COMMERCE SPECTRUM MANAGEMENT ADVISORY COMMITTEE (CSMAC)

5G SUBCOMMITTEE

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1 NTIA QUESTIONS

1.1 Question: What technologies (including waveforms and architectures) might be included in 5G standards to facilitate sharing between federal and non-federal systems?

1.1.1 Response

1.1.1.1 Interference Suppression / Interference Cancellation

Interference Suppression / Interference Cancellation are candidates for inclusion in 3GPP 5G standards, and can be exploited to facilitate sharing between federal and non-federal systems. There are already several techniques in study phase for inclusion into New Radio (3GPP term for 5G), and in LTE Release 13/14, which are explicitly designed to reduce or cancel interference. For the most part, these techniques are intended to address inter-site cell interference concerns and are focused on managing interference within the technology.

1.1.1.2 Transmitter Techniques

The advanced antenna technologies developed for New Radio (NR) such as beamforming, active antenna system (AAS), massive Multiple Input Multiple Output (MIMO) and network/cooperative MIMO can help reduce interference in a shared environment and thereby increase access to the spectrum.

In addition, some of the techniques being considered on transmitter side are Interference Information exchanges over sidehaul (base-station to base-station link) to allow individual nodes to coordinate transmissions and avoid interference by enabling scheduler optimizations to coordinate individual scheduling decisions to be orthogonal in time and/or frequency. Another technique is beam-forming coordination to limit overlap of directional transmission beams. Interference aware power control to restrict transmit power in order to prevent interference is also a transmitter technique.

1.1.1.3 Receiver Techniques

Both interference suppression and interference cancellation are possible. For interference suppression, information about the interferer (assuming co-channel interference) is not required. Usually adjacent channel interference is reduced using filtering. On the receiver side for interference suppression, a MIMO degree of freedom is reduced to avoid admitting energy from a desired direction.

The assumption of technology neutrality limits how effective commercial systems can implement improved techniques like interference cancellation, which are only possible to a limited extent because of the need for greater knowledge of the interference environment. When considering interference cancellation to help facilitate sharing with federal systems, the degree of knowledge of the waveform and channel matters. If exact knowledge of the channel is available to the federal user and the 5G mobile user and knowledge of the source waveform is known, interference cancellation techniques can be performed more effectively. Alternatively, if the direction and angular spread of the channel towards a federal victim receiver (*e.g.,* Fixed Satellite Service) is known, attenuation of the channel response towards the victim using antenna techniques is possible. If the federal system is radar, knowledge of the waveform would not be used explicitly. In this case, sensing techniques are necessary to understand the time signature of the channel and some second order statistics.

1.1.1.4   IS/IC Inclusion in 3GPP Standards for 5G

1.1.1.4.1   Interference Suppression

New technologies are being developed in 3GPP that can address sharing between federal and nonfederal systems. For instance, 3GPP Release 14 incorporates means to reduce uplink interference at the receiver by utilizing MMSE-IRC (minimum mean square error – interference rejection combining) -based eNB receiver. This technique is the unassisted kind with no side information and relies on blind estimation to autonomously model interference as correlated noise in space or frequency. It is more robust in the sense that it estimates the aggregate correlation and tunes its processing to suppress it. This receiver approach is probably the right direction for disparate networks sharing the spectrum and having little to no coordination.

1.1.1.4.2   Interference Cancellation.

Cancellation across disparate systems is not likely assuming the information about federal systems will be secured. But in theory, nothing prevents a complete receiver for various federal systems to be incorporated into a 3GPP cancellation receiver. For instance, in some kinds of radars (*e.g.,* FAA), it may be possible to get detailed information about the signatures and waveforms. Without this information, the receiver will be incapable of doing much to cancel interference. However, depending on the implementation there could be many complex and costly challenges.

1.1.1.5   Spectrum Management Utilizing Automated Coordination (database)

The use of database techniques to facilitate shared access to underutilized spectrum, while providing interference protection, has developed over several years starting with television whitespaces, licensed shared access and more recently in the 3.5 GHz CBRS band. Specifically, spectrum sharing has been facilitated in these examples using automated techniques that permit disparate and separate services to coexist in

the same band without incurring harmful interference. In general, co-existence of mutually exclusive spectrum use can be supported in some cases by geographical separation between the disparate systems to avoid interference. In other cases, the spectrum may be utilized only at certain times and at certain locations utilizing specific technical parameters. It is unclear what the best architecture might be for spectrum sharing with 5G because each sharing scenario must be determined based on its own merits. Ideally, the sharing architecture should be as simple as possible to minimize cost and complexity.

