Spectrum Sharing

October 2014

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EXECUTIVE SUMMARY

Spectrum is the fuel powering today's mobile broadband revolution. The role of wireless communications is becoming increasingly important in providing ubiquitous broadband coverage and capacity. Today, the growth of new and existing mobile broadband services, such as on-demand video; the large scale acceptance of mobile applications, such as social networking; and rapid growth of new types of user equipment, such as tablets, smart phones and smart watches are generating increasing amounts of data traffic which is expected to continue for the foreseeable future. Historically, capacity on mobile broadband networks has been augmented in three basic ways: (1) driving increased spectral efficiency from spectrum allocations (typically measured in "bits per Hz"); (2) increasing the number of cell sites via network densification to intensify frequency reuse; and (3) securing additional spectrum.

Network operators have a long history of driving spectral efficiency improvements and investing significant resources to densify their networks. The technological and economic limits on cell densification and spectral efficiency as a means to bolster capacity indicate that they cannot be relied upon exclusively to address capacity concerns. In fact, there is no single solution to meeting future mobile broadband communications needs. All three means of increasing capacity will continue to be vital, especially the incorporation of additional spectrum resources into mobile networks.

Securing such additional spectrum has been difficult, partly because spectrum usable by today's mobile broadband technologies is currently designated for a variety of other uses. To alleviate these challenges, efforts have turned to include spectrum sharing with incumbent users. Spectrum can be shared in several different dimensions: time, frequency and geography. Spectrum sharing technologies hold great promise, but substantial additional research and development efforts are needed to move these technologies into mainstream use.

Indeed, spectrum sharing already exists in many forms today in both coordinated and uncoordinated networks. Wide area cellular networks have enabled operators to provide seamless mobility for voice and data applications to millions of users through coordinating access to limited spectral resources via advanced cellular technologies. Also, uncoordinated sharing has created a convenient way of providing access to users in local environments such as via Wi-Fi connectivity, yet it cannot support the same level of spectrum utilization as a commercial cellular network deployed using licensed spectrum.

Certainty and transparency for licensees are the cornerstones of any successful licensing regime. Without certainty, regarding licensees' spectrum rights, investment in the new spectrum band will be hindered and innovation will be stifled. A regulatory regime that provides greater certainty and provides greater predictability to prospective licensees will help ensure that the spectrum is put to its highest and most productive use. For sharing to be successful, the sharing environment must be well understood, commercially feasible, and suitable for the provision of the envisioned services.

Providing access to additional spectrum based on coordinated licensed sharing is widely accepted as a key response to the mobile broadband capacity challenge. To date, spectrum sharing in the U.S. has been focused on sharing by unlicensed devices; however, the deployment of Authorized Shared Access (ASA)/Licensed Shared Access (LSA) approaches discussed herein is another promising tool that maintains regulatory certainty, which is a critical component for investment decisions. ASA/LSA is a framework for controlled, coordinated binary use of the shared spectrum by either the operator or primary incumbent user; it is a "third way" spectrum management system that combines elements of traditional "command and control" spectrum management with geolocation technology and leverages existing Commercial Mobile Radio System (CMRS) technologies.

An additional spectrum management approach is being considered in the Federal Communications Commission's (FCC) current 3.5 GHz proceeding through using a brand new type of Spectrum Access System (SAS). The proposed capabilities of the SAS include a complex and unprecedented three-tier spectrum sharing framework, which will require significant development, extensive testing and subsequent refinement. The role of managing spectrum access for *three* tiers of users would necessarily rely on currently unproven interference management techniques for successful coexistence.

4G Americas proposes that the Commission adopt a transitional licensing approach in the 3.5 GHz band that initially provides greater segregation between the various tiers of users, implementing two tiers in most of the 3.5 GHz band, such as through ASA/LSA, and experimenting with three tiers in a limited portion of the band until three tiers is shown to operate successfully. As confidence is gained with the SAS's management of three spectrum access tiers, the approach can be expanded to the entire band. The transitional licensing framework preferred by 4G Americas would provide spectrum users with the certainty and stability needed to invest and deploy innovative services in this band. This will allow the band to be quickly put to use via a two-tiered approach and allow the experimentation with three tiers to simultaneously occur in a limited portion of the band.

Many discussions of spectrum sharing have involved the possibility of repurposing federal spectrum, such as spectrum exclusively used today by the Department of Defense for commercial mobile use. Some federal spectrum is not used on a coast-to-coast basis, which could allow it to be used for mobile broadband services outside certain "exclusion zones" where federal users operate. Exclusion Zones should be based on protection of incumbent federal users from wireless broadband, and not vice versa, and should be based on realistic models for clutter, terrain and coexistence protection criteria. The regulator's ultimate goal in these sharing situations should be to convert the Exclusion Zones to Coordination Zones so as to permit some commercial mobile use inside the Coordination Zones when and where federal users are not operating.

In 2014, the FCC Technological Advisory Council (TAC) established a working group to specifically deal with spectrum sharing. Future topics on spectrum sharing will need to address applications, usage patterns, and information delivery business models of 5G. Spectrum sharing policies and techniques must also consider forward compatibility. 4G Americas believes strongly that the ultimate goal of spectrum sharing should be to increase utilization of all spectrum resources, and our member companies are working hard to make that a reality.

1 INTRODUCTION

Today, the growth of mobile broadband services is generating significant traffic on mobile networks, and this growth trend is expected to continue for the foreseeable future. For example, premium video content viewing has moved beyond the living room and into many aspects of our mobile lives. From using a smartphone at a café to record and share a video with friends, to catching the final episode of a favorite series on a tablet before going to bed; mobile devices are allowing us to create and view content wherever we may be. High-quality video streaming is now expected across the entire content landscape and broad collection of mobile devices. In addition to the one billion connected smartphones currently in use, tablets have become a key tool for viewing content on the go. As a result, the adoption of appropriate spectrum policies that open access to additional licensed spectrum is critically important to enable the cellular industry to continue satisfying consumers' mobile broadband demands.

The provision of mobile broadband service requires supporting a large number of active users each with constantly increasing data demands using mobile operators' finite spectrum resources. As a result, intra-system interference management often is particularly challenging. If the mobile provider uses licensed spectrum, this constantly changing interference environment can be managed dynamically and in a coordinated manner, minimizing its effects on users and without causing any harmful interference. At the same time, a large-scale mobile network employing spectrum opportunistically due to the need to share spectrum with an incumbent federal user for example, faces a many-fold increase in the complexity of this task.

There are some spectrum bands that are not uniformly used by the incumbent licensee in all locations. Examples include spectrum that is used primarily by point-to-point links, spectrum that is used intermittently for radar or radiolocation purposes and spectrum that is assigned for defense purposes but is not used most of the time. In these situations, spectrum sharing tools can be used to allow spectrum to be more fully utilized and offer efficient ways of repurposing spectrum for specific uses. For sharing to be successful, the sharing environment must be well understood, commercially feasible and suitable for the provision of the envisioned services. Spectrum that is available over most of the nation, barring certain limited exclusion zones, is far more valuable to mass-market applications, such as cellular systems, than spectrum that is solely available in rural locations; in other words, spectrum that is unavailable in major metropolitan areas where the need for additional spectrum is much greater is of less value. The constraints imposed by the sharing environment will determine whether real-time services can be supported or, instead, the spectrum is only suitable for less critical communications. This, in turn, is dependent on the ability of a service provider to properly manage its use of the spectrum with implicit guarantees of quality within certain defined constraints such as traffic loading, geographical or timing limitations.

As a result, any spectrum sharing mechanism under consideration requires technology research and development and public testing to ensure that it provides sufficient protection to the primary users of the spectrum while providing beneficial new broadband capacity. Unproven assumptions about the operational environment create both regulatory and technical uncertainty, which impedes investment and innovation by the private and public sectors.

In the sections that follow, we discuss the key factors that should be considered when developing successful spectrum sharing policies.

2 SPECTRUM SHARING APPROACHES

Spectrum can be shared in several discrete dimensions including: frequency, time and geography. For instance, the simplest means of spectrum sharing is the operation of systems in the same frequency band but in different geographical areas. These geographical areas could be defined as different markets or defined by geographic exclusion zones.

Spectrum sharing can be more complex and involve multiple dimensions. For instance, it is possible to share frequencies in the same geographical area but not at the same time. This can be accomplished by using a geolocation database, spectrum sensing techniques or a spectrum sharing etiquette. The notification of when a spectrum band is available also can be supported by the ASA/LSA framework, which is a binary access arrangement between an incumbent and mobile operator. There are more complex arrangements, such as the three tiers of usage proposed by the FCC in its 3.5 GHz proceeding. Some of these techniques are more readily achievable than others and may require a higher level of interaction between the incumbent and sharer(s). In these cases, spectrum could be shared in the same geographical area but only when the incumbent is not using the spectrum. Depending on the dynamic nature of the spectrum availability and access criteria, technology solutions will need to be developed and polices created to allow this level of spectral efficiency.

Current approaches to spectrum sharing between disparate systems that operate within the same spectrum band may be achieved through a coordinated or an uncoordinated mechanism, or a hybrid combination of such mechanisms. These approaches are discussed below.

2.1 COORDINATED SHARING APPROACHES

Most commercial cellular networks today use spectrum bands that have been assigned to operators in dedicated blocks via competitive auctions. Mobile operators control access to their scarce spectrum resources via ongoing innovation, implementing a multitude of spectrum access techniques to provide the greatest number of users with the highest level of service possible.

Coordinated spectrum sharing mechanisms typically rely on a coexistence infrastructure that knows how a particular swath of spectrum is being used by a primary user in a given geographic area and uses this knowledge to manage spectrum access by all other users. Coordinated sharing relies on a communications framework between the systems that have rights to use the spectrum swath, a coexistence infrastructure and a database that is used to assign channels to those systems. This allows the coexistence infrastructure to collect value-added information and guide channel allocations at each given place and time. It also allows the coexistence infrastructure to direct a system to release a channel, modify how the system is using a channel (e.g., change maximum transmission power), or change the system operating channel (e.g., swap channel x for channel y). The coexistence infrastructure can be implemented via a single centralized entity or be distributed across a number of nodes. Coexistence studies that include intra-system and also inter-system interference are ongoing among various standard organizations.

The main advantage of coordinated sharing over uncoordinated sharing, which occurs with most unlicensed uses such as TV White Space (TVWS) operations, are discussed in Section 3.2 below as a well-defined business model. In contrast to uncoordinated sharing where spectrum access is typically a best-efforts service within a limited area and user base, coordinated spectrum sharing approaches can be used by mobile operators to provide end users with critical communications services and a specified quality of service.

2.1.1 GEOGRAPHIC SHARING

With geographic sharing, a given spectrum user's transmissions are limited to within a predefined protected area, often called a Protection Zone or Sharing Zone. Protection Zones are typically established around operations where detailed device-to-device sharing is not feasible or possible. This can be due to several issues, such as the sensitive nature of the protected operation and the inability to openly share that data or the fact that the protected operation may not permit device-to-device analysis or both.

