, and methods and tools for interference measurement. This might include the analysis and development of recommendations for institutional relationships and processes for detecting, identifying, locating, mitigating and reporting interference

[7] For example, internal noise may be inconsequential in lower frequency bands where it is typically greatly overshadowed by external natural noise. At very high frequencies, on the other hand, it may be the predominant source of noise.

sources. After the fact, the same comprehensive set of interference categories could be used as the basis for classifying and reporting on interference incidents for the purpose of identifying trends. In turn, these can be used to revise interference resolution and enforcement strategies (e.g., by adjusting priorities, procuring new equipment, designing new processes, establishing new or revised rules, or seeking new legislation).

III. Traditional Enforcement Tools

As part of its early work, the S/RWG developed a list with brief descriptions of the tools used by the Commission in addressing interference resolution and enforcement issues. While Commission's effort in this area is often associated with the investigative work of the Enforcement Bureau through its network of field offices, there are a host of other tools that have played or are currently playing an important role in interference resolution and enforcement. The role of some tools – such as radio operator licensing – has diminished over time because of technological advances. This White Paper will now identify and briefly describe these tools.

Call Signs and Related Identifiers

Call signs or call letters have been used since the early days of wireless communications to uniquely identify transmitting stations. In a service like marine radio, call signs were used by one station to initially establish communications with a specific other station – i.e., to "call" that station. Although call letters are used for many purposes in wireless communications, they are also a fundamental tool in interference resolution and enforcement activities. As indicated earlier, such activities typically include detection, identification, location, mitigation and reporting of interference sources. Call letters or related identifiers often play a key role in identifying and locating a source of interference. By listening to and deciphering the call letters of an interfering fixed (not mobile) transmitter, the station can be identified and, if the geographic coordinates associated with that station are known, located. Note that call signs (or their equivalents) can be assigned by a regulatory authority, an interested industry group or informally by station owners/users themselves. In some situations, voluntary naming and addressing plays a critical role in interference resolution and enforcement by the Commission, even though such regulatory uses were not the primary motivation for their adoption. Examples of this is the SSID codes and MAC addresses found in Wi-Fi networks and Cell ID for cellular networks.[8]

The use of call letters and equivalents varies widely among services and, as discussed in more detail below, their utility for enforcement activities has been impacted by the widespread movement to digital rather than analog transmitters and from aural to data

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[8] SSID (service set identifier) is the signal identifier most commonly associated with IEEE 802.11 (Wi-Fi) networks. The SSID simultaneously serves as the 'name' of a network that is seen by connecting devices and a password that must be sent by a device in order to connect to the network. MAC (media access control) addresses also serve as unique network identifiers, but for the physical network layer (such as a modem). Cell ID is a unique alphanumeric identifier used to identify each base station in a cellular network.

communications formats. In studying the role and use of call letters, the S/RWG noted that a more systematic, in-depth study of call letters and their equivalents might be useful in view of these changes.

Construction Permits/Station Licenses

Depending upon the service, a construction permit from the Commission may be required before the requesting party can build a new transmitting facility. Over the years, construction permits have been used for various purposes to protect or extend the public interest. By requiring the applicant to demonstrate in advance that the new facility will not cause "objectionable" interference to other stations, later interference can be avoided. A closely related obligation in some services is a requirement for the applicant to "coordinate" their application with the owners/operators of other stations. This can reduce or mitigate the possibility of interference once the facility is constructed and a license to operate it issued. The requirements for construction permits and prior frequency coordination are examples of *ex ante* regulations which, among other things, are designed to reduce the need for *ex post* interference resolution and enforcement efforts by the Commission.[9] After the station is constructed, the party may file an application for a station license.

If neither a construction permit nor evidence of frequency coordination is required, the party may simply file an application for a station license and, if granted, the Commission may assign unique call letters to the station as discussed in the sub-section immediately above. The station license authorizes the new licensee to operate the station for a defined period of time after which they must seek a renewal from the agency. The issuance of a license is important from at least two perspectives in terms of interference resolution and enforcement. First, the Commission typically has more information on the licensee and can perform the normal interference resolution and enforcement steps listed above. Second, the threat of license revocation or other sanctions tied to the license (e.g., at renewal) often acts as a strong incentive to obey the Commission's rules and to cooperate fully with the agency in investigating and resolving interference complaints.[10]

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[9] *Ex ante* ("before the event") regulations can reduce market uncertainty by laying out clear ground rules for spectrum use parameters. They can also entail fewer costs than *ex post* ("after the fact") enforcement by reducing the need for policing. However, *ex ante* regulations may stifle investment by casting too wide of a restrictive net. *Ex post* enforcement is more flexible; this flexibility may be better suited to highly complex regulatory areas where an extensive *ex ante* framework may have unintended consequences.