Critical components in determining the appropriate sharing framework will be the degree of protection and the type of services involved. Spectrum sharing can be difficult for some of the 5G services especially the ones that require low latency and high quality of service (QoS). 5G networks may also use different access mechanisms for different services. For example, Non-Orthogonal Multiple Access (NOMA) may be used for mMTC, and the sharing framework should consider these aspects too, which are unique to 5G. Propagation at frequencies greater than 6 GHz can be more directional which may allow spectrum sharing at shorter separation distances with management of interference in the angular domain, *e.g.,* using beamforming. Incorporating directional information in a location-based sharing framework may be considered if the directional information is fixed. However, this is often not the case for point to multipoint systems. The utility and benefit of dynamic beamforming coordination decreases in this framework.

Another degree of freedom for spectrum sharing is utilizing the concept of "bandwidth part" that is being specified as part of 5G in 3GPP. This feature allows radio systems to schedule services for its users by utilizing frequencies on either side of the interference, essentially creating a null within its operating bandwidth. This information, when available in a database, could allow 5G systems to automate frequency selection.

1.1.1.6 Licensed Shared Access (LSA)

The use of a database to facilitate shared spectrum access is defined for Licensed Shared Access (LSA) where there are two tiers of usage in the band. ETSI announced the completion of the specification for the support of LSA in April 2017. The ETSI specification defined the LSA protocol for operation in the 2300 MHz - 2400 MHz band.

1.1.1.7 Spectrum Access System (SAS)

In the 3550-3700 MHz band in the U.S., the shared spectrum is organized in three tiers where the SAS facilitates access to the spectrum and ensures protection to the

various tiers of the band utilizing a database and incorporating interference mitigation techniques.

The lowest tier in the hierarchy, General Authorized Access (GAA), is open to anyone with an FCC-certified device. In the Priority Access tier, users of the band can acquire at auction licenses that provide interference protection from GAA users. At the top of the hierarchy, incumbent federal and commercial radar, satellite, and other users will receive protection from all Citizens Broadband Service users. The SAS would assign and maintain appropriate frequency assignments and ensure that lower tier users do not interfere with higher tier users. Therefore, under this framework, the SAS would be responsible for determining the available and appropriate frequencies at a given location using the location information supplied by Citizens Broadband Service Devices (CBSDs), Exclusion Zone parameters, FSS earth station registration information, the authorization status and operating parameters of CBSDs in the surrounding area, and such other information necessary to ensure the operation of CBSDs on a non-interference basis.

Geographic exclusion zones would be established along the coastlines and around designated ground-based radar locations. These Exclusion Zones would convert to Protection Zones once the Environmental Sensing Capability (ESC) system is in place. The ESC will consist of a network of sensors that will detect federal radars operating in and around the 3.5 GHz Band and relay information regarding those transmissions to the SAS. SASs will process the information communicated by the ESC and instruct associated CBSDs to cease operations or move to unencumbered frequencies in geographic areas where federal use has been detected. As a consequence of ESC deployment, the Exclusion Zones will be converted to Protection Zones and Citizens Broadband Radio Service operations will be allowed in the 3550-3650 MHz band.

The FCC conditionally approved the initial (Wave 1) SAS administrator applicants in Dec 2016. All Wave 1 applicants have been working in the WinnForum in conjunction with the FCC, NTIA (ITS), Navy, and other DOD personnel to define the technical standards and test cases for certification of the SAS and ESC platforms. Testing and certification of the SAS platforms will begin in late August and continue throughout the 4th quarter of 2017. Once the SAS is certified, ITS will begin the certification of the ESC platforms. The timeline for certification of the ESC is in process. Commercial deployment though is expected towards the end of year 2017.

In the spring of 2017, the FCC opened the window for a Second Wave of applicants.