One example of geographic sharing is in the shared federal portion of the AWS-3 bands: 1695-1710 MHz and 1755-1780 MHz. The incumbent operations in these bands comprise a broad collection of federal systems, and the commercial systems must share spectrum with the federal systems through using Protection Zones established around the federal operations.

When these bands were being considered for commercial use, the Protection Zones originally identified by the National Telecommunications and Information Administration (NTIA) were found to be prohibitively large and overly restrictive.[1] In addition, they initially were called Exclusion Zones, indicating that operation within the zones was prohibited. Consequently, NTIA used the Commerce Spectrum Management Advisory Committee (CSMAC) to study geographic sharing in this context.

CSMAC's deliberations, studies and analyses identified several key parameters that the earlier NTIA analyses failed to consider, including:

- The use of mutually agreed upon equipment parameters and deployment scenarios including the actual (or similar) system layout, system loading factors and realistic transmit power levels
- Using less restrictive Interference Protection Criteria (IPC) for Federal systems
- Applying clutter and more realistic terrain-specific propagation models
- Agreeing to apply the terms "Protection Zone or "Sharing Zone" instead of "Exclusion Zone" to allow coordinated operation within the zones.[2]

The CSMAC work resulted in several sets of recommendations and ultimately informed the FCC's AWS-3 rules for sharing with Federal systems.[3]

A key lesson learned through this process is that geographic sharing among a set of spectrum users must be established through mutual collaboration.

2.1.2 SHARED ACCESS USING GEOLOCATION TVWS DATABASE

Geolocation capabilities in networks may be assisted by databases that map location, time, and usage characteristics to rules and policies for managed spectrum access.

TV White Space (TVWS) operation refers to the use of TV channels that are not used by any licensed services at a particular location and at a particular time. To exploit the unused TVWS spectrum for

[1] See "An Assessment of the Near-Term Viability of Accommodating Wireless Broadband Systems in the 1675-1710 MHz, 1755-1780 MHz, 3500-3650 MHz, and 4200-4220 MHz, 4380-4400 MHz Bands", ("NTIA Fast Track Report"), NTIA, October 2010; and "An Assessment of the Viability of Accommodating Wireless Broadband in the 1755 – 1850 MHz Band", NTIA, March 2012.
[2] In this document, the terms "Protection Zone" and "Sharing Zone" are used interchangeably.
[3] See CSMAC WG1-5 Reports, http://www.ntia.doc.gov/category/csmac.

improved spectrum efficiency, some regulatory agencies have developed regulations to permit use of TVWS by unlicensed wireless devices as long as they do not cause harmful interference with any licensed services.

Devices that operate in TVWS spectrum, which are commonly referred to as TV Band Devices (TVBD), are either fixed or portable. Fixed TVBDs are intended to be deployed at a fixed location with a fixed antenna height. In some jurisdictions the antenna height is limited by rule. Fixed TVBDs typically must store their location, which can either be entered by a professional installer or self-determined via using geolocation technologies. Geolocation typically needs to be accurate to within ± 50 meters. The device must update its information immediately whenever its position changes. Portable TVBDs must be able to self-geolocate (to the same accuracy as fixed devices) whenever they move more than a specific distance (typically 50 meters). The issues inherent with self-geolocation (e.g.., latency, accuracy, and time-to-fix) mean that the use cases for these devices tend to be limited. Accordingly, while there are several devices available for fixed TVBD applications in the U.S., there presently are no portable devices in use.

At least two standards bodies are working on TVBD standards: the Institute of Electrical and Electronics Engineers (IEEE) and Internet Engineering Task Force (IETF). The IEEE standards align under the IEEE 802 family, which currently include 802.11af which is Wi-Fi over White Space, sometimes called “Super Wi-Fi”; and 802.22 which is Wireless Regional Area Networks (WRAN), now called the “Wi-FAR.” The other body addressing TVWS is the IETF, through the Protocol to Access WS Database (PAWS). While the IEEE efforts address the operation of the devices, PAWS addresses interaction with databases.

Like many of the sharing technologies described in this paper, TVWS operations rely on databases of licensed incumbent operations to effect sharing. These databases typically are provided by third parties approved by regulatory agencies using the regulatory agency’s public databases. The third party database providers are commonly called TV White Space Database Administrators (WSDBA). Regulatory agencies have typically certified multiple WSDBAs and require that they share all data equally among themselves. The goal is to promote competition and keep costs low. However, in the U.S., the requirement to collaborate and share data has delayed the introduction of database services.

In general, the regulators’ databases are used to describe the identities, types and locations of protected systems. These databases are provided to the WSDBAs who apply protection criteria to these systems. WSDBAs process queries from TVBDs and apply these protection criteria to determine the available channels for the TVBD query. TVBD queries typically provide device location, device information (e.g., type, serial number, certification ID, etc.), antenna height (for fixed) and additional identifying information (e.g., device owner).

The protection criteria are established through regulatory proceedings allowing feedback from all stakeholders. In the case of TVWS operations, the majority of incumbents are TV station licensees whose TV viewers are typically protected within a contour. This protection contour describes the area within which a given TV receiver is protected from interference due to other co- and adjacent-channel TV stations. For TVWS applications, an additional buffer is added to these contours to define the exclusion zone. This zone exists for the specific TV channel and sometimes for the adjacent-channel as well.

There are several other types of TV band licensees to protect, such as Low Power Auxiliary (LPAux) uses, which includes wireless microphones. Since the locations of the victim receivers are also generally not known, protection criteria tend to be exclusion zones established at specific radii around the transmitter locations. Some of the more periodic or itinerant uses such as wireless mics, are accommodated through exclusion zones with specified times of operation.

It is also important to note that TVWS operations face some challenges. To begin with, geolocating portable TVBDs is problematic when trying to support indoor operation or full mobility at high speed. Geolocation accuracy, latency and time-to-fix limitations may not easily support the requirement to re-query the database whenever the device moves more than 50 meters. In addition, the TVBD Out-of-Band Emission (OOBE) mask is more stringent than for most unlicensed devices in order to protect operation close to TV receivers. This OOBE limit has proven difficult to achieve at a cost point low enough to make TVBDs broadly attractive. Regulatory uncertainty also has plagued TVWS operations. The current uncertainties stem from the FCC's Incentive Auction proceeding in the 600 MHz band, particularly repacking and auctioning since it is unclear how much spectrum will be available for TVWS following the auction where TV stations are repacked and the repurposed spectrum is auctioned for mobile licensed services.

These technical challenges and uncertainties have limited investment and interest in TVWS, particularly in the U.S. and Canada. While other countries are moving forward (such as the UK, Singapore and South Africa), demand is limited given the above technological hurdles coupled with sufficient availability of low cost unlicensed devices in other spectrum. Consequently, it will be at least several years until we see "significant benefits" for the public of new and innovative types of unlicensed broadband devices and services as the FCC envisioned in its initial Notice of Proposed Rule Making (NPRM).

In spite of these challenges, the capability of database-enabled devices to operate in vacant TV spectrum without causing interference is possible as shown by the over 600 registrations of database-controlled fixed TVBDs in the U.S. Thus, while the market for TVWS devices has been weighed down by regulatory uncertainty and technological challenges, the spectrum sharing concept may be applied in other spectrum bands.

2.1.3 DYNAMIC SHARING UNDER SAS

The FCC is proposing a three-tiered spectrum access approach in the 3.5 GHz band under which existing primary operations (i.e., authorized federal users and grandfathered Fixed Satellite Service (FSS) earth stations) would make up the Incumbent Access tier and be protected from harmful interference by means of well-defined exclusion zones[4]. The Citizens Broadband Radio Service (CBRS) which supports mobile users would be divided into Priority Access License (PAL) and General Authorized Access (GAA) tiers of service, where PAL users would need to protect Incumbent users and GAA users would need to protect both PAL and Incumbent Users.

This three-tier spectrum access approach, which has not been deployed anywhere in the world, presents serious challenges that could impede putting the band to use for mobile broadband in a timely manner. Unfortunately, the FCC's proposals do not align with the industry's serious needs to address substantial and near-real time increases in traffic demand in a predictable manner. The wireless industry would benefit greatly from the establishment of a framework that encourages investment in mobile broadband devices and infrastructure. The industry very much needs a business environment where commercial operators retain control of both business and engineering decisions, and for information sharing models that do not involve an operator sharing technical knowledge about equipment and deployment characteristics with external entities.

[4] Exclusion zones are the current proposal, but the FCC intends to work with stakeholders to consider more interoperable sharing approaches.

An additional challenge is the proposed means of facilitating spectrum access and interference management dynamically using a geolocation database where the incumbent use will vary in time, frequency and location. The FCC proposes requirements for interaction between the geolocation database and a carrier’s network that may circumvent spectrum reuse and radio resource management techniques designed to optimize spectrum use in a carrier’s network and achieve maximum efficiency. In a carrier’s network, the infrastructure must know how spectrum is being used in a geographical area, and based on this knowledge, manage its utilization by assigning a specific channel to a system. In fact, many of the innovations in cellular technology are methods to manage self-interference and thus support data and voice services to its customers. Relegating some of that functionality to an external Spectrum Access System (SAS) would render the operator at a disadvantage for quality of experience towards their customers and for competitive reasons.

The following sections address specific spectrum sharing issues that the FCC raises in the *3.5 GHz Further Notice of Proposed Rulemaking (FNPRM)*.[5]

2.1.3.1 SAS

Access to the three tiers, according to the *3.5 GHz FNPRM,* would be managed by a Spectrum Access System (SAS). The SAS would consist of a dynamic database (or multiple databases) that incorporates technical and functional requirements necessary to manage access and operation across all three tiers. Under the FCC proposal, in place of fixed channel assignments, the SAS would dynamically assign available bandwidth within given geographic areas to PAL and GAA users. In other words, the exact spectral location authorized by SAS to either PAL or General Authorized Access (GAA) would not be fixed. For example, a licensee might have Priority Access rights for a single PAL, but the specific channel location assigned to that user would be managed by the SAS and could be reassigned from time to time (from 3550-3560 MHz to 3630-3640 MHz for example). Individual GAA users would be assigned available bandwidth of a size and spectral location determined by the SAS (such as from 3550-3556 MHz or 3662-3673 MHz).

As proposed by the FCC, the SAS would work to ensure that PAL users have access to allotted 10 MHz channels and GAA users are provided access to at least 50 percent of the band and be permitted to operate in unused PAL channels. Each PAL would hold an exclusive use licensed to a single 10 MHz channel in a given census tract for one year, which may be aggregated for up to five years but not have any renewal rights that today attach to virtually all other mobile spectrum licenses. PALs may be aggregated across time, channels and geography. The GAA tier would operate under a license-by-rule authorization approach.