[10] An important distinction in licensing is the difference between the grant of a traditional license and "license by rule." "License by rule" is an authorization paradigm in which an operator of a radio is deemed to have been granted a license to operate in a given band even though no license has been applied for or issued by the FCC. Congress amended the Communications Act in 1982 to permit these grants of authority. *See* Pub. L. 97-259, Section 113(a), enacted September 13, 1982.*See also* 47 U.S.C. § 307(e) ("the Commission may by rule authorize the operation of radio stations without individual licenses"). The radio owner is presumed licensed upon purchase of authorized equipment. Licensing by rule reduces regulatory uncertainty and costs to the FCC and the authorized user. In addition to no license being issued, "license by rule" authorizations do not assign call sign identifiers. However, licensing by rule may change the incentives structure described. Although the band previously required a license and call sign, Citizen Band radios are now "license by rule," as is the Family Radio Service.

In studying the role and use of construction permits, frequency coordination and station licenses, the S/RWG took note of the differences, interrelationships and advantages and disadvantages associated with *ex ante* and *ex post* techniques in interference control and regulation. More specifically, the S/RWG observed that the optimum balance between *ex ante* and *ex post* depends strongly on the characteristics of the service involved and is apt to change, perhaps dramatically, with technical and market changes.

<u>Operator Licenses</u>

Traditionally the FCC has had rules that required those who operate, install, maintain and repair transmitter stations to be licensed.[11] Historically, the need for operator licenses was justified because (a) transmitting equipment (e.g., using vacuum tubes) could, for example, drift out of adjustment or fail in such a way that it caused interference or loss of service and (b) operating procedures (e.g., for gaining accessing to channels, exchanging traffic or calling for help) were manually controlled and required training and expertise in order to facilitate efficient use of channels and avoid unnecessary interference. Over the years, wireless technology has improved significantly and the resultant increase in stability and reliability has greatly diminished the threat of interference caused by malfunctioning equipment. Moreover, in most -- but not all -- services, procedures for accessing channels are controlled by computer logic and minimal or no expertise on the part of the operator or end user is required to ensure efficient operation and control interference. Consequently, operator licensing has been largely phased out except in services where operator actions could cause harmful interference or otherwise disrupt communications.[12]

In reviewing the role of operator licenses, the S/RWG noted that they are a form of *ex ante* regulation and that their diminished role in most services is understandable in light of technology advances over the last several decades. The S/RWG became aware of recent allegations of improper (and interference causing) installations of certain unlicensed wireless systems and that a return to a minimal form of industry-led technician licensing in certain services or bands might be worth exploring.

<u>Equipment Authorization and Labeling</u>

Another important *ex ante* tool used by the Commission in addressing interference resolution and enforcement issues is its equipment authorization program. Basically, the equipment authorization program seeks to control the amount of RF energy produced by certain types of electronic devices and minimize the risk of interference to spectrum

[11] Note that the requirement is actually on the licensee to hire only licensed operators.

[12] The Commercial Radio Operator License Program is one such example, wherein operators are licensed for various devices and grades of service. "FCC rules require that licensees of ship, aircraft, and international fixed public radiocommunication stations permit only persons holding the appropriate FCC-issued commercial operator license to perform specified transmitter operation, maintenance, and repair duties." FCC, *Commercial Radio Operator License Program* http://wireless.fcc.gov/commoperators/index.htm (last visited May 25, 2014).

users.[13] As described in the Code of Federal Regulations Title 47 Part 2, the Commission's rules distinguish between unintentional radiators and intentional radiators. The Commission carries out the program in two basic steps: First, it establishes (or revises existing) technical regulations governing such emissions using its normal "Notice and Comment" rulemaking process. Second, it establishes associated regulations, including those governing the testing of the devices,[14] to ensure that they comply with the rules when they reach the marketplace.

The Commission currently utilizes three levels of authorization; the level that is applied depends upon the devices' potential to cause interference. Devices covered by the regulations cannot be imported and/or marketed until they have completed the authorization process and shown compliance with the technical requirements. The standards are published in the section of the Commission's rules that govern the service under which the devices will be operated. Devices licensed under the highest level of approval are given a unique identifier (FCC ID number) consisting of a grantee code that identifies the applicant and a product code that is assigned by the applicant. These FCC IDs are attached to devices to indicate that they have been authorized by the agency. Information on all approved devices is publically available on the Commission's website.

In reviewing the Equipment Authorization program, the S/RWG observed that it plays a notable role in interference control and regulation in both *ex ante* and *ex post* terms. In *ex ante* terms (a) it discourages the importation and/or marketing of devices that are apt to cause interference when deployed and (b) the device identification and labeling requirement facilitates enforcement efforts assuring compliance with rules designed to control such interference. In *ex post* terms, the program helps identify the manufacturer or importer of a device that is alleged to be causing interference. While the S/RWG was convinced of the importance of the Equipment Authorization program to interference resolution, enforcement and noise abatement, it was also very much aware of the challenges of evaluating the overall costs and benefits of the program and its individual elements – e.g., between intentional and unintentional radiators. The costs include those

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[13] Note that interference occurs within the receiver system itself. In other words, RF transmissions do not physically interfere with one another as they propagate from one place to another. Interference is dependent upon a receiver system's ability to isolate the desired transmission while disregarding unwanted energy. Receiver susceptibility to interference therefore depends upon the quality and design of a receiver. There is a trade-off between higher quality receivers that can reject a large amount of unwanted energy and lower cost equipment.