1.1.1.8   Spectrum Management Techniques Inclusion in Standards for 5G

The wireless industry still prefers the regulatory certainty that is offered by licensed, dedicated spectrum. However, it is not always possible that spectrum can be cleared in a timely manner or that the incumbents can be relocated. Under such circumstances, spectrum sharing may be necessary. Appropriate technologies and co-

existence techniques can facilitate the shared use of spectrum if done in a timely manner prior to the freeze of the specifications for 5G.

1.2 Question: Among other things, please consider specifically the key receiver performance requirements for sharing, particularly with respect to IoT devices, including a device's capacity for resilience and interference detection and avoidance.

1.2.1 Response

The responses provided below represent a general overview of potential technologies, methodologies, and techniques for interference mitigation that are under consideration for inclusion in 5G standards. Such mitigation technologies must be evaluated for suitability to facilitate spectrum sharing based on all relevant factors, including:

- the frequency band under consideration for the technique (5G in the below 6 GHz range will look very different from 5G in the 40/50 GHz range);

- the nature and use cases of the incumbent federal systems;

- and whether the interference case being examined is a co-channel or adjacent/near-adjacent channel case.

Typically, "sharing" involves co-frequency considerations between services with equal rights to access the spectrum under the relevant domestic and/or international tables of frequency allocations, while all other assessments are considered compatibility assessments.

When considering compatibility, both receiver and transmitter characteristics, as well as the system design, and performance requirements must be considered. For emerging communications services and applications, including IoT devices, it is important to evaluate protection, and opportunities for sharing based on operational and design requirements. These requirements vary from service to service and system to system, and it is critical to be mindful of them in order to gain an understanding of the impact and effectiveness of potential protection criteria.

For IoT devices, receiver protection from noise and interference is achieved through stringent requirements for the performance parameters like ACS (adjacent channel selectivity), blocking characteristics, spurious response, and intermodulation response as defined below:

1. Adjacent Channel Selectivity (ACS) is a measure of a receiver's ability to receive a desired signal at its assigned channel frequency in the presence of an adjacent channel signal at a given frequency offset from the center frequency of the assigned channel
2. The blocking characteristic is a measure of the receiver's ability to receive a wanted signal at its assigned channel frequency in the presence of an unwanted interferer on frequencies other than those of the spurious response or the adjacent channels, without this unwanted input signal causing a degradation of the performance of the receiver beyond a specified limit
3. Spurious response is a measure of the receiver's ability to receive a wanted signal on its assigned channel frequency without exceeding a given degradation due to the presence of an unwanted CW interfering signal at any other frequency at which a response is obtained
4. Intermodulation response rejection is a measure of the capability of the receiver to receiver a wanted signal on its assigned channel frequency in the presence of two or more interfering signals which have a specific frequency relationship to the wanted signal

3GPP has defined the required value of the above parameters for LTE receivers and specifically for Narrow Band IoT devices. Adhering to these requirements allows LTE devices to combat in-band and out-of-band interference. Device interference protection can be further improved through other means like diversity, multiple antenna techniques (MIMO), and beamforming.

1.2.1.1   System Resilience

In addition to the above requirements and techniques which are necessary for interference resilience of individual devices, overall system resilience can be improved through intra-system protection techniques like CoMP (Coordinated MultiPoint), multi-TRP (multiple TX/Rx Point)[1] and enhanced Inter-Cell Interference Coordination (eICIC) and inter-system technique interference avoidance like Listen Before Talk similar to the one used in Wi-Fi, LTE-U, and LAA.

CoMP, which is primarily designed to reduce inter-cell interference, reduces the impact of interference, especially inter-cell interference, by turning it into a useful signal specifically at the cell border. CoMP must be supported by multiple geographically separated base stations to enable dynamic coordination in scheduling/joint transmission and joint processing of received signals. The eICIC mechanism is designed to solve downlink interference challenges that arise in co-channel deployment of macro, pico, and femto cells. The concept relies on accurate

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[1] 3GPP RAN1 Contribution 3GPP R1-1704395, multi-beams from one or multiple gNBs can be used for interference coordination

time- and phase-synchronization on a one millisecond (subframe duration) basis between all base station nodes within the same geographical area.