2.1.3.1.1 SAS FUNCTIONALITY

The proposed core SAS functions provide for direct interaction with all Citizen Band Service Devices (CBSD).[6] However, the FCC will need to differentiate treatment applicable to CBSDs operating in a managed network from that applied to CBSDs operating on a stand-alone, opportunistic basis. As discussed in the following sections, managed networks rely upon network planning where power limits, operating frequencies, neighboring cell information and physical cell identities are set. The emissions

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[5] *See* Amendment of the Commission’s Rules with Regard to Commercial Operations in the 3550-3650 MHz Band, GN Docket No. 12-354, *Further Notice of Proposed Rulemaking* (rel. Apr. 23, 2014) (“*3.5 GHz FNPRM*”).

[6] *See 3.5 GHz FNPRM* at ¶ 95 & *see* proposed Rule Section 96.43.

within a managed network are controlled by the carrier's supervisory framework, consistent with regulatory limits. In the managed network scenario, the SAS should interact at the network management function level within the mobile broadband network instead of at the level of the individual CBSDs. Such an assignee would be certified differently from a GAA CBSD that interacts directly with the SAS.

2.1.3.1.2 SAS DEVELOPMENT, TESTING AND CERTIFICATION

The FCC encourages the idea of multi-stakeholder groups to "develop industry coordination agreements and protocols, including technical options and methods for managing spectrum access that would improve access to and make efficient use of the 3.5 GHz Band".[7] This concept should be explored for development of the environment necessary to support development, coordination and operation of multiple SASs. While the Commission should develop the regulatory approach, industry collaboration via multi-stakeholder groups should work to advance this approach into a network of interoperable standards-compliant SASs.

In addition, while the FCC would establish baseline testing and certification requirements or goals, the agency expects multi-stakeholder groups to develop a testing and certification program.

2.1.3.1.3 COORDINATION AMONG MULTIPLE SAS

The proposed rules assume that multiple SAS administrators would be authorized to operate in the 3.5 GHz band, just as multiple databases are authorized to operate under the TVWS rules.[8] The FCC proposes to authorize multiple competing SAS operators, which the agency believes could benefit the overall ecosystem by providing a choice of SAS system providers to stakeholders in the band and promote innovation in SAS development and operation and result in a more robust sharing ecosystem.

At the same time, the FCC is using the rulemaking process to seek input on whether it is feasible for multiple SASs to operate effectively in the 3.5 GHz band. TVWS databases synchronize information with each other in near real-time using secure web service techniques, and SAS operators also could achieve near real-time synchronization and information interchange via web services that are both mature and secure. Endpoints can be authenticated using certificate authentication techniques to prevent unauthorized access and the information interchange can be secured from eavesdropping through use of HTTP on top of the Secure Sockets Layer / Transport Layer Security (SSL/TLS) transport protocol.

The SAS administrator qualification procedure proposed by the FCC[9] closely reflects the procedures used to qualify and govern the operation of TVWS databases currently in service in the TV bands. However, as noted above, multi-stakeholder groups can take on the responsibility of coordinating with the multiple SAS providers to establish procedures and protocols for interoperation consistent with the regulatory responsibilities. The FCC would establish the regulatory approach governing coordination among SAS administrators and allow multi-stakeholder groups to develop procedures to enact that approach.

[7] *See id* at ¶89.
[8] *See id*. at ¶ 91 (definition of Spectrum Access System); *see also* proposed Rule Section 96.48.
[9] *See id.* at ¶¶ 105-108; *see also* proposed Rule Section 96.48.

2.1.3.1.4 COORDINATION/OPERATION WITH INCUMBENTS

The primary role of the SAS is to provide protection to incumbent users, which requires understanding incumbent use. In the case of Fixed Satellite Stations (FSS), this means maintaining accurate geolocation coordinates for the incumbent, the incumbent's operating parameters (e.g., antenna pointing angle and discrimination pattern) and the protection criteria for deployment of high power macro base stations, urban macro, microcellular and indoor systems in terms of distance from the earth station. The FSS and point-to-point microwave communities have established frequency coordination procedures for sharing with point-to-point microwave systems.[10] In addition, Report ITU-R M.2109 can be used as a guideline for FSS coexistence, with model parameters modified as needed for operation in the United States. In the case of coastal radiolocation operations, similar criteria can be established for protection contours close to the coast.

The SAS would then communicate allowed frequencies of operation, permitted transmit power levels and duration at a designated location upon request from a registered and authenticated CBSD. Any change of incumbent site characteristics, including change in location, must be communicated to the SAS. CBSDs would not be permitted to operate without registration of location and connection to an authorized database. In order to operate within bands designated for sharing, registered stations must have the capability to geolocate in three dimensions in near real time with high accuracy for the SAS to be able to provide them with an accurate set of allowed channels in a timely manner (i.e., on the order of seconds).

In the case of federal incumbents, data sufficient for performing sharing analyses with federal operations is typically either classified or not publicly available. Thus, sharing analyses with these federal systems may involve a private SAS that indicates what use is allowed (e.g., available frequencies, duration, etc.) at a given location. In this way, federal incumbent operational information can be protected from public view.

2.1.3.2 REDUCED EXCLUSION ZONES AND COORDINATION ZONES

The proposed Exclusion Zones approach that was designed to avoid harmful interference to federal incumbents must be revised if the 3.5 GHz band is to succeed. These Exclusion Zones are based on the 2010 *NTIA Fast Track Report* and cover about 60 percent of the U.S. population, extending hundreds of kilometers inland from the nation's east, west and Gulf coasts.[11] If these Zones were adopted, the 3.5 GHz band would be unavailable in Boston, New York, Philadelphia, Baltimore/Washington, Atlanta, Miami, Houston, Dallas, Los Angeles, San Francisco/Silicon Valley, Portland and Seattle. A fragmented U.S. market limited to 40 percent of the nation's population, all in inland areas, would not be too attractive to equipment vendors or service providers especially if the area available for use does not include the many densely populated markets along the coasts where the small cells that are envisioned to be used in these higher frequency bands would be particularly beneficial.

There are several bases to revise the Exclusion Zones identified by NTIA in 2010. First, the *NTIA Fast Track Report* based the Exclusion Zones on the assumption that mobile broadband service at 3.5 GHz would use high-powered WiMAX-based, cellular infrastructure rather than use LTE-based small cells, as is presently contemplated.

[10] National Spectrum Management Association, Report WG 3.87.001, "Primer On Frequency Coordination Procedures", (www.nsma.org).
[11] *See 3.5 GHz FNPRM* at ¶ 6.

Second, any restrictions on spectrum availability, whether in the form of modified Exclusion Zones or, as discussed below, Coordination Zones, should be based exclusively on protection of Federal incumbents from mobile and base station transmissions, and not on protection of mobile and base stations from interference by Federal radar transmissions. Wireless networks can employ a variety of techniques to address temporary instances of interference, and placing the burden on wireless operators to address interference from a primary user makes more sense than using an Exclusion Zone that limits access to key areas of the U.S. and the incentive to invest and innovate and stretch performance by developing new interference mitigation techniques.

2.1.3.3 INTERFERENCE/SHARING CRITERIA AND METHODOLOGIES

In the 3.5 GHz band and other bands contemplated for spectrum sharing opportunities, policymakers should use Coordination Zones rather than Exclusion Zones to allow mobile operations anywhere federal incumbents are not operating. This would optimize spectrum availability without causing harmful interference to federal users. A Coordination Zone approach would allow small cell mobile operations within what would otherwise be an Exclusion Zone. A Coordination Zone could include all or part of an Exclusion Zone—thus, there could be some areas where the federal incumbent would retain exclusive use and remain as Exclusion Zones, while other areas could have more fluid requirements that allow certain radio operations, subject to specified emission levels, time limits on operation, or other applicable constraints. There is no question that the establishment of Coordination Zones would increase the geographic availability of the 3.5 GHz spectrum band, for example.

The Commission's three-tiered approach to providing licensing and interference protection within the 3.5 GHz band could offer additional capacity for mobile broadband operations in the longer term. However, 4G Americas reiterates that the federal government should pursue clearing as its preferred approach, particularly in bands below 3 GHz. 4G Americas also believes that a phased approach to the introduction of dynamic sharing in the 3.5 GHz band presents the best path forward. For instance, the initial approach to utilization of this band should be to implement a two-tiered approach with PAL and GAA operations in separate portions of the band. This would allow GAA and PAL users to experience and test coexistence with only the incumbent services. In a separate, limited portion of the band, three-tiered operations can be studied with the end goal of establishing the sharing environment described in the 3.5 GHz docket. Allowing two tiers (PAL + incumbent and GAA + incumbent) in the majority of the 3.5 GHz band at the outset will provide infrastructure investment certainty and ensure that spectrum access management can protect incumbent services before three tiers are implemented in the entirety of the band.

2.1.3.4 SPECIFIC CONCERNS INVOLVING MANAGED NETWORKS

Today's wireless broadband networks are carefully managed to ensure capacity is available when and where it is most needed. Managing interference in an opportunistic sharing environment is extremely challenging, considering current wireless networks are designed with spectrum reuse and radio resource management techniques that are utilized to optimize spectral efficiency. Specific channel assignments help network operators manage their networks efficiently. Indeed, network operators need to coordinate spectrum usage over large geographical areas and for multiple purposes, not merely at a single location where a call is placed or a data session is initiated. How a particular block of spectrum is used in one location affects how that same spectrum block can be used in other nearby locations. Network operators need access to spectrum in many different license areas spanning a metropolitan area, highway, or major portions of a rural service area. The operators will use that spectrum most efficiently if they hold common frequency assignments across their service areas.

There are some major differences between managed networks and unmanaged networks. Managed networks rely upon network planning, whether the network uses licensed PAL spectrum or unlicensed GAA spectrum. In the network planning process, power limits, transmitter frequencies, neighboring cell information and other characteristic information are taken into account. The transmissions within a managed network are thus carefully controlled. This simplifies the role of the SAS, as it would not need to track the location of all CBSDs, for example. None of this is possible in an unmanaged network. Moreover, intervention into the operations of a managed network, like power control, can have unforeseen consequences.

Self-Organizing Networks (SON) are increasingly essential for today's complicated cellular networks. By using SON technology, wireless broadband networks are fully aware of the spectrum environments and thus are able to organize and optimize their performance. Operators can then benefit from significant improvements in terms of both capital expenditure and operational expenditure. Ceding network planning authority to an SAS, for example, would diminish the efficiency of system performance.

The use of stable, reserved frequency assignments for PALs, exclusive in nature except as to incumbents, will provide PALs with incentives to innovate and to invest in the infrastructure that is needed to provide reliable wireless broadband service across metropolitan, suburban, and some rural areas.

2.1.3.5 LICENSES WITH LONGER TERMS AND LARGER GEOGRAPHIC AREAS ENCOURAGE INVESTMENT

The *3.5 GHz FNPRM* proposes a short license term of one year (that can be aggregated for five years) without any expectation of renewal in each census-tract license area.[12] The FCC believes that allowing aggregation for up to five years of licenses would provide PALs with the certainty needed to make capital investments.[13] While a five-year license term is better than a one-year term as a timeframe for business investments, 4G Americas believes that uncertainty remains as to whether access to the spectrum used for the construction of facilities and to provide services to customers will still be available after the terms have expired, and if so, at what cost because the lack of a renewal expectancy could lead to a spectrum free for all. 4G Americas feels that the lack of renewal expectancy breeds uncertainty and will unquestionably deter innovation and investment in the band.