[14] In 1998, the FCC adopted rules providing for the establishment of Telecommunications Certification Bodies (TCB). TCBs are accredited, private, third-party certification bodies which are authorized to issue grants for equipment using RF spectrum and subject to the FCC's certification procedures. As noted, devices subject to the procedures cannot be imported and/or marketed until they have completed the authorization process and demonstrated compliance with the associated technical requirements or standards.

incurred by the Commission in administering the program and any added equipment or device costs incurred by industry in complying with the agency's rules and regulations.

Logging/Record Keeping Requirements

Traditionally the FCC has had rules that required licensees of transmitting stations to prepare and maintain detailed records or logs of their operational and maintenance activities and to make them available to FCC personnel upon request. Station logs played a role in *ex ante* regulation, such as by requiring certain routine measurements using specified techniques. They were also especially useful in *ex post* interference resolution and enforcement. For example, station logs enabled a Commission field agent to correlate an interference complaint with a recorded change in transmitting equipment or an antenna at the station. As in the case of operator licensing discussed above, technology improvements have greatly diminished the need for and value of routine technical measurements.[15] In some services, requirements for maintaining station logs have been eliminated or significantly reduced. For example, in broadcasting, the remaining requirements primarily focus on the national Emergency Alert System (EAS) and antenna tower lighting obligations.

In reviewing the role of station logging in interference resolution and enforcement, the S/RWG observed that, while the need for certain types of measurements and logging had diminished, the cost of making, recording, processing and storing interference-related measurements has declined significantly in recent years. The working group observed that the increase in capabilities and decline in cost of spectrum monitoring could be leveraged to (a) improve the effectiveness and efficiency of routine enforcement activities designed to ensure compliance with the Commission rules, (b) facilitate voluntary resolution of interference complaints, (c) gather evidence for formal enforcement actions and (d) archive information to study the changing interference environment. The S/RWG concluded that, under these conditions, there might be significant benefits to having a public-private partnership that would facilitate the voluntary sharing of interference incidents on an open, transparent and systematic fashion.

Miscellaneous Other Enforcement Tools

A basic tool in spectrum management is a data base containing information on transmitting stations such as the name of the licensee, call sign, assigned frequencies, geographic coordinates, tower/antenna height, and transmitter power.[16] At the Commission, this information is gathered and made available publically through its

[15] For example, decades ago, the RF emissions of transmitters tended to drift in frequency with changes in time and/or temperature. Therefore, they needed to be monitored and, if necessary, retuned on a regular basis in order to avoid causing interference to other users. Today, transmitters tend to be much more stable thus eliminating the need for routine checking and retuning. Devices such as mobile telephones almost never need to retuned and even lack externally accessible controls for doing so.

[16] Not all of this information is collected for every service. For example, as stated in footnote 10, no call signs are issued in services that are licensed by rule. Also, market-based cellular licenses do not require all tower/antenna location information to be registered in the ULS.

Universal Licensing System (ULS). Time constraints did not allow the S/RWG to study the ULS in detail. However, they noted that it serves as a powerful information tool allowing research on "applications, licenses and antenna structures." The information contained in the ULS and its associated tools are essential, not only in *ex ante* analyses designed to avoid or minimize interference before stations/systems are placed in service, but also in *ex post* activities involving interference resolution and enforcement. As a result of its brief review, the S/RWG noted that private sector groups (e.g., frequency coordinators) and other government agencies, such as the FAA, may collect information beyond that collected by the FCC. Such additional information can be useful to these outside groups in filing applications, in resolving interference events on a voluntary basis or in filing formal complaints. A related Antenna Structure Registration program requires tower owners to register certain antenna structures with the FCC. While the primary focus of the ASR program is on hazards to air navigation, environmental protection and historic preservation, the information gathered is frequently useful in *ex post* interference resolution and enforcement activities. For example, in many services, the station licensee using a tower for transmissions may be a different entity than the owner of the tower itself. Being able to quickly identify and then locate the tower owner (e.g., to gain access to antenna site) may be important to resolving interference issues.

Educational Efforts/Outreach/Advisories/Call Center Activities

In conducting its review of traditional interference resolution and enforcement tools, the S/RWG gained increased awareness of the myriad of educational and other efforts the agency engages in to inform the public on how to avoid causing RF interference in violation of the Commission's rules, how to mitigate such interference in devices or systems on a self-help basis when it does occur, and when and how to file a formal complaint. Once again, time constraints did not allow the S/RWG to identify all such activities or evaluate their usefulness in reducing instances of objectionable or harmful interference.

Monitoring and Inspections[17]

Prior to the passage of the Telecommunications Act of 1996, the responsibility for enforcement was spread among the Commission's various bureaus and offices. With the passage of the '96 Act, all such activities were centralized in the Enforcement Bureau (EB). Although EB is responsible for much of the agency's work in spectrum-related enforcement activities, it carries out a substantial range of other efforts such as investigations relating to violations of non-technical rules involving broadcasting, hearing aid compatibility of wireless telephones, prepaid calling card marketing violations, and antenna tower painting and lighting rules. In carrying out its enforcement activities, EB has at its disposal the tools described above plus a range of other tools such as utilizing the agency's authority to impose monetary forfeitures, issue cease and desist orders, seize equipment and revoke operating authority (e.g., a station license).