1.2.1.2 Reduced IoT Complexity

Most of the IoT devices are expected to have limited capability necessary for a specific task like temperature sensing.   Beyond the basic in-band and out-of-band interference protection, incorporation of the other techniques mentioned above would add complexity to the receiver design and may not be suitable (*i.e.,* feasible/economical) for relatively simple IoT devices. However, simplicity of the IoT devices and low throughput requirement, results in low transmit power, which results in lower overall cross interference among IoT devices, and interference to other adjacent systems. Furthermore, majority of sensor based IoT devices are expected to turn on only for short durations a few times during a 24-hour period and therefore cause much less interference than a typical mobile device. In deployments where many IoT devices are in close proximity, cross-interference among these devices can be controlled by having the wake-up times for each device scheduled through their associated network or via a central controller for devices connected to different networks.

IoT devices based on technologies such as NB-IoT and eMTC are designed to operate deep indoors where the desired carrier signal strength is much lower than traditional cellular systems, and these devices operate on very narrow spectrum. Features such as lower modulation schemes and high repetitions rates allow IoT receivers to operate in severe interference conditions which are not ideal for broadband-type service. Such features, in combination with narrow spectrum requirements, could make IoT technologies more favorable to spectrum sharing compared to traditional voice or broadband type services.

1.3   Question: Consider any 5G-specific technologies that might facilitate interference prevention, detection, and resolution.

1.3.1   Response

5th Generation systems are expected to have diverse deployments ranging from macro-cells to small indoor wireless access-points operating on various bands (below and above 6 GHz) and supporting services with wide range of requirements. Two main standards bodies are involved in setting standard specifications for 5G wireless systems' radios: 3GPP via its 5G NR standard Rel. 15 and 16 and IEEE via its 802.11ax standard. 3GPP has an extensive set of features that could explicitly address interference management.

1.3.1.1 3GPP

3GPP's standardization efforts in 5G encompass a multitude of frequency bands as well as both TDD and FDD. The 3GPP specifications work is ongoing and is expected to continue for next few years, but there are certain design principles that can be used for interference management in spectrum sharing across all deployment scenarios.

3GPP offers many tools and techniques for interference management that can be categorized in three different buckets: prevention, detection, and resolution.

As stated in the previous section, 3GPP has defined many co-channel interference management techniques over many releases such as inter-cell interference coordination (ICIC) and Coordinated Multipoint (CoMP) communication. These techniques were mostly a network-side operation and transparent to the receivers. In 5G, advanced UE receivers may be used to complement network-side interference management by introducing UE-side interference management. It is expected that new device centric techniques could be specified in future releases.

1.3.1.1.1 Interference Prevention

5G networks will focus heavily on adopting network virtualization techniques to perform majority of processing needed to run commercial networks. The virtualization allows 5G system to schedule users effectively and simultaneously reduce interference significantly.

1.3.1.1.2 Context-Aware Networking

NFV supports virtual functions that can be tied to operate many different wireless topologies and technologies like small-cells, macro-cells, Wi-Fi, and legacy networks using a centralized architecture that uses Commercial-off-the-Shelf (COTS) hardware. As deployments move toward increasing density, it will become critical to make networking decisions within the additional context of radio access technology type and service requirements. A multi-radio access technology (RAT) deployment essentially creates an environment where different transmission and reception mechanisms are mixed and there is lack of commonality between network processes and functions. NFV can support the network side processes and air-interface functionality selection in a context-aware sense to provide resource allocation decisions based on RAT availability, quality-of-service (QoS) requirements, and traffic load on RAT. Such techniques can reduce overall interference across a multi-RAT network by steering traffic from high utilization RAT to low utilization RAT thereby distributing resource utilization across RATs. Such distribution reduces spectrum utilization of one type of RAT and allows greater flexibility in making scheduling decisions to avoid certain portions of spectrum that cause or suffer from interference.

1.3.1.1.3   Coordinated Resource Scheduling

Another major benefit of virtualization is that it allows pooling of several virtual base stations as virtual processes, which can perform coordinated resource scheduling. The inherent benefits are in coordinating scheduling of frequency resources. As an example, a central node can combine resource demand information from many radio sites and coordinate allocation of downlink and uplink resources to users in such a way that there is minimal overlap of time-frequency resources, thereby reducing interference. Alternatively, a central node can signal to distributed-nodes a resource map that contains available and restricted radio resources. This method prevents interference by blanking certain frequencies for uplink or downlink use if interference prone regions of spectrum are known *a priori*.