The small geographic size of licenses—based upon the 74,000 census tracts in the U.S.—is also a source of concern for 4G Americas. In dense urban environments, where small cells are most needed to provide capacity, census tracts only cover a few city blocks. Manhattan, for example, was comprised of 288 census tracts in the 2010 census.[14] Therefore, a wireless broadband operator would need to file well over a thousand applications (each with a filing fee) to bid on a five-year license comprising a 10 MHz spectrum block in Manhattan. The inefficiency and transaction costs resulting from this micro-licensing building block scheme is unnecessarily complex and will place burdens on applicants, licensees, and the SAS and the FCC without any compelling countervailing benefit.

[12] See 3.5 GHz FNPRM at ¶ 49.
[13] See id.
[14] See U.S. Department of Commerce, United States Census Bureau, http://www2.census.gov/-geo/maps/dc10map/tract/st36_ny/c36061_new_york/ (last visited July 14, 2014).

2.1.3.6 ENFORCEMENT

In the *FNPRM*, the FCC asks some questions regarding enforcement.[15] The fundamental questions are who is responsible when interference occurs, what the roles are for the Commission and SAS providers in identifying and mitigating interference and how quickly it can happen.

The FCC needs to assure that harmful interference in both 3.5 GHz band incumbents and PAL licensees, in the limited area of the band where three tiers are implemented, will be addressed quickly without impacting their ongoing operations. SAS providers also will need assurance that they bear no responsibility and liability for proper spectrum decisions made with bad input data.

2.1.4 ASA/LSA MODEL

As noted in the Executive Summary and Introductory sections of this paper, spectrum is fundamental to the success of mobile wireless communications. The industry has relied on the exclusive spectrum license as a key asset that provides investment certainty and helps assure high service quality and reliability for the customer. Therefore, we recommend that the federal government pursue full clearing and auctioning of spectrum as its preferred approach, particularly in bands below 3 GHz.

At the same time, the range of frequencies over which mobile communications networks can operate has increased significantly over time. During the past three decades, mobile network operators have gained the ability to operate on frequencies up to 6 GHz and over increasingly wide system bandwidths. This increase in applicable frequencies and bandwidths has been driven by demand for spectrum that today is exceeding the available spectrum for new exclusive use licenses. The scarcity of exclusive use spectrum has created a need for greater flexibility in making use of new bands while still maintaining the certainty and service quality supported with licensed spectrum.

Authorized Shared Access / Licensed Shared Access (ASA/LSA)[16] is a spectrum sharing approach that combines elements of traditional “command and control” spectrum management with geolocation technology. This regulatory approach, which has been standardized in Europe, unlocks and improves access to underutilized spectrum where it is not possible or desirable to repurpose the spectrum to other services within a reasonable time frame. ASA/LSA provides access to such spectrum and certainty for large scale investment, and reliable protection of incumbent users. ASA/LSA nicely complements fully cleared, exclusive licensed spectrum.

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[15] See 3.5 GHz FNPRM at ¶ 162.

[16] The LSA framework was proposed by European Commission’s Radio Spectrum Policy Group, “Report on CUS and other spectrum sharing approaches: ‘Collective Use of Spectrum’”, 2011. The European Conference of Postal and Telecommunications Administrators (CEPT) Electronic Communications Committee (ECC) Frequency Management working group has issued an ECC Report on LSA (ECC Report 55): “Report A from CEPT to the European Commission in response to the Mandate on ‘Harmonised technical conditions for the 2300-2400 MHz (‘2.3 GHz’) frequency band in the EU for the provision of wireless broadband electronic communications services”. Also, the group has developed ECC Decision 14(02) on "Harmonised technical and regulatory conditions for the use of the band 2300-2400 MHz for Mobile/Fixed Communications Networks (MFCN)“ and an ECC Recommendation (14)04 on “Cross-border coordination for mobile/fixed communications networks (MFCN) and between MFCN and other systems in the frequency band 2300-2400 MHz”. As a next step, in accordance to the EC Mandate, a Report on “Technical sharing solutions for the shared use of the 2300-2400 MHz Band” will be developed. Also, a report on LSA (ECC Report 205) was finalized and issued. The European Telecommunications Standards Institute (ETSI) Reconfigurable Radio Systems (RRS) technical committee continues to advance standardization activities on LSA technical conditions and geolocation databases. Two LSA work items are in development: LSA System Requirement (ETSI TS 103 154) and LSA System Architecture and High Level Procedures (ETSI TS 103 235). A System Reference Document related to LSA usage in 2.3-2.4GHz (ETSI TR 103 113) was issued in 2013.

ASA/LSA assigns secondary licenses that are similar in structure to dedicated, licensed spectrum with similar benefits. Spectrum use under LSA is binary; either the incumbent or the ASA/LSA licensee may operate in a given spectrum band at a given place and time. This allows for secure and dependable conditions that enable large-scale investment. A novel aspect of ASA/LSA licenses is that the licensee, in order to use the license, needs an agreement with the incumbent user that regulates the terms of shared use (e.g., geographical areas, technical conditions for protection and how to vacate the band when the incumbent needs the spectrum). Since ASA/LSA licensees are known and limited in number, the incumbent user will be quickly able to remedy interference concerns in the unlikely event they occur.

ASA/LSA regulations facilitate agreements between incumbents and mobile licensees through well-defined processes and standardized technical conditions. This approach could form the framework for the sharing environment described in the FCC's *3.5 GHz FNPRM*. Such an approach would serve to address many wireless industry concerns with the completely novel and unproven three-tiered approach proposed in the FNPRM. In this way, PAL licensees could use an ASA/LSA approach and thus create a trusted environment with incumbent users. In particular, spectrum geolocation databases, with standardized information elements, access protocols, and policy mechanisms, are an important component to enable incumbent protection, enforce national regulatory policies and objectives, and minimize restrictions to shared use by LSA licensees.

2.2 UNCOORDINATED SHARING

Uncoordinated spectrum sharing exists, for example, where multiple distinct systems operate in the same spectrum band on an unlicensed basis in the same relative area. It is generally characterized by low transmit power levels that limit the ability of the radios to interfere with one another. In essence, each radio system is responsible for sharing spectrum successfully. Examples include present-day 802.11 networks, Bluetooth systems and walkie-talkies which operate in the same unlicensed band (e.g., 2.4 GHz Industrial, Scientific and Medical (ISM), 5 GHz Unlicensed National Information Infrastructure (U-NII)). Rights of use for unlicensed (or license-exempt) equipment are typically based on demonstrating that the equipment meets specified technical conditions when it is presented for certification to the appropriate regulatory body or self-certified, depending upon jurisdiction.

More sophisticated unlicensed equipment follows an agreed or voluntarily assumed (by means of industry consensus or standardization) spectrum sharing etiquette. Contention resolution using Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) is one such accepted practice in unlicensed standards, such as IEEE 802.11 Wi-Fi systems. The IEEE 802.11 protocol also compels the radio to pause in its transmissions – creating a quiet period that allows other radios in the vicinity to transmit. The protocol also allows the receiving radio to ask for missing packets to be present in the event that packets are lost due to interference during transmission.

The sharing conditions result in systems that work well for short-range, best-efforts traffic, recognizing that degradation can occur in throughput capacity and, for some applications in quality, where multiple devices attempt to access the spectrum at the same time. However, highly engineered 802.11 networks in dense usage environments, such as stadiums, can deliver sufficient throughput even in the face of high demand. Design considerations include: reduction in cell size and corresponding increase in the number of cells, use of MIMO antenna technologies to allow different spatial streams to operate independently of each other, broad channelization, such as 802.11ac, which utilizes channels of 80 MHz or 160 MHz widths to achieve speeds of 1 Gbps or more and multi-band operation. These same technologies are increasingly being put to work in home environments, particularly to move video from room to room.

Unlicensed radios have also been required to share spectrum with completely different radio systems, such as government radar systems in the 5 GHz band, for example. The unlicensed radio is responsible for sharing the spectrum and using signal detection to determine if a local radar system is operating. With regard to the 5 GHz band, if a radar signal is detected, the unlicensed device must move to a different channel. This technique, known as Dynamic Frequency Selection (DFS) is used to avoid high-powered radar signals that are approximately 1 MHz wide.

There may be conditions in which an unlicensed device cannot detect the signals of a different radio system or the system requires special protection from interference, such as TV receivers that operate in the TV bands. These problems have tested the limits of radio-based sharing technologies and, in the case of the TV band, have resulted in implementation of database-administered sharing technologies in which the database provides permission for the unlicensed radio to operate, as explained above. The capabilities of radio-based signal detection and sharing databases will continue to advance as new bands are identified for spectrum sharing. Some of the advantages of uncoordinated sharing in unlicensed spectrum include the support for a large ecosystem of devices, neutral host support and support for analytics. These advantages have enabled Wi-Fi to flourish in unlicensed bands.

Though, uncoordinated sharing has created a convenient way of providing access to users in local environments, such as via Wi-Fi connectivity, yet it cannot support the same level of spectrum utilization as a commercial managed cellular network deployed using licensed spectrum.

3 ENGINEERING FUNDAMENTALS ON SPECTRUM SHARING

Interference management is the primary concern in any spectrum sharing scenario. Harmful interference in radio systems arises when a receiver is not able to successfully receive transmissions from the intended transmitter due to the reception of unintended signals. For successful spectrum sharing, a primary user needs to know that it can communicate without experiencing harmful interference and that it will be protected from interference caused by secondary and other users of the band.

At the simplest level, the Radio Frequency (RF) transmitter should be designed to generate clean signals within the assigned spectrum band and keep signals that are generated outside the transmit band below the defined levels for undesired signals. The receiver, likewise, must reliably demodulate the wanted signal and reject interference from unwanted signals. Two radio systems can coexist in the same environment with proper filtering and signal attenuation. Rules can be designed to provide compatibility between disparate systems.

The following are the important engineering issues to be considered in technical and policy discussions relating to spectrum sharing.

3.1 INTERFERENCE SOURCES

Due to today's emerging wireless applications and the concomitant spectrum scarcity, coexistence and sharing among disparate wireless systems becomes increasingly important as spectrum is being used more and more intensively. Things like separation distance between co-channel operations and frequency separation between adjacent channels are key considerations. Coexistence models use transmitter and receiver characteristics (which are delineated in the taxonomy appendix of this document) along with propagation models to derive geographical and/or frequency separation between systems.

A fundamental issue in sharing spectrum is to understand the impact that two or more technologies have on each other when operating on the same or adjacent frequency at the same time. The categories of interference that are of principal concern include co-channel coexistence issues along adjacent market boundaries and adjacent frequency interference issues within the same geographic locations.