[17] Portions of this section rely heavily upon presentations of and discussions with David H. Solomon of the law firm of Wilkinson Barker Knauer. However, any errors are the responsibility of the Principal Author. Solomon is a former chief of the Enforcement Bureau at the FCC.

Within EB, spectrum related enforcement activity is focused within the Spectrum Enforcement Division and the Regional and Field Offices. The Spectrum Enforcement Division addresses issues including public safety, unauthorized equipment, and unauthorized construction and operation. Nearly one-half of EB's staff is deployed in three Regional Offices and 24 Field Offices distributed throughout the country and its territories. In addition to conducting routine on-site inspections and investigations, the Field Offices are the locus of the agency's complaint-driven interference resolution and enforcement duties. The highest priority of these duties is working with entities at the federal, state, county and local levels of government to resolve interference to systems critical to the safety of life and property. In carrying out its investigations, interference resolution and enforcement activities, the agency's field agents employ both commercial and specialized spectrum monitoring equipment in fixed, vehicular mounted and portable versions. Such equipment, including associated software and the knowledge and experience of the field agents utilizing it, is vital to detecting, identifying, locating, and resolving interference issues.

In conducting its (admittedly limited) review and analyses of the Commission's field activities, the S/RWG took note of several relevant developments. First, it observed that a large fraction of all interference situations are resolved by the parties involved without a complaint being filed with the Commission. Of those incidents that do result in a complaint, most of them are resolved with the aid of FCC personnel in the field and without the need of a formal enforcement action. Second, the resources devoted to enforcement have declined over the years and many of the agency's most experienced field personnel are at the age where they could retire. Third, much of the agency's specialized monitoring equipment is developed, designed, fabricated, installed and maintained at EB's Equipment Development Group in Hiram, GA.

IV. Challenges/Opportunities Associated With Rapidly Changing Technical and Market Trends

In its deliberations, the S/RWG aspired to systematically identify and describe the technological and marketplace trends in wireless communications that present challenges to the traditional means that the Commission has utilized in its interference resolution and enforcement activities. As a starting place, the working group observed that early wireless mobile telephone systems and private land mobile radio systems typically used high power base stations on high antenna sites that covered large areas, and that these were noise limited rather interference-limited systems. These early systems carried conversations, signaling messages and station identifying information (e.g., call letters) using simple analog techniques and usually involved a single waveform in a given service or band. Systems typically operated in a single band or a very limited number of manually selected bands, and channel assignments were made on a long term (e.g., call-by-call) or permanent basis (e.g., in case of radio paging systems). Finally, the end-user devices were "dumb;" that is, they had very limited processing, information storage and user interface capabilities.

In contrast, today's terrestrial wireless systems used for voice and data services often utilize low power base stations on low antenna sites and provide coverage over small areas on an interference-limited basis. Conversations (or data communications sessions), signaling messages and station identifying information (to the extent it is provided) are carried using digital transmission techniques and may involve the use of multiple waveforms on multiple channels in multiple bands. Moreover, the channels or bands may be accessed on a dynamic (even packet-by-packet) basis using devices that have (a) significant and increasing amounts of digital processing and storage capabilities and (b) have the ability to locate themselves (or be located) by GPS or other means. These changes are motivated by the incentive to use spectrum more efficiently (e.g., through frequency reuse associated with small cell technology) and by, *inter alia*, the desire to provide multiple services – voice, data, image, video and combinations thereof – on a common platform to facilitate the provision of sophisticated new services while capturing economies of scale and scope. This is illustrated by the proliferation of smartphones, tablets and laptop computers operating on commercial cellular systems.

Another major development is the emergence of unlicensed systems and devices (e.g., Wi-Fi access points and their associated devices). Although it is widely agreed that these systems/devices have provided enormous benefits to their users and to the nation, they present special challenges to the Commission's interference resolution and enforcement efforts. For example, because there are no formal licenses issued, there is no station (or operator) license to revoke. Moreover, given the millions of devices in the hands of consumers, it may not be possible to remove them from service. The devices may also lack the electronic equivalent of call letters or other systematic means of identification. Such systems and devices may be installed and configured by individuals with little or no technical training working for entities whose core business interest or mission lies elsewhere.

More generally, today's low power/low antenna height network architectures, coupled with the high mobility and low power of individual end user devices, make spectrum monitoring from a limited number of fixed locations problematic. It also necessitates more sensitive mobile and portable monitoring devices that can process signals from devices that operate with multiple, sophisticated waveforms on multiple channels in multiple bands on a highly dynamic basis. In short, modern network architectures make it harder to detect, decipher, identify, locate and isolate interference sources. From an end-user (and service provider) perspective, the interference may manifest itself as a loss of capacity rather than an outright disruption of service. Similarly, the operation of vast numbers of intentional and unintentional radiators in close proximity may increase the ambient noise floor and thereby reduce the capacity and/or increase the cost of the affected systems or devices. More practically, the operation of interfering transmitters from the sides and tops of buildings makes inspecting a potential interfering transmitter more difficult for field agents. The operation of unintended radiators, such as switching power supplies or electronic light ballasts operating indoors but causing outdoor interference, also complicates the investigatory process. Finally, falling costs and increased processing power in end-user devices has increased the ability of "bad guys" to build, at relatively low cost, both "brute force" and, even worse, sophisticated jamming and spoofing equipment that can target specific channels and even specific users.