Techniques like coordinated scheduling and joint reception can also prevent interference and use diversity techniques and advanced receiver algorithms to convert interference into usable signal, as in the case of Joint Reception.

1.3.1.1.3.1 Beamforming

Beam forming technologies also provide an inherent mechanism that can prevent interference to an extent. 5G Massive beam-forming mechanisms favor high frequency bands because high frequency bands make it possible to increase antenna element density without increasing physical size of the antenna. High antenna element density allows much narrower beams to be formed. These beams can be pointed toward individual UEs and therefore prevent interference to nearby UEs. Beamforming also works for lower frequency bands but to a lesser extent as higher antenna element spacing required in lower frequencies results in lower antenna element density and thus higher beam width, thereby resulting in larger interference zones.

1.3.1.1.4   Device to Device Communications

Device-to-Device communications (D2D) introduces devices to directly communicate with another device by bypassing the network. 3GPP defined D2D under *Proximity Services* standards specification starting from Release 12, but this technology is sparsely used. It is expected that machine-to-machine communications will be a major driver for 5G. D2D can provide interference avoidance in both uplink and downlink direction. D2D reduces interference in uplink direction by allowing devices to communicate directly over the air-interface rather than communicate via the network. This allows devices to use lower power than they would have used if they were to communicate via the network. In the downlink, D2D reduces interference by obviating the need for downlink transmissions associated with data delivery to device. Since base-station radios transmit at constant high power, irrespective of device location, using D2D can lower overall interference in the network.

1.3.1.1.5   Selective Retransmissions

5G plans to support both ultra-reliable low latency (URLLC) traffic as well as high throughput enhanced Mobile Broad-Band (eMBB) traffic. For low latency traffic, 5G specifications could allow short low latency packets to pre-empt transmission of long

data packets scheduled already. This is done by puncturing of the long data packet scheduled resources or superposition coding. This technique can potentially cause interference to portions of long data packet and result in transmission errors. The conventional hybrid -ARQ utilizes one-bit acknowledgement to indicate whether the transmission was successful or not which requires re-transmission of the whole packet, resulting in lower efficiency. This issue of full retransmission is addressed by a new feedback mechanism known as Code block group (*CBG*)-based transmission.

With CBG, a long packet is grouped into multiple separate code blocks (CBs) where each subset is acknowledged separately. Additionally, receiver uses a multi-bit mechanism to acknowledge the reception of the CBGs. Therefore, the transmitter requires re-transmission of only the failed subsets (CBGs) of the corrupted long packet in response to CB-based (HARQ) feedback. This technique is designed to optimize network utilization but can also reduce interference by reducing the amount of air-interface resources required for re-transmission. This helps to significantly mitigate the impact of interference created by short bursty traffic or frequency localized interference.

1.3.1.1.6 Shortened Frame Structure

5G technologies provide optimizations for short bursts of traffic to support massive connectivity for IoT devices. These optimizations include shortened frame structure that is specifically targeted to reduce latency. A side effect of this optimization is that it reduces average interference duration in the network.

1.3.1.1.7 Control and Data Containers

Another optimization in 5G for IoT provides support for self-contained control and data containers to allow IoT devices to transmit data and control signaling within the same allocation. This reduces interference by reducing total number of messages required to establish or re-establish connection with the network.

1.3.1.2 Interference Detection

1.3.1.2.1 Transmission of Special Signals

With channel sensing based schemes, both base station and UE can perform measurements to detect and/or identify an interfering signal. The UE and base station both need to transmit an identifiable signal so that other nodes can detect and identify interference. Similar to one being considered in 5G NR for cross-link-interference, a front-loaded DMRS/SRS/CSI-RS scheme can be considered as a measurement signal that can be measured/detected by the adjacent nodes, which support measurement signal reception and measurements.

1.3.1.2.2 Special Measurement Modes

UEs or base stations can periodically switch to receive-only mode and detect interference from other UEs or base stations respectively. In the case of base stations,

it could be possible to identify a source of interference using decoded RS and PCI information and a query-enabled database. In the case of UEs, a UE can detect high interference from nearby UEs and choose to back off on any uplink transmissions.