3.1.1 CO-CHANNEL INTERFERENCE

This type of interference occurs when two or more systems operate in the same geographic area and are transmitting on the same frequency. Co-channel interference reduces the Signal-to-Noise Ratio (SNR), which, in turn, reduces throughput and can even interrupt communications when the SNR drops below the level necessary for a particular technology to operate effectively. Co-channel interference is problematic for many services. Unlike other forms of out-of-band interference, such as adjacent channel interference, this in-band interference problem cannot be corrected by filters or by improving the interference rejection capability of the receiver. Moreover, because the interference is occurring in-band, directly on the desired RF channels, improvements in receiver sensitivity actually make the receiver more susceptible to co-channel interference.

In addition, co-channel interference can occur over broader geographic areas than other types of interference. Co-channel interference can be mitigated by use of greater distance separations between co-channel emitters and by the use of directional antennas.

3.1.2 ADJACENT CHANNEL INTERFERENCE (ACI)

Adjacent Channel Interference (ACI) is the signal impairment that occurs within a receiver due to presence of strong out-of-band signals from a transmitter operating in an adjacent band. This occurs when filters within the receiver are unable to sufficiently attenuate the out-of-band signals which swamp the receiver's desired signal. High spectral efficiency can be attained in a network by placing adjacent channels close to each other with minimum guard band as long as adjacent channel interference can be effectively managed so that the system links do not experience performance degradation.

3.2 TRANSMITTER AND RECEIVER CHARACTERISTICS

The main objective and challenge for a radio designer is to build a transmitter that guarantees the quality of intended transmissions in the desired band and controls the level of unwanted emissions into bands outside the band of operation. The transmit power level and the magnitude of unwanted emissions directly influences inter-cell and intra-cell interference, which impacts the system's ability to maximize spectral efficiency.

The receiver is trying to reliably demodulate the desired signal and avoid susceptibility to interfering signals. A receiver's performance is based on its ability to be able to extract the desired signal from a noisy background environment. The key criteria for the systems to share the same (co-channel) or neighboring frequencies (adjacent channels) is determined by the transmit and receive characteristic of the two systems along with the appropriate adjustments for the propagation path loss and losses from clutter among others.

A number of transmitter and receiver parameters are described in the taxonomy appendix of this document.

3.3 RECEIVER STANDARDS

Since interference typically occurs in receivers, regulatory bodies are studying regulations regarding receiver performance. For example, the FCC TAC has a work group focused specifically on spectrum and receiver performance. [17] Regulatory bodies typically regulate transmitter performance by establishing power and OOBE limits and have traditionally refrained from regulating receivers. When allocating spectrum for new services, a realistic assessment of the potential for OOBE interference is analyzed to ensure the size of the appropriate guard bands. This assessment is beginning to consider performance and practical limits of commercially available transmitter and receiver filter technology.

The FCC has not yet promulgated regulations regarding receiver performance, and has allowed the marketplace to determine the appropriate receiver specifications that trade-off complexity versus susceptibility to interference. Realizing that inefficiently designed receivers may be more prone to interference and thus limit the number and type of transmitters that can operate within a given environment, the FCC is now seeking input on the adoption of receiver standards.

Industry associations and standards-setting bodies have published voluntary receiver standards for some radio services. Many manufacturers adhere to these standards in the interest of providing systems that perform uniformly across the ecosystem, thus creating economies of scale. As an example, the cellular industry has developed certain transmitter and receiver standards; and two primary examples are the standards created by the 3rd Generation Partnership Project (3GPP) and 3GPP2.[18] These requirements sufficiently protect licensed providers from harmful self-interference as well as from adjacent band interference from other operations. All such cellular mobile equipment must meet the industry-driven certification processes and interoperability testing. This process helps to ensure that mobile licensed spectrum is put to the most efficient use. The 3GPP transmitter and receiver industry-driven standards approach can serve as a guideline on transmitter and receiver standards for other systems.

4 TECHNIQUES THAT FACILITATE SPECTRUM SHARING IN AN LTE SYSTEM

LTE and LTE-Advanced cellular networks operate in a tightly managed radio environment where LTE base stations dynamically allocate resource blocks to users with a time granularity of 1 millisecond and frequency granularity of 180 kHz. There are a number of interference management techniques designed into LTE-Advanced specifications to help an LTE base station or device (depending upon uplink or downlink) manage the interference received from other nearby LTE base stations or devices (again depending upon uplink or downlink communications) which can be dynamic and unpredictable.

A managed LTE cellular network deploys sophisticated techniques to manage intra-system interference in a highly dynamic radio environment. In order to achieve the necessary level of spectrum efficiency and latency, network operation decisions are continually made on fine granular level with respect to both time and frequency. Most of the interference management techniques in an LTE system mitigate self-

[17] *See, http://transition.fcc.gov/oet/tac/tacdocs/reports/TACInterferenceLimitsIntrov1.0.pdf.*
[18] *http://www.3gpp.org/dynareport/36101.htm*
http://www.3gpp.org/dynareport/36104.htm

interference, where the level of interference is predictable and generally well known. In contrast, when diverse systems are sharing spectrum, the interference from various systems can vary tremendously across the coverage area. Different transmit power levels, signal waveforms and bandwidths are some of the parameters that lead to complexities in managing interference between non-LTE systems.

4.1 CARRIER AGGREGATION (CA)

To meet LTE-Advanced requirements, support of wider transmission bandwidths than the 20 MHz bandwidth specified in 3GPP Release 8 and 9 is necessary. The preferred solution to this is Carrier Aggregation (CA), which is a distinct feature of 4G LTE-Advanced. CA allows expansion of effective bandwidth delivered to a user terminal through combining radio resources across multiple bands. With CA, the signals in several discrete bands are aggregated to form a larger overall transmission bandwidth. Two or more carriers (with the same band or in different bands) can be aggregated to support wider transmission bandwidths of up to 100 MHz, which allows for much greater throughput and improved Quality of Experience (QoE).

4.2 TIME-DOMAIN MULTIPLEXING (TDM)

While carrier aggregation aims at isolating interference by segmenting spectrum, Time-Domain Multiplexing (TDM) techniques are targeted at using the same frequency channel on all layers of a Heterogeneous Network (HetNet) while leveraging the time domain to manage interference between the layers.

TDM techniques feature the suppression of transmissions in certain sub-frames of the aggressor base station. This reduces interference and allows the victim base station to schedule transmissions during these quiet sub-frames. However, transmission suppression typically is incomplete; rather some control signaling will continue to be broadcast for backward compatibility. Therefore, this technique is referred to as Almost Blank Subframe (ABS) and will take full form in LTE Release 11 when mobile User Equipment (UE) will be able to apply interference suppression to better receive control signaling from the victim (low-power) base station. ABS results in a base station losing capacity, but this is acceptable as ABS allows for many more small cells to be deployed.

4.3 SELF-ORGANIZING NETWORK (SON)

The increasing demand for mobile communications services must be met with additional spectrum as well as network densification. Densification involves the introduction of small cells and the use of cellular technology based on a flat network architecture to reduce latency, which has complicated the network planning needs: configuration, management, optimization and healing. Self-Organizing Network (SON) capabilities have become an essential element to address the increased network complexity and ensure efficient and optimal performance by providing the capability to self-monitor, organize and optimize performance. The three main elements that comprise SONs are described below.

Self-configuration: This element automates the configuration process for base stations, so there is as little manual intervention as possible. For example, the configuration process called Dynamic Radio Configuration (DRC) allows base stations to be adaptive to the current radio network topology by configuring parameters including the cell ID, initial power and antenna tilt settings, etc. Another configuration process is the update of the neighbor base station frequency table to facilitate handovers. It is necessary to have the correct neighbor frequencies in place, so a call or data connection is not dropped during roaming.

Self-optimization: Self-optimizing is a process to analyze the network performance and, based on the results; tune the operational characteristics of the network for efficiency. Specific optimization includes compensation for propagation conditions that are temporary, like foliage. Optimization can also be performed to support new traffic patterns. Additional optimization also is necessary whenever new base stations are added to the network, especially in proximity of existing base stations in the network so as to optimize overall performance.

Self-healing: Self-healing operations provide the detection and management of network faults. This is especially critical whenever there is cell degradation and the coverage area of the network is reduced. The role of self-healing operations is to establish key performance indicators as a baseline of operation. These indicators help determine when a fault has occurred. In some cases, the network operations and characteristics can be changed temporarily to avoid impacts on the network. Once the failure is identified, the next step is for administration and management centers to take action either through manual or automated functions to resolve the fault.

SON capabilities are essential to manage today's increasingly complicated cellular networks, for they provide an automated means of ensuring that networks operate efficiently and minimize the complexities involved in network planning, configuration management, optimization, fault detection, isolation and recovery functions.

4.4 COORDINATOED MULTIPOINT (COMP)

CoMP (Coordinated Multipoint), which is primarily designed to reduce inter-cell interference, aims to turn the inter-cell interference into a useful signal specifically at the cell border. CoMP must be supported by multiple geographically separated eNBs (Enhanced Node Base stations) to enable dynamic coordination in scheduling/joint transmission and joint processing of received signals. The multi-point transmission schemes discussed in LTE-Advanced include joint transmission and coordinated scheduling/beamforming. These schemes can be implemented in downlink and uplink as discussed below.

4.4.1 DOWNLINK COMP

In downlink CoMP, the Joint Processing (JP) can be realized in the form of Joint Transmission (JT) or Dynamic Point Selection (DPS). Both modes require detailed UE feedback on channel properties. In joint transmission, cooperating eNBs jointly transmit data to one or more corresponding UEs (Physical Downlink Shared Channel (PDSCH) transmission from multiple points) at a time which results in dynamic multi-point cooperation. In dynamic cell selection, UEs receive their data (PDSCH) from one cell at a time or effectively are handed over to the best cell considering the interference environment. In joint processing, the eNBs need to share the transmit data which would generally require high-capacity and low latency X2 interface between eNBs. On the other hand, Coordinated Scheduling/Coordinated Beamforming (CS/CB) can be realized only if the channel state information and scheduling information are shared among eNBs; data sharing is not required. In the CS/CB, a UE receives data from only one eNB, its own serving node, while the precoding and scheduling are coordinated among related eNBs in such a way to reduce interference and improve the throughput.

4.4.2 UPLINK COMP

For the case of Uplink (UL) CoMP, LTE-Advanced considers joint detection and coordinated scheduling / beamforming. Joint detection can be considered as an UL counterpart of the Downlink (DL) joint transmission. Data transmitted by the UE is received jointly at multiple points (part of or the entire CoMP cooperating set) at a time. For joint detection, eNBs need to share received signal samples as well as channel state information and scheduling information. For CS/CB, user scheduling and precoding selection decisions are made with coordination among the corresponding CoMP cooperating points and data is intended for one point only.

4.5 INTER-CELL INTERFERENCE COORDINATION (ICIC)/ENHANCED ICIC (EICIC)

4.5.1 INTER-CELL INTERFERENCE COORDINATION (ICIC)

The basic idea of Inter-cell Interference Coordination (ICIC) is to avoid having mobile stations served by neighboring base stations scheduled on the same resource blocks (i.e., time and frequency resources) with too much power.