Although changes in (a) system architectures (and supporting exponential increases in digital processing power and memory capacity), (b) the regulatory and policy climate, and (c) business models or their public sector equivalents have all created challenges in interference resolution and enforcement, they also provide new capabilities for significantly expanding the efficiency and effectiveness of tools used to detect, identify, mitigate and report on interference incidents. The S/RWG observed that this seemed to be particularly true when technical capabilities are coupled with opportunities provided by "big data."[18] Examples of the use of these elements and big data concepts in interference resolution and enforcement are presented in the following section.

V. Potential New Strategies or Approaches for Addressing Enforcement Challenges

In conducting its studies, the S/RWG used the collective knowledge of its members and an informal survey to identify strategies or approaches that could improve the efficiency or effectiveness of the tools used for interference resolution and enforcement. The S/RWG included strategies or approaches that could be used by the Commission itself or, perhaps more interestingly, in combination with other affected entities or groups as part of a public-private partnership. The purpose of this section is to outline those strategies or approaches. Before doing so, however, three things should be recognized: First, the list is far from exhaustive. Second, the ideas expressed came from multiple sources and, in some cases, the origins were not always clear to members. Third, while the ideas are generally believed to be worthy of further consideration, there may be other technological, policy/regulatory, or economic/business considerations that would militate against their adoption.

<u>Crowdsourcing</u>

Like the above reference to "big data", there appears to be no widely agreed upon definition of crowdsourcing. However, the notion is one of "obtaining needed services, ideas, or content by soliciting contributions from a large group of people, and especially from an online community, rather than from traditional employees or suppliers."[19] If one considers the needed service as one of detecting and identifying interference, the Commission has always relied upon large segments of the public to detect and, in some cases, identify interferers (e.g., by listening to and recording the call letters of the interfering station). For example, the amateur radio community has traditionally supplied

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[18] There appears to be no widely agreed upon definition of the term "big data" but a recent article in Forbes entitled "What is Big Data" defined it as "a collection of data from traditional and digital sources inside and outside your company that represents a source for ongoing discovery and analysis." *See* Lisa Arthur, *What is Big Data?*, Forbes http://www.forbes.com/sites/lisaarthur/2013/08/15/what-is-big-data/ (last visited May 25, 2014).

[19] http://en.wikipedia.org/wiki/Crowdsourcing (last visited May 25, 2014)

the Commission with information on potentially illegal intruders in the bands allocated to their service.

While amateur radio operators often possess relatively sophisticated receiving equipment (e.g., with direction-finding capabilities) and technical skills that enable identification of interference type (e.g., power line noise), the general public traditionally did not. This is no longer the case. Due to the growth of "intelligent" end user devices with extensive digital processing power, memory capacity and online connectivity, crowdsourcing (as defined above) in spectrum enforcement and resolution is entirely plausible. Existing consumer devices (or a selected number of specially enhanced devices owned by consumers) could be used on a voluntary basis to assist the Commission in detecting, identifying and locating malfunctioning devices or devices being used for the deliberate jamming or spoofing of critical systems.

In contemplating the use of crowdsourcing in interference resolution and enforcement, the S/RWG took note of the Commission's recent efforts to use crowdsourcing to gather anonymous data from the smartphones of thousands of volunteers in order to assess broadband performance nationwide. Conceivably, at least, the FCC Speed Test, as the app is known, could be expanded on a voluntary basis to include utilizing the smartphone or similar device to detect and then store and report information on suspected interference incidents.[20] The S/RWG also noted that such monitoring could present additional privacy issues that the Commission would have to address.

<u>Propagation Model Calibration</u>

Modern radio propagation models play a critical role in the design and implementation of wireless radio systems and in constantly re-optimizing them in the face of changing demand. However, due to all sorts of vagaries and uncertainties, there are always discrepancies between what the models predict (e.g., for signal strength or geographic coverage) and on-the-ground observations. The accuracy of these models can be improved, sometimes significantly, by using local measurements to calibrate the model to better fit unique and changing local conditions. However, collecting geographically widespread measurement data is time consuming and expensive. As in the potential use of crowdsourcing to detect and identify interference, similar techniques could be used to improve propagation models. Such improvements not only provide direct benefits to service providers, they can also be used by regulators in establishing and refining exclusion and/or coordination zones and in addressing interference limits violations.[21]

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[20] Additional information on FCC Speed Test is available at http://www.fcc.gov/measuring-broadband-america/mobile (last visited May 25, 2014)

[21] Widespread measurements of current signal levels could (1) provide an *ex ante,* factual basis for setting equitable and enforceable harm claim thresholds for an operator next to an existing service; and (2) help calibrate propagation models that could be harnessed for *ex post* adjudication since models calibrated with a small number of measurements could be an economical way to establish the validity of claims.