1.3.1.2.3 Centralized Analytical Engines

A centralized server, similar to a Self Organizing Network (SON) server, can be used to collect and analyze measurement reports from UEs and base stations, and detect if there is a pattern and also predict probability of interference. This mechanism will require new definitions of information exchange mechanisms, exchanged formats, and a centralized processing server that can perform analysis in real time and enforce rules.

1.3.1.3 Interference Resolution

1.3.1.3.1 Coordinated Scheduling

Based on their own interference detection results and that of neighboring base stations, base stations can adjust resource allocation for uplink or downlink, and may even change downlink transmit power to reduce interference. For example, a base station can avoid allocation of uplink resource grants to a UE if nearby base stations report increased uplink interference via an Xn link.

1.3.1.3.2 Resource Blanking

Another example is *resource blanking* or *selective sub-band blanking*, which uses information collected during detection phase to selectively apply restrictions on radio resource usage. Several sections of spectrum can be partially or fully restricted for allocation if it is detected that these frequency sections are causing or suffering from interference. This technique can also be applied on a less dynamic basis to facilitate sharing in cases where a federal entity is occupying a narrow channel relative to the broadband channel and resources blocked can be turned off to avoid interference.

1.3.1.3.3 Flexible Control Channel Broadcast

Base stations may use optimal mechanisms to reduce frequency of always ON transmissions like broadcast signaling that causes interference to neighboring base stations. 3GPP radios have signals that are always broadcast – like Pilot signals, control channel broadcast signals for timing and synchronization, and broadcast signals that provide critical parameters to user devices to enable radio access. It is possible to temporarily change the frequency allocation, periodicity, or power of such signals when periods of high interference are detected. The 3GPP standard allows configurable ranges for changing these parameters. Most of these techniques can be automated.

1.3.1.3.4 Network Assisted Mechanisms

Network assisted mechanisms (NAICS: network assisted interference cancellation and suppression) can help UEs to reduce or cancel interference. For example, a base station may send information about CRS of neighboring base stations to a UE so that the UE can use an advanced receiver to cancel this interference.

1.3.1.3.5 Advanced Interference Cancellation

There are discussions in 3GPP about using signal processing techniques for successive interference cancellation (SIC). With the SIC techniques, the interference signals are reconstructed based on the detector/decoder output and cancelled from the received signal to improve the desired signal decoding performance. Some of the SIC interference cancellation techniques do not require complete detection and decoding of the interference signals; even partial detection and decoding of outputs can help to improve the performance of desired signal decoding.

1.3.1.4 Inter-RAT coordination

3GPP has adopted LAA technology in Release 13 and 14, which allows LTE-A networks to access the unlicensed bands. Any transmitter intending to transmit on the unlicensed bands needs to perform CCA (LBT) before transmission. One important challenge is that an LAA transmitter and an LAA receiver may be geographically separated apart from each other, so a clear channel sensed at the LAA transmitter side does not mean that the channel is also clear at the LAA receiver side. This phenomenon is known as the hidden terminal problem. Therefore, interference management between LAA and IEEE 802.11n/ac/ax is important.

The following mechanisms have been included as mandatory functions in the LAA design:

- Listen-before-talk (LBT): An equipment applies a clear channel assessment (CCA) check before using the channel.

  Discontinuous transmission on a carrier with limited maximum transmission duration. For LAA, the maximum channel occupation time is 10 ms as a transmitter launches a transmission.

- Dynamic frequency selection (DFS). This mechanism is provided to change frequency carriers on a relatively slow time scale, so as to avoid interference to/from weather radar systems.

- Dynamic carrier selection (DCS). This function enables an LAA network to select a carrier frequency with low interference level.

- Transmit Power Control (TPC). An equipment should be able to reduce the transmit power in a proportion of 3dB or 6dB compared to the maximum nominal transmit power.

The following mechanisms may be studied for inclusion in 5G standards for greenfield bands based on the conclusions of the 5G NR-Unlicensed and Shared Spectrum Workshop held in San Diego, CA in Oct, 2017:

- Common time reference for synchronization. Interference among Time Division Duplex (TDD) systems can be minimized by synchronizing them using a common clock.
- Common signal design for channel reservation. A common signal / preamble for all technologies to be used for channel reservation would greatly improve coexistence among disparate technologies, but could restrict technology flexibility or innovation.
- Spatial sharing. At mmWave bands spectrum sharing happens natively as high antenna directionality and beamforming generally avoid interference without requiring LBT. Some ideas to improve spatial sharing include: directional LBT, receiver-side LBT, on-demand LBT, and listen after talk.