The ICIC methods covered in LTE Release 8 and 9 are mainly designed for macro-layer and focus on interference control of physical data channel. They are generally frequency-domain techniques and can be divided into static or dynamic categories. An example of static methods is Fractional Frequency Reuse (FFR) which involves partitioning the usable spectrum into a number of sub-bands and assigning a given sub-band to a cell in a coordinated manner that minimizes inter-cell interference. Such a static pattern, though effective in reducing the inter-cell interference, may not improve the overall throughput of the system.

Dynamic ICIC methods can be proactive or reactive. In proactive techniques, the eNB avoids scheduling on resource blocks where a neighbor UE has been scheduled, and in reactive methods, the eNBs inform each other about high interference through X2 signaling.

LTE facilitates reactive dynamic ICIC through the use of reactive DL Relative Narrowband Transmit Power (RNTP), and UL Overload Indicators (OI). A cell will use the RNTP indicator to inform neighboring cells which DL resource blocks it is using to serve UEs within the cell, as well as the transmit power level for the corresponding resource blocks. The OI is used to inform neighboring eNBs of another eNBs self-estimated interference level on UL resource blocks. When other eNBs receive this information, they would attempt to reschedule or reduce activities on those resource blocks. LTE also defines proactive UL High Interference Indicators (HII). This indicator allows one eNB to warn neighboring eNBs that certain UL resource blocks will be heavily loaded in the near future to serve its own cell-edge UEs. Other eNBs would abstain from using those resource blocks to avoid mutual interference.

4.5.2 ENHANCED INTER-CELL INTERFERENCE COORDINATION (EICIC)

The Enhanced Inter-cell Interference Coordination (eICIC) mechanism is designed to solve downlink interference challenges that arise in co-channel deployment of macro, pico and femto cells. They extend the ICIC improvements to both physical data and control channels. The concept relies on accurate time- and phase-synchronization on a 1 millisecond (subframe duration) basis between all base station nodes within the same geographical area. A base station reduces the interference to its surrounding neighbors by using so-called Almost Blank Subframes (ABS). An ABS is characterized by minimum transmission, where just the most essential information required for the system is transmitted. Thus, during ABS, the signals that are mainly transmitted are Common Reference Signals (CRS), as well as other mandatory system information. Compared to a subframe with normal transmission, the average transmission power from an ABS is reduced considerably. However, the reduced power can, in some cases, still result in interference problems. It is therefore often assumed that eICIC is operated together with advanced UE receivers that are capable of further suppression of the residual interference from ABS, so UEs virtually experience close to zero interference from base station nodes using ABS.

4.6 MULTIPLE-INPUT AND MULTIPLE-OUTPUT (MIMO)

Multiple-Input and Multiple-Output (MIMO) technology offers significant improvements in data throughput and range of a communications network without additional bandwidth or increased transmit power through the use of multiple antennas at both the transmitter and receiver. MIMO provides these performance enhancements by taking advantage of natural radio-wave phenomenon called multipath. Multipath occurs when the radio transmission arrives at the receiver by more than one path. This can occur by reflection and refraction of the transmission from terrestrial objects such as mountains, buildings and other objects. Therefore multiplexing is considered a source of interference to transmissions as they cause errors and affect the quality of communications.

MIMO takes advantage of multipath behavior by spreading the transmission power over multiple transmit antennas and receiving the transmission via multiple receive antennas. Combining individual transmissions from different paths and at different times creates an array gain that improves the number of bits per second per hertz of bandwidth that can be transmitted. Multiple antennas also have an added spatial dimension. When there are more antennas than spatial streams, the antennas can add receiver diversity. Receiver diversity can help reduce radio link fading and thereby increase reliability. With array gain and receiver diversity, MIMO systems provide significant capacity gains over conventional single antenna systems, and increase the overall communications reliability.

4.7 LICENSED-ASSISTED ACCESS

The challenge to support ever increasing traffic demands is fueling new innovation to increase the capacity of cellular networks. Recognizing that opportunities to address the capacity needs of networks with dedicated, licensed spectrum are increasingly difficult, cellular networks need to look at other sources of spectrum to fill-in including unlicensed spectrum.

Complementing the LTE platform with unlicensed spectrum is a natural choice as it would enable the cellular industry to leverage existing or planned investments in LTE Evolved Packed Core hardware in the radio and core network. However, unlicensed spectrum is viewed as a complement to licensed spectrum. Therefore the focus during the standardization process, currently within 3GPP, will likely be on Licensed-Assisted Access (LAA), a carrier aggregation operation where a primary licensed band is used to deliver critical information and guaranteed quality of service and is coupled with a secondary band in unlicensed spectrum to opportunistically boost data rates. The unlicensed spectrum can be used for downlink only (Supplemental Downlink (SDL)) as well as for both downlink and uplink. Hence, LAA uses both licensed and unlicensed spectrum, where the primary LTE carrier uses licensed spectrum and, through carrier aggregation, the secondary LTE carrier(s) use unlicensed spectrum.

However, operating on unlicensed spectrum may have design implications for LTE, which are currently being studied in 3GPP. For instance, in some regions in the world, unlicensed technologies need to abide by certain regulations (e.g., Listen-Before-Talk (LBT), radar protection, or transmit power limitations). In addition, LAA is expected to coexist with other technologies such as WiFi as well as between LTE operators utilizing the same unlicensed spectrum. Licensed-Assisted Access must also support equitable access to the unlicensed spectrum with these shared users. A study is currently underway to determine which enhancements to LTE are needed to enable licensed-assisted access to unlicensed spectrum coexisting with other technologies and fulfilling the regulatory requirements. Licensed-Assisted Access holds great promise in helping to address the current capacity constraints of cellular networks by utilizing unlicensed spectrum to increase the network throughput and QoE. The innovative use of unlicensed spectrum as a complement to licensed deployments benefits from the scale and investment that have been made in the LTE ecosystem.

5 CHALLENGES OF SPECTRUM SHARING

Spectrum is a scarce resource. In current cellular networks, spectrum reuse and radio resource management techniques are designed to optimize spectrum use and to achieve the maximum efficiency. In order to do universal frequency reuse in a coordinated fashion, the infrastructure has to be aware of how spectrum is being used in a geographical area, and may use this knowledge to manage how spectrum is allocated to specific systems by assigning a specific channel to a system. In fact, many of the innovations in cellular technology have been methods used to actually decrease noise in the channel in order to push the theoretical speeds further up the curve of Shannon's Law (*i.e.,* the lower the interference, the higher the capacity gains).

5.1 IN LTE SYSTEMS

Strict requirements are met in a highly spectrally efficient technology such as LTE because it is designed to operate in high-interference environments by having the ability to selectively use a subset of subcarriers at particular times and to avoid frequencies which are subject to excessive interference. The LTE system has intimate knowledge and estimation of the interfering OFDMA channel in a fast changing RF environment; it has adaptable transmission modes and defined protocols between interfaces, all of which is achieved with low latency and minimal power consumption.

In a closed system like LTE, managing interference is the crux of advanced LTE techniques. The interference tolerance and avoidance features of LTE that enables effective sharing that LTE was designed for is self-interference, namely from those same subcarriers being used by LTE in neighboring cells. That level of interference is predictable and somewhat consistent across cells and across city-by-city deployments. In contrast, the interference from diverse systems could vary tremendously across the coverage area.

5.2 IN 3.5 GHZ

In the 3.5 GHz band, as proposed by the FCC in the recent *FNPRM*, a three-tiered Spectrum Access System (SAS) is recommended with an associated licensing approach which can be complicated and completely novel, thus requiring substantial testing and proof-of-concept efforts before it can be implemented. All three tiers of spectrum users must have confidence in the SAS's management capabilities. Federal incumbent users must be comfortable that the SAS will protect existing operations. Priority Access Licensees (PAL) must have certainty that they will not experience harmful interference in their authorized spectrum and that it will not mistakenly be reallocated to other users. General Authorized Access (GAA) users must also have confidence that SAS algorithms will permit dynamic use of available spectrum without causing interference to higher tier users. The FCC should adopt a detailed transitional licensing approach, enabling immediate use of this spectrum while the SAS is further developed and refined.

The inter-cell interference coordination techniques (ICIC, eICIC, and CoMP) discussed above by and large depends on the UE signal level measurement and the interference environment reports. It is important to recognize that these UE reports in most cases are required on a very short time frame basis. Furthermore, the information exchange between the cooperating nodes has to occur with a very small time delay, which in most cases requires low latency inter-node communication. For any external system like SAS to implement similar interference coordination mechanisms among different systems, (such as multiple operators' systems in 3.5 GHz band) handling and processing of very large amount of Citizen Band Service Device (CBSD) measurement data and the required low latency backhaul from CBSDs to the SAS does not seem feasible. It is more practical to leave interference coordination mechanisms to the affected parties, especially in the case of PALs.

5.3 SPECTRUM COORDINATION ACROSS INTERNATIONAL BORDERS

Arrangements for cross-border coordination are broadly specified in global regulations developed by the ITU-R, and in regional regulations developed by organizations such as CITEL. In general, each country has sovereign authority over the spectrum within its borders. Spectrum sharing is essential near international borders where wireless systems can interfere with operations in a neighboring country's territory. In these scenarios, nations typically will negotiate cross-border coordination agreements with each other in order to mitigate any extraterritorial interference. These arrangements derive their legal authority from treaties between the nations. Today, there are agreements for terrestrial wireless and broadcast systems, satellite systems and other technologies.

Cross-border coordination agreements are negotiated between the appropriate national regulatory agencies, which could include the Federal Communications Commission (FCC), National Telecommunications and Information Administration (NTIA), Industry Canada (IC), Instituto Federal de Telecomunicaciones (IFT) and other agencies. Separate agreements are negotiated for each border by the countries on both sides of the relevant border (e.g., United States-Canada and United States-Mexico).[19]

There are generally separate agreements for each frequency band or technology. The objective of these agreements is to provide interference protection for users while making efficient use of spectrum. These agreements generally provide high-level guidance to operators on how to configure systems to minimize cross-border interference. In those situations where these measures are inadequate to prevent interference, the agencies often will negotiate a remedy on a case-by-case basis.

In many cases, operators' spectrum sharing agreements apply only to those frequency bands in which the operator has a license for exclusive use of the spectrum. The spectrum sharing agreements generally extend that exclusivity right up to the border, but not beyond. For example, there is considerable overlap

[19] For the United States, current agreements can be found on the FCC website at: http://www.fcc.gov/encyclopedia/international-agreements. For Canada, current agreements can be found on the website of IC at: http://www.ic.gc.ca/eic/site/smt-gst.nsf/en/h_sf06010.html. For Mexico, current agreements can be found on the website of IFT at: http://www.ift.org.mx/iftweb/industria-2/unidad-de-prospectiva-y-regulacion/internacional/

in the cellular band between systems operated by AT&T and Verizon in the Buffalo, New York area, and systems operated by Rogers and Bell in the Fort Erie, Ontario area. The spectrum sharing agreements along this border area permit spectrum sharing only to the extent that the operators are able to engineer their systems to minimize cross-border coverage. Despite their best efforts, users experience "accidental roaming" where they roam onto the network of an operator on the other side of the border.