Forensic Analysis of Interference Incidents

While an end user may complain of dropped calls or other indications of poor performance at particular times and/or locations, it is often very difficult to determine the actual cause of the problem after the fact. It can be caused by lack of an adequate signal, by some glitch in software at the application layer, or, of interest here, by interference. It has been suggested that, just as Flight Data Recorders ("black boxes") are used in aircraft accident investigations or for studying air safety issues, data could be collected during wireless performance incidents by taking advantage once again of the increasing digital processing power, memory capacity and online connectivity of end user devices. One possible implementation would involve having the end user device continuously record a few seconds of basic (physical layer) signal information (including the device's current location) on a continuous loop basis. In the event of a performance problem, such as a dropped call or interrupted Internet session, the temporarily stored information covering that time period would be moved into more permanent storage and, at an appropriate time, uploaded for forensic analysis.[22]

By using the basic information recorded at the time and place of the incident, analysts could extract sufficient information to determine whether interference was the likely cause. If numerous such incidents of interference occurred at a particular location or time, service provider engineers or Commission field agents could be dispatched to resolve the interference or to launch a formal enforcement process. Using the signal classifier technology described immediately below, it might be possible to determine the type of device or system causing the interference – e.g., a faulty RF lighting fixture. Once more, the working group recognized that such monitoring could present additional privacy issues that the Commission would have to address.

Interfering Signal Classifier

In the old days of analog systems, radio operators and the operators of monitoring equipment could listen to received signals and identify them using their experience as a guide. For example, a skilled operator could simply listen to the channel and determine whether an interfering signal was from a distant broadcast station, from a nearby automobile ignition system, or from a nearby power line. As pointed out in the introductory sections of this report, the situation is much more complicated today with many more types of noise and interference sources and declining availability and use of trained operators at the end points of a communications path. But today, with the enormous increases in computer power that can be applied to signal processing, it may be possible to accomplish such classification on either a near real-time basis or subsequently for interference identification purposes.

[22] This mechanism could work similarly to crash reporters in software operating systems. Windows, Mac OS, and other operating systems rely on crash reporters to record and transmit system data prior to and during a crash. Engineers analyze this data to correct software bugs and provide updated software versions.

Interference Information Transparency and the Use of Big Data Techniques

As the work of the S/RWG on interference resolution and enforcement proceeded, it became apparent that there is a dearth of reasonably detailed and searchable historical information on interference incidents. Since interference incidents are frequently and voluntarily resolved by the parties involved without EB intervention, the remainder of the agency and the engineering/research community are unaware of them. Moreover, even when the Commission receives a complaint, the working group understands that there is generally no information made public about the incident. While information on the small number of cases that result in formal enforcement actions (e.g., a consent decree) is made public, complete technical and other details are typically not available. Thus, it is very difficult to ascertain what particular devices or classes of devices are causing interference and what the associated trends are.

The working group observed that policymakers, regulators and operators collectively need more information on the nature, frequency and severity of interference incidents in order to ascertain the significance of the interference threat as spectrum becomes increasingly valuable and more complex to manage. In addition, the working group observed that making such information available to the engineering community and others on a more open and transparent basis could facilitate the development of innovative techniques for reducing the number and severity of costly-to-resolve interference incidents.[23]

Furthermore, the S/RWG became increasingly aware of the vast and increasing amount of interference and related monitoring data being collected by a wide range of government, private sector, academic, and multi-stakeholder institutions and observed that there have only been limited efforts to collect, extend and curate this information for the public benefit. There are multiple ways that increasing coordination and using the "big data" concepts discussed earlier could provide tangible benefits in terms of increased spectrum utilization. For example, interference measurements made on a routine basis by wireless carriers could be voluntarily combined with data collected by the Commission in response to complaints to identify emerging forms of harmful interference from unlicensed devices (such as RF lighting fixtures and electronic ballasts). In this specific example, the big data concept could be extended to include the agency's equipment authorization data base.

Advanced Spectrum Access System Techniques

While the technological developments set forth in Section IV above do present spectrum measurement, direction finding and other enforcement challenges, the strategies and approaches described can also improve the efficiency and efficacy of the tools used in interference resolution and enforcement activities. Increased spectrum sharing capabilities are being harnessed by modern Spectrum Access Systems (SAS) that utilize some combination of geolocation/database and spectrum sensing techniques to avoid

[23] While some specific information might have to be withheld because of on-going enforcement investigations, useful information could still be released in "sanitized," anonymized, or summary form.

interference between and among users. In the geolocation/database approach, sharing is facilitated by (a) storing information on spectrum utilization by incumbents and other authorized users in a central database and (b) requiring the new users to communicate with the central data base to dynamically select channels, times and/or locations in order to avoid interference. In the spectrum sensing approach, sharing is facilitated by (a) requiring new users to monitor the actual usage of spectrum by incumbents and other authorized users and (b) restricting them from selecting channels, times and/or locations that would cause interference to incumbents and other authorized users.