1.3.1.5 IEEE

IEEE has largely focused on interference management.

1.3.1.5.1 Channel Assessment and Power Control

To improve system performance in a dense environment, a dynamic Clear Channel Assessment (CCA) (also known as listen before talk) is adopted to increase special reuse while avoiding interference. The CCA threshold is fixed in the current standard. Studies are ongoing to determine whether the CCA threshold should be dynamic.

In IEEE 802.11ax, dynamic CCA and transmit power control (TPC) are proposed to improve spatial reuse and manage interference in dense areas. In general, a conservative configuration of CCA threshold and TPC level can reduce frame collisions and thereby reduce interference, but this could also reduce the number of concurrent transmissions thereby reducing spectral reuse efficiency. On the other hand, an aggressive configuration of CCA threshold and TPC level increases the number of concurrent transmissions at the cost of increased collisions and interference. Hence, a distributed and dynamic algorithm, which can appropriately tune the CCA threshold and TPC level based on run-time measurements, is the key to reach an optimal trade-off between collision probability and transmission opportunity. Both research groups and standard bodies are studying CCA threshold and TPC levels considering multiple factors such as frequency, topology, transmission power, and fair coexistence with legacy IEEE 802.11 stations.

1.3.1.5.2 Coordinated resource use

In dense areas, the legacy APs are usually assigned the same transmission channels due to the scarcity of available channels, and so the legacy IEEE 802.11 does not include any channel resource allocation algorithm to allow APs to negotiate with each other for better channel resource allocations. With Overlapping Basic Service Sets (OBSS), IEEE 802.11ax allows the APs to interfere with each other to improve the overall system throughput. Another way to improve the spatial reuse in the OBSS environment is careful planning of channel allocation and AP position. Hence, an AP-initiated renegotiation mechanism shall be provided for IEEE 802.11ax in order to better allocated channel resources and improve spatial reuse in OBSS environment.

1.4 Question: Identify the standardization challenges with respect to such technologies and what actions NTIA should take to address these challenges.

1.4.1 Response

1.4.1.1 Standardization Challenges

Challenges in standardization arise from both technical and procedural aspects. Implicitly, Standards Development Organizations (SDOs) create standards that are inward facing. For example, 3GPP and IEEE create specifications that among other things focus on waveforms, messaging, and signaling, and performance which will assure that resulting technology can be implemented to achieve pre-established use cases. Consequently, any tradeoffs between aspects like interference mitigation, sharing, or transmitter and receiver performance are motivated by goals such as spectral efficiency, reliability, and capacity. Mindful of these aspects, the following challenges are identified:

1.4.1.2 Operating procedures

While SDOs, like 3GPP, IEEE, LoRa and ATSC, are driven by uniformity in their vision for creating specifications for a given technology, their operating procedures for consensus building are different. 3GPP approves specifications through 100% consensus of the attending members; while there could be a subsequent voting process triggered, but it is avoided as it requires a 71% majority[2]. In contrast, IEEE does not operate on 100% consensus, but relies on a 75% approval rate as long as 75% of total voting members have voted.[3] 3GPP member companies can have

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[2] ftp://www.3gpp.org/Information/Working_Procedures/3GPP_WP.htm
[3] https://standards.ieee.org/develop/balloting.html

multiple votes through international subsidiaries, therefore major vendors and operators have more influence.

To introduce new work-items (3GPP) or projects (IEEE), one needs sponsorship from multiple companies or committees, respectively. The sponsors are responsible for driving the work-item or project through approval process by providing technical oversight and analysis, and leading the item through various process points.

Specifically, for 3GPP, if the NTIA initiates a work item (as it did through its Department of Commerce membership for FirstNet requirements), it would need to have 3 additional supporting companies co-sign the work item and verbally support it during the session.