Spectrum sharing agreements are not used for low power opportunistic technologies, such as WiFi, because the impacts of cross border interference are negligible and are typically remedied via self-help when they do occur.

International coordination across borders involving licensed services is easier for all parties if the band plans, transmitter power, and other characteristics of services are the same or similar on both sides of the border. Mobile broadband services generally fall into this category, as the band plans and technologies are generally aligned.

It may be challenging for regulators in the United States and Canada to manage interference in the 600 MHz band where the U.S. is in the process of converting this band from high power broadcast television service to low power mobile broadband service, while Canada has not begun the transition. During the transition period in the U.S., there likely will be interference from Canadian TV broadcasters into U.S. mobile broadband networks along the border, which will diminish when Canada similarly transitions its 600 MHz band spectrum.

International spectrum sharing agreements are essential for those services which cross national borders; examples include air-to-ground services for commercial aircraft, broadcast television and satellite based services. In these cases, the coverage area may be large and/or moving, so that interference into the neighbor country must be regulated by international agreement.

5.4 ONGOING WORK

NTIA performed interference-effects testing between radar signals and broadband digital communication receivers in the 3.5 GHz band and issued two reports describing the results of the testing. The first provides the results of measurements and analyses of the effects of radar interference on prototype LTE equipment. The second presents the results of measurements and analyses of the effects of LTE interference on a type of radar receiver that may eventually share spectrum with LTE systems.[20] Taken together, these reports express optimism that the data NTIA collected can be used to refine and update the 2010 *Fast Track Report* for future spectrum sharing between LTE and radars in the 3.5 GHz band. In particular, the reports provide data that can be used by spectrum managers and engineers as building blocks in constructing band sharing criteria with reduced Federal incumbent exclusion zones. The FCC should consider these NTIA reports and analyses in re-crafting smaller exclusion zones that will foster investment and innovation in the 3.5 GHz band.

In addition, the Department of Defense (DoD) is studying the concept of real-time sharing with radar systems through Defense Advanced Research Projects Agency's (DARPA) Shared Spectrum Access for Radar Communications (SSPARC)) program. SSPARC seeks to develop sharing technology that enables

[20] NTIA, EMC Measurements for Spectrum Sharing Between LTE Signals and Radar Receivers, NTIA Technical Report No. 14-507 (rel. Jul. 2014) ("Report 14-507"), *available at* http://www.its.bldrdoc.gov/publications/2760.aspx. See also NTIA Technical Report TR-14-506: Effects of Radar Interference on LTE (FDD) eNodeB and UE Receiver Performance in the 3.5 GHz Band (rel. July 2014).

sufficient spectrum access in the 2 GHz to 4 GHz bands for radar and communications systems to accomplish their evolving missions while still permitting communications systems to operate. The program includes research on the following mitigation mechanisms to improve performance or reduce interference when sharing spectrum:

- Radar beam avoidance by communications systems
- Communication nodes adjust transmit power based on measured path loss to the radar receivers
- Identify the specific devices causing interference followed by modifying their transmission parameters to mitigate it
- Hardware components, subsystems, waveforms and signal processing methods that improve separation

While SSPARC is a research project, it could evolve to become (or at least to support) the Federal SAS described above.

Certainty and transparency for licensees are the cornerstones of any successful licensing regime. Without certainty regarding licensees' spectrum rights, investment in the 3.5 GHz band will be hindered and innovation will be stifled. A regulatory regime for the 3.5 GHz band that provides greater certainty and provides greater predictability to prospective licensees will help ensure that the spectrum is put to its highest and most productive use.

6 SPECTRUM SHARING IN 5G NETWORKKS

Change is constant. Even while 4G networks and technologies are being deployed and further enhanced, the industry is looking toward the next generation, the next big thing and the next challenge to providing even greater capabilities with wireless data. The industry has begun discussions of the topics that will be of importance to 4G LTE networks as they continue to mature. Key to those discussions will be what changes to spectrum sharing are to be made to address the future applications, usage patterns and information delivery business models of 5G networks. The term 5G is commonly used to describe that next step.

Details on 5G requirements and technologies are being captured by 4G Americas in another white paper.[21] That paper explains that the timeframe for 5G implementation will be 2020 and explains that "the concepts of spectrum sharing and unlicensed operations must be part of any 5G vision." Thus, any discussion of spectrum sharing must also consider forward compatibility in the 5G world and beyond.

5G systems are expected to have advanced inter-node coordination which would improve the spectrum sharing techniques. For example, centralization of radio processing functions (one of the contemplated 5G features) reduces the signaling burden and would therefore be a driver for efficient inter-node coordination. Other techniques like massive MIMO would enable highly directive beam-forming which indirectly would help in interference coordination

While regional discussions on 5G are occurring, the ITU-R has been working to update its 5G vision. Tentatively called International Mobile Telecommunications 2020 (IMT-2020), it is still a work in progress

[21] http://www.4gamericas.org/index.cfm?fuseaction=page&sectionid=334

within the ITU-R WP5D.[22] ITU-R IMT-Vision and other projects within ITU-R WP5D are evaluating the needs for sharing in near term and longer term evolutions. As of yet, no unique 5G items have been included.

When the discussions of 5G spectrum sharing requirements are being addressed, it is important to remember that 5G is still in the initial stages of being defined. There are no 5G standards in place at this time, nor is there any technology that could be termed 5G when this paper is being published. It is fair to assume, however, that many of the spectrum sharing issues discussed for 4G is this paper will also apply to 5G.

5G discussions around the globe have focused on being able to support denser distributions of users with higher average data rates than what is currently being deployed. To do this many new ideas focus on the use of small cells and new spectrum above 6 GHz, such as in mm-wave frequencies. The idea of allocating spectrum above 6 GHz for use by cellular is not new. It is being considered in the ITU-R. There is higher band spectrum being considered as potential candidate bands for mobile use at WRC-15, yet it is likely that the higher bands will discussed at WRC-19 as new opportunities are realized. Sharing is likely to play an important role in these bands as much of the higher band spectrum is occupied by other users.

7 SPECTRUM SHARING RECOMMENDATION FROM TAC

The FCC's Technological Advisory Council (TAC) has been looking at spectrum sharing issues over the past several years. In 2013, the TAC published a white paper titled, "The Use of Harm Claim Thresholds to Improve the Interference Tolerance of Wireless Systems." It proposes, among other things, that spectrum use can be made more efficient by introducing an "interference limits" policy for receivers. This involves establishing ceilings, called harm claim thresholds, on in-band and out-of-band interfering signals that must be exceeded before a radio system can claim that it is experiencing harmful interference. The TAC believes that this will allow the FCC to provide guidance on improving receiver performance, but not prevent manufacturers from using improved technology or impact their business decisions on receiver performance.

In 2014, the TAC established a working group to specifically deal with spectrum sharing. The working group defined three basic types of spectrum sharing:

- Separation in space: Operate primary and secondary systems in mutually exclusive / non-overlapping areas of space allowing concurrent use of same channel

- Separation in Time: Primary and secondary systems operate in same space and frequency but transmit at mutually exclusive times

- Separation in Frequency: (Dynamically) assign different frequencies to primary and secondary systems for concurrent operations in space and time

They then identified four different approaches to sharing:

[22] http://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/Pages/default.aspx

- Dynamic Frequency Sensing and Switching (DFS), e.g., used in 5 GHz
- Spectrum Coordination through Static Exclusion Zones, e.g., planned for AWS-3
- Database approach to spectrum management:
    - Static/Passive Spectrum Coordination in TV White Space
        - Database simply provides a list of available spectrum
        - Usage follows unlicensed type access
        - Static rules for max power levels/masks
    - Dynamic Spectrum Access System (SAS) pilots in 3.5 GHz
        - A granular (time, location, frequency) and dynamic approach to spectrum management
        - Database (re)assigns specific channels and sets max power levels based on deployment
        - Supports three tiers of access including priority/licensed access and general authorized access

The FCC has also created two sub-working groups within the spectrum sharing working group: (1) Database Sub-Working Group (DB-SubWG) and (2) Enabling Technologies Sub-Working Group (ET-SubWG). The sub-working groups are described below.

7.1 DATABASE STRUCTURE SUB-WORKING GROUP (DB-SUBWG)

This sub-working group is tasked with studying issues related to the design of the SAS. The charter of this group is to: "Develop requirements for the architecture and interfaces of an advanced Spectrum Sharing database, and investigate options for improving the efficiency and capability of database operation by increased coordination with licensee's systems." The sub-working group has identified possible areas of further study including:

- Core Architecture and Database processes
- Multi-Tier Access in Spectrum Sharing
- Interference Modeling/Prediction
- Additional degrees of coordination to improve efficiency
- Mechanisms to enhance enforcement and compliance
- Using interference measurements to detect devices operating outside defined rules
- Technologies to aid in restricting devices to compliant modes of operation

7.2 ENABLING TECHNOLOGIES SUB-WORKING GROUP (ET-SUBWG)

This sub-working group focuses on investigation of technologies that help and enhance spectrum sharing. The scope of work is broad and presently focused on: (1) interference cancellation technology to enable co-existence, (2) indoor-only services as a feasible means to achieve coexistence and developing better understanding of indoor propagation from outdoor sources at various bands, (3) better understanding of primary characteristics such as RADARs and (4) evaluation of various spectrum bands to propose candidate bands for spectrum sharing.

8 SUMMARY AND CONCLUSIONS

Spectrum is fundamental to the success of mobile wireless communications and the industry has relied on the exclusive spectrum license as a key asset that provides investment certainty and helps assure high service quality and reliability for the end user. These factors are critical to the competitive environment service providers operate in and drive them to invest billions of dollars each year to expand their network reliability, capacity and coverage.

The scarcity of spectrum has created a need for greater flexibility in making use of new frequency bands while still maintaining the certainty and service quality supported by licensed spectrum. For instance, there are many situations in which a given frequency band is not uniformly used by a primary user in all locations and at all times. Commercial mobile broadband may be able to benefit by reusing such spectrum on a shared basis.

However, the sharing environment must be well defined, commercially feasible and suitable for the provision of the envisioned services. As such, spectrum sharing may be possible as a complement to commercial, wide-area networks that today operate using exclusively licensed spectrum. Spectrum that is available over most of the nation, barring certain limited exclusion zones, is far more valuable to mass-market applications, such as cellular systems, than spectrum that is excluded from use in metropolitan areas and solely available for use in rural areas. Sharing criteria with restrictive constraints such as low transmit output power have a profound impact on the business case for sharing, because they may unduly limit the type of services for which the band can be used or increase costs to the point of economic infeasibility.

This paper has also explained that spectrum can be shared in several discrete dimensions including: time, space and frequency. Current spectrum sharing schemes between disparate systems that operate within the same spectrum band may be achieved through a coordinated or an uncoordinated approach, or a hybrid combination of such mechanisms, depending on the desired coverage area and user base performance levels required.