The two approaches -- geolocation/database and spectrum sensing techniques -- alone and in combination can play an important role in interference resolution and enforcement. For example, a technique used to determine whether a transmitting device is the source of interference observed at another location is to briefly turn off the suspected emitter and observe whether or not the interference ceases. In the geolocation/database approach (wherein the infrastructure nodes or, possibly, individual end user devices are under the control of a SAS) this could be accomplished quickly and easily. If the suspected transmitter is the source of the interference, the SAS could remotely change the transmitter power of the infrastructure node, change the antenna radiation pattern (using antenna beam steering), turn the infrastructure node off entirely, change channels within the shared band to avoid causing or receiving further interference, and perform other diagnostic and forensic analyses. Logging channel access decisions could allow the determination of which devices in an area might have been operating on a channel and at a location and time where interference occurred.[24] In the spectrum sensing approach, real-time spectrum measurement, analyses and direction finding techniques can be used to detect, identify/classify, locate and record/archive sources of harmful interference.

While the S/RWG was constrained in terms of its ability to fully assess the implications of advanced SAS techniques for interference resolution and enforcement, it made two observations. First, interference resolution and enforcement challenges need to be considered early in the design phase of advanced Spectrum Access Systems and that such systems may vary significantly from one shared band to another. Second, full advantage should be taken of the capabilities of geolocation/database and spectrum sensing techniques to detect, identify/classify, locate and record/archive sources of harmful interference. This could help modernize the Commission's enforcement tools and processes.

VI. Recommendations for Immediate Action

A. Short Title: Release Additional Information on Interference Complaints and Investigations

Finding: The explosive growth in wireless devices and systems that operate in increasingly close proximity to one another in space, time and frequency, coupled with rapid technological, operational and business development, is

[24] As noted in the subsection entitled "Logging/Record Keeping Requirements" in Section III, traditional log-keeping rules were originally adopted for exactly these reasons.

changing the interference environment and putting increased pressure on traditional interference resolution and enforcement methods. Without effective action, the Commission is faced with the prospect of more cases of intentional interference – both malicious and non-malicious. While the Commission routinely collects information on interference incidents and complaints, only a limited amount of information is released to the public (e.g., in the form notices of formal actions against licensees found to be in violation of its rules). We recognize that there are valid reasons for not publicly releasing some of this information (e.g., information on specific on-going investigations) but we find that significant public benefits would be produced by the regular release of aggregated information on interference complaints and investigations, including those that are voluntarily resolved without any formal enforcement action. Ideally, technical and operational details would be included in the releases. Such information would be invaluable to academic and government researchers, industry researchers and system designers, incumbent providers and new entrants in the wireless space, and to advisory groups like the TAC who may be tasked with proposing new strategies for modernizing the Commission's interference resolution and enforcement activities.

Recommendation: The Commission should take early steps to release publicly information on interference complaints and investigations, including ones that are voluntarily resolved by the affected parties.

B. Short Title: Convene a Workshop of Academic, Government, and Private Sector Practitioners and Researchers in Spectrum Enforcement

Finding: Recently, research interest in the topic of interference resolution and enforcement has increased. This interest has been driven largely, but not exclusively, by the growing acceptance in the spectrum policy making community that increased spectrum sharing is one key to accommodating the explosive growth in wireless communications devices and systems. Increased spectrum sharing is made possible by modern Spectrum Access Systems (SAS) that utilize some combination of geolocation/database and spectrum sensing techniques to avoid interference between and among new users and incumbent and other authorized users. Evidence of this increased interest is exemplified by the vigorous development of the data base driven dynamic frequency selection system in TV White Space (TVWS) and other applications, and by supporting research funded by the National Science Foundation (NSF), the Defense Advanced Research Project Area (DARPA) and other domestic and international bodies. Based upon our professional knowledge and analyses of this increased research activity, we find that significant public benefit could be realized by enhanced communication between academic, government, and private sector practitioners and researchers in spectrum enforcement.

More specifically, the Commission would benefit, for example, by gaining exposure to the latest research results – results that might then be incorporated into rulemaking proceedings or into the Commission's internal interference resolution and enforcement activities. Conversely, researchers and their funders would benefit from a deeper understanding of the interference resolution and enforcement challenges faced by the Commission and the private sector because of a rapidly changing technological, operational and business environment. Finally, providers, consumers and other potential beneficiaries of more dynamic forms of spectrum management (including sharing) also stand to benefit. They would gain from increased confidence that more advanced interference resolution and enforcement tools, processes and personnel will be adequate to avoid harmful interference to systems that are critical to the safety of life and property, homeland security and national defense.

Recommendation: The Commission should convene a workshop of (a) academic researchers and their funding agencies working in the field of interference resolution and enforcement, (b) practitioners and other experts in the field of interference resolution and enforcement from within the Commission itself and other federal government agencies (e.g., the National Telecommunications and Information Administration), and (c) similar practitioners and experts from private stakeholder groups for the purposes outlined above.