Interference management is the primary concern in any spectrum sharing scenario. A primary user needs to know that they can communicate without receiving harmful interference and that they will be protected from interference caused by secondary and other users of the band. For this reason, an exclusively licensed spectrum environment considerably simplifies the interference situation when compared to a shared environment. The licensee’s exclusive access to its spectrum creates an environment of predictable interference and access, and thus there is a level of protection from external co-channel interference.

Also, managing interference in a sharing environment is extremely challenging considering current wireless networks are designed with spectrum reuse and radio resource management techniques that are utilized to optimize spectral efficiency. In order to do universal frequency reuse in a coordinated fashion, the infrastructure has to be aware of how spectrum is being used in a geographical area so it can use this knowledge to manage how spectrum is allocated. Taken together, these algorithms provide spectrum re-provisioning and bandwidth-allocating solutions while managing interference between cells that would reduce capacity. These techniques generally fall under the categories of interference coordination or cancellation and are critical components to the operation of these networks and must be recognized in any sharing solution.

When a band of spectrum is contemplated for shared access, consideration must be afforded for both the existing use (and potential future uses) and the desired use of that spectrum. The context should also be considered to determine how or whether or not sharing can be accomplished from economic, technical and operational perspectives. Meanwhile, mobile broadband networks continue to evolve with even greater capabilities to support increased traffic demands and a variety of new use cases.

The industry has begun discussions of which topics will be of importance to the evolution of today's networks as they continue to mature. The key to those discussions will be what changes to spectrum sharing can be made to address the future applications, usage patterns and information delivery business models of 5G. What will remain important is that regulatory certainty is the common thread that provides network operators not only with an incentive to invest in new networks, but also to continuously upgrade their networks to compete with others and to expand capacity and bandwidth.

Therefore, any spectrum sharing mechanism under consideration will likely require further technology research and development, testing and refinement to ensure that it provides sufficient protection to the primary users of the spectrum while providing beneficial new broadband capacity. Unproven assumptions about the operational environment create regulatory and technical uncertainty can impede investment and innovation by the private and public sectors.

4G Americas is excited about the future of spectrum sharing. Notwithstanding, it will be even more important to continue to provide additional exclusive licensed spectrum for mobile broadband via band clearing and more efficient spectrum use by the current incumbent users in bands targeted for future mobile broadband use.

LIST OF ACRONYMS

3GPP	3rd Generation Partnership Project
ABS	Almost Blank Subframe
ACIR	Adjacent Channel Interference Ratio
ACLR	Adjacent Channel Leakage Ratio
ACS	Adjacent Channel Selectivity
AWS-3	Advanced Wireless Service
CA	Carrier Aggregation
CBSD	Citizen Band Service Device
CBRS	Citizens Broadband Radio Service
CITEL	Inter-American Telecommunication Commission
CMRS	Commercial Mobile Radio Systems
CoMP	Coordinated Multipoint
CS/CB	Coordinated Scheduling and Beamforming
CSMA	Carrier Sense Multiple Access
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
CSMAC	Commerce Spectrum Management Advisory Committee
DARPA	Defense Advanced Research Projects Agency
DB-SubWG	Database Sub Working Group
DL	Downlink
DoD	Department of Defense
DPS	Dynamic Point Selection
DRC	Dynamic Radio Configuration
eICIC	Enhanced Inter-cell Interference
eNB	Enhanced Node Base station
ET-SubWG	Enabling Technologies Sub-Working Group
FCC	Federal Communications Commission
FFR	Fractional Frequency Reuse
FNPRM	Further Notice of Proposed Rulemaking
FSS	Fixed Satellite Service
GAA	General Authorized Access
HetNet	Heterogeneous Network
HII	High Interference Indicator
HTTP	Hypertext Transfer Protocol
IC	Industry Canada
ICIC	Inter-cell Interference
IEEE	Institute of Electrical and Electronics Engineers
IETF	The Internet Engineering Task Force
IF	Intermediate Frequency
IFT	Instituto Federal de Telecomunicaciones
IMT	International Mobile Telecommunications
IM	Intermodulation
IPC	Interference Protection Criteria
ISM	Industrial, Scientific and Medical
ITU-R	International Telecommunication Union - Radiocommunication
JP	Joint Processing
JT	Joint Transmission

kHz	kilohertz
LAA	Licensed-Assisted Access
LBT	Listen-Before-Talk
LPAux	Low Power Auxiliary
LSA	Licensed Shared Access
LTE	Long Term Evolution
MHz	Megahertz
MIMO	Multiple-Input and Multiple-Output
NPRM	Notice of Proposed Rule Making
NTIA	National Telecommunications and Information Administration
OFDMA	Orthogonal Frequency-Division Multiple Access
OI	Overload Indicators
OOBE	Out-of-Band Emissions
PAA	Priority Authorized Access
PAL	Priority Access Licensee
PAWS	Protocol to Access White Space Database
PDSCH	Physical Downlink Shared Channel
QoE	Quality of (User) Experience
QoS	Quality of Service
RF	Radio Frequency
RNTP	Relative Narrowband Transmit Power
SAS	Spectrum Access System
SDL	Supplemental Downlink
SEM	Spectrum Emission Mask
SINR	Signal to Interference & Noise Ratio
SNR	Signal-to-Noise Ratio
SON	Self-Organizing Network
SSL/TLS	Secure Sockets Layer / Transport Layer Security
SSPARC	Shared Spectrum Access for Radar and Communications
TAC	Technological Advisory Council
TDM	Time-Domain Multiplexing
TVBD	Television Band Devices
TVWS	Television White Spaces
UE	User Equipment (e.g., a smartphone)
UL	Uplink
U-NII	Unlicensed National Information Infrastructure
WiMAX	Worldwide Interoperability for Microwave Access
WRAN or Wi-FAR	Wireless Regional Area Networks
WSDBA	White Space Database Administrator

TAXONOMY

Adjacent Channel Interference Ratio	*ACIR* – The ACS and the ACIR together define Adjacent Channel Interference Ratio. It is the ratio of the total power transmitted from a source to the total interference power affecting a victim receiver resulting from both transmitters and receiver imperfections. (ACIR = 1/1/ACLR+ 1/ACS). ACIR is a term extensively used in coexistence studies.
Adjacent Channel Leakage Ratio	ACLR is defined as the ratio of the transmitted power to the power in the adjacent radio channel. Both powers are measured after a receiver filter. It measures the power that leaks into the nearby radio channel. Leakage power influences the system capacity as it interferes with the transmission in adjacent channels. It must be rigorously controlled to guarantee communication for all end users.
Adjacent Channel Selectivity	ACS is a measure of the receiver's ability to receive the desired signal in its assigned frequency channel in the presence of adjacent channel interfering signal at a given frequency offset. It measures the power that leaks into the adjacent radio channel. It estimates how much of the neighboring radio receiver is impacted by OOBE from the transmitter leakage power in the adjacent channels. Leakage power influences the system capacity as it interferes with the transmission in adjacent channels. It must be rigorously controlled to follow the system specification and guarantee communication for all subscribers under the specified network.
Coordination Zone	See Protection Zone.
Desensitization	Desensitization is the measure of a receiver's ability to reject off-channel signals. Desensitization of a desired signal at reference sensitivity level due to an adjacent channel signal is called Adjacent Channel Rejection.
Exclusion Zone	An Exclusion Zone is an area around a protected system where operation of any other system (not associated with the protected system) is prohibited.
Out of Band Emissions	OOBE is unwanted transmitter emissions that fall outside of the transmitter's intended channel bandwidth .This noise splatters into the adjacent channels and into other bands, generally getting smaller and smaller in strength as the frequency offset from the transmitter band increases. Increasing the power level of the wanted transmission signal will usually increase the level of unwanted OOBE. One of the strongest constraints for the maximum power of a UE is the need to meet the OOBE requirements set by the FCC in USA and ITU for IMT2000 family of products. Because the interference is on-channel to the neighboring band receiver, there is nothing that can be done

	at the neighboring band receiver to mitigate interference.
Protection Zone	A Protection Zone is an area around a protected system where operation of any other system (not associated with the protected system) may be permitted under certain circumstances. Usually these circumstances require some type of coordination with the entity responsible for the protected device or system. An example of a Protection Zone is the area around certain Radio Astronomy (RA) sites where operation within the Zone may be permitted with permission from the entity controlling the RA site. Protection Zones are sometimes called Sharing Zones or Coordination zones.
Receiver Blocking	Receiver Blocking is a measure of receiver's ability to receive the wanted signal at its assigned channel frequency in the presence of interfering signal in the adjacent band and beyond. The receiver front end can be overloaded by a single high level unwanted signal, residing outside of the desired channel.
Receiver intermodulation	Receiver IM is the result of mixing two or more over-the-air signals within a radio's receiver circuitry such that the mix products fall within the IF bandwidth of the receiver and add to its thermal noise floor, thus reducing the receiver sensitivity
Receiver noise figure	The receiver noise figure is a measured SNR degradation within a receiving system caused by components in the RF signal chain. This includes the antenna filter losses; noise introduced by the analog part of the receiver and other noise sources.
Receiver sensitivity	Receiver sensitivity is the ability of the radio receiver to pick up the required level of radio signals to enable it to operate more effectively within its application.
Reference sensitivity power level	Reference sensitivity power level is the minimum mean received signal strength applied at the antenna port at which there is a sufficient SINR for a specific modulation scheme to meet ≥ 95% of the maximum throughput possible. In LTE, RFEFSENS is specified over a range of channel bandwidth and likely modulation and coding schemes. The link budget uses the receiver sensitivity of channel to estimate the coverage limit of a system designed for a particular throughput requirement at the cell edge.
Sharing Zone	See Protection Zone.
Spectrum emission mask	SEM is a mask defined for out of channel emission relative to in-channel power. This mask provides the key input in dictating spectrum sharing

	among systems.
Thermal noise floor	Thermal noise floor is also represented by the term kTB depends on a specified channel bandwidth (B) In specifications the thermal noise density, kT, is defined to be -174 dBm/Hz where k is the Boltzmann's constant (1.380662 x10-23) and T is the room temperature at 290K or 17^{o}C.

ACKNOWLEDGEMENTS

The mission of 4G Americas is to advocate for and foster the advancement and full capabilities of the 3GPP family of mobile broadband technologies, including LTE-Advanced, throughout the ecosystem's networks, services, applications and wirelessly connected devices in the Americas. 4G Americas' Board of Governors members include Alcatel-Lucent, América Móvil, AT&T, Cable & Wireless, Cisco, CommScope, Intel, Ericsson, HP, Mavenir Systems, Nokia, Openwave Mobility, Qualcomm, Rogers, Sprint, T-Mobile USA and Telefónica.

4G Americas would like to recognize the significant project leadership and important contributions of Neeti Tandon of AT&T and her able staff of magicians, as well as representatives from the other member companies on 4G Americas' Board of Governors who participated in the development of this white paper.