VII. Recommendations for TAC 2014 Work

A. Short Title: Investigate Costs and Benefits of a Public-Private Partnership to Share Information on Interference Incidents

Finding: In the description of our first recommendation for immediate action (above), we mention that the regular publication by the Commission of aggregated information on interference complaints and investigations would be invaluable to many parties, including academic and government researchers, industry researchers and system designers, incumbent providers and new entrants in the wireless space, and advisory groups like the TAC (who may be tasked with proposing new technologies, systems, processes and training programs for modernizing the Commission's interference resolution and enforcement activities). However, even if the aggregated statistics include information on interference complaints that are voluntarily resolved by the affected parties without formal enforcement actions and an associated public notice, they would not include information on interference incidents that are resolved without informing the Commission.

We understand that, in the past, carriers and other spectrum users have often chosen not to publicize such interference incidences, perhaps because of competitive concerns or the possibility that they might be implicated in some inadvertent rule violation themselves. But we sense that this may be changing and that wireless service providers and other spectrum users may be more willing to routinely gather (if they are not already doing so) and release such information. They have incentive to do so because it could better inform (a) policymakers and regulators on the nature, frequency and severity of such incidents as spectrum becomes increasingly valuable and increasingly complex to manage and (b) the engineering community and individual vendors in order to facilitate the development of interference mitigation techniques. Consequently, this would reduce the number and severity of costly-to-resolve interference incidents now and in the future.

Based upon our professional knowledge and analysis of the situation, we find that there could be significant public benefits from routine, voluntary collection, organization and release of information on important interference incidents that are resolved without a formal complaint being filed with the Commission. One possibility is the information could be released to a neutral, independent third-party who would aggregate, curate, "anonymize," and publicly release the information on a regular basis. This information would be in separate from, but supplement, the aggregated information on formal interference complaints and investigations described in our first recommendation for immediate action.

Benefits that could emerge from the availability of such information include allowing carriers and other spectrum users to benefit from the experience of others in terms of how they detected and resolved certain interference issues. It would also incentivize spectrum users and the manufacturers of frequently interfering devices to voluntarily work out longer term solutions and thereby avoid direct Commission regulation. The information would facilitate initiatives by equipment vendors, system providers and standards making groups to develop technological solutions to mitigate or avoid harmful interference. It would allow the Commission to get an early warning of specific forms of interference and to assess the ability of organizations (e.g., frequency coordinators) to resolve interference issues without filing formal complaints. Finally, it would provide the Commission factual information upon which to establish internal priorities for its enforcement activities.

Recommendation: Task TAC 2014 with the responsibility of investigating the costs and benefits of a Public-Private Partnership that would serve as a forum for the voluntary sharing of information on interference incidents in a systematic fashion.

B. Short Title: Develop New Strategies for Interference Resolution and Enforcement

Finding: In the descriptions of our first and second recommendations for immediate action (above), we noted that increased densification of devices and systems, coupled with rapid technological, operational and business trends, is changing the interference environment and putting increased pressure on traditional interference resolution and enforcement methods. Dynamic frequency selection, together with increased mobility of end user wireless devices and increasingly sophisticated digital transmission systems, raises the prospect of interference that is more transient in nature and more difficult to identify and locate. Moreover, increased sharing of spectrum between federal government and non-federal government devices and systems creates new challenges for institutional relationships and interagency processes for detecting, identifying, locating, reporting, and mitigating unintentional interference and malicious interference or jamming. Based upon our professional knowledge and analysis of the situation, we find that there could be significant public benefits from having the 2014 TAC identify, analyze and recommend new strategies for interference resolution and enforcement. This work would build upon the results of the workshop proposed in our first recommendation for immediate Commission action. It might include evaluation of crowdsourcing models based upon increasingly "intelligent" end user devices and cloud computing for both automated real time and forensic analysis of interference incidents. It might also include the development of techniques for integrating the data base management systems associated with modern Spectrum Access Systems into new, advanced methods and procedures for interference resolution and enforcement.

Recommendation: Task TAC 2014 with the responsibility for identifying, analyzing and recommending new strategies for interference resolution and enforcement in an increasingly challenging interference environment.

C. Short Title: Investigate the Changing RF Noise Floor and Its Impact on Services

Finding: One effect of the increased densification of devices and systems described in our first and second recommendations for immediate action (above) is the potential for an increase in the radio frequency (RF) noise floor. We find that the RF noise floor is a critical parameter in radio system design because the capacity of a communications channel or path (as measured in bits-per-second) depends upon (a) the bandwidth of the channel and (b) the strength of the desired signal relative to the strength of the noise and interference in that channel. Based upon the interference taxonomy, associated definitions and analyses developed during our deliberations, we find this category of interference to be particularly troublesome. It is troublesome because (a) aggregated, unidentifiable interference from multiple sources tends to be noise-like in character and difficult to distinguish from natural sources of RF noise and from noise produced internally in the receiver, (b) there is a lack of long-term, scientifically sound measurements of RF noise levels associated with this category of interference (generated by a host of individual intentional radiators, including out-of-band emissions, harmonics and other spurious signals emitted by hundreds or even thousands of nearby licensed and unlicensed devices) and (c) any net increase in the RF noise floor could have adverse consequences for wireless system performance and, more broadly, for efficient and effective use of the radio spectrum resource.

Recommendation: Task TAC 2014 with the responsibility for investigating the changing RF noise floor and its impact on wireless services.