1.4.1.3   Technical Aspects

3GPP and IEEE have developed a suite of technical specifications based on the primary premise of the regulatory requirement of bands, and homogeneity of radio access technology. As an example, interference management techniques that provide some form of detection, avoidance, and resolution are designed to allow the technology addressed by the standard to make efficient use of radio resources in the presence of interference or to cause as little interference as possible in intra-technology scenarios. Although standards organizations have developed carrier sensing techniques, interference measurement methods, and information exchange protocols to enable interference management, a lot of these techniques assume that the characteristics of interfering or coordinating system are known *a priori*. This assumption is not by chance; most companies involved in working through technology specification work-groups are also engaged in developing products that incorporate these standard specifications into their product. Consequently, there is no active effort for such companies to develop specifications which will consider sharing between other networks, whether commercial or federal. Only in instances where the technology requires coexistence with another technology within the device or infrastructure (*e.g.,* GPS), sharing is considered.

There is also another technical aspect that needs to be considered: whether the specification requires any change for sharing. For example, in the case of AWS-3 coordination work done by CSMAC, 3GPP decided that the sharing could be done through implementation and did not need standardization changes.

1.4.2   Alternative Avenues

Besides standardization organizations, several industry organizations, forums, and consortiums exist, which exert sufficient influence to modulate the technological direction of standardization activities and outcomes. LAA and LTE-Unlicensed are examples where 3GPP directed its efforts toward recognizing sharing use cases to

take advantage of unlicensed spectrum. This effort resulted in techniques like Listen Before Talk (LBT), which is a mandated feature in Europe, to get adopted in US in order to promote coexistence among different technologies (LTE and 802.11).

Global participation in these forums and consortiums promotes cross-pollination of ideas, and provides momentum to get new use cases and techniques pushed through standards. Next Generation Mobile Networks (NGMN) alliance [4] is a global body comprised of network operators, vendors, and research institutes that has successfully pushed innovative ideas like network slicing and open 5G architectures through SDOs.

Therefore, if the NTIA chooses to introduce standards efforts to enable more efficient sharing, there needs to be a case made for why the coexistence would impact resources and why it would require a change in standards. Forming partnerships with global forums and alliances could provide the desired traction.

1.5 Question: What commercial 5G deployment scenarios (e.g., specific commercial use cases) exist that could potentially maximize the shared use of this spectrum (e.g., dynamic shared access between federal and non-federal users)?

1.5.1 Response

5G commercial deployment scenarios or use cases will be driven by the development of user-driven technical features such as long battery life, low power, high reliability, high data rate, low latency, and context-aware services. To meet user needs and expectations, 5G applications will be enabled seamlessly across multiple frequency bands, connectivity types, and network paths across platforms, including terrestrial, satellite, and broadcast. For example, multi-platform networks may facilitate mobile connectivity in geographic exclusion zones used in federal/non-federal sharing.

This section describes four categories of 5G use cases: Enhanced Mobile Broadband, Ultra-reliable Communications, Massive Machine-Type Communications, and Backhaul/Access Integration. Each 5G use case will have its own technical specifications.   However, certain use cases, like Massive Machine-Type communications and Internet of Things (IoT) devices and applications, may more easily facilitate co-existence with federal users. In addition, newer technologies that allow more integration of access and backhaul in the same spectrum may also possibly allow for more sharing with federal users.

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[4]http://www.ngmn.org/fileadmin/ngmn/content/documents/pdf/about_us/170815_NGMN_Alliance_Overview.pdf

1.5.1.1 Enhanced Mobile Broadband
Explosive data usage on mobile handsets, vehicles, and other devices will require more intensive use of diverse range of spectrum bands.

1.5.1.1.1 Smart Vehicles:
Connected consumer cars and industrial vehicles operating both on and off the road in urban, suburban, and rural areas (*e.g.*, tractors, combines, mining trucks, construction and forestry vehicles using telematics).
- Reliable broadband connectivity across terrestrial and satellite networks will be necessary in order to ensure seamless and safe operation of smart vehicles in each of these environments.
- These applications will require ultra-high-speed radio links and support for high Doppler environments.

1.5.1.1.2 Virtual/Augmented Reality:
VR/AR applications will require ultra-high-speed radio links with low latency.

1.5.1.2 Ultra-Reliable Communications:

1.5.1.2.1 Industrial automation
Requires ultra-high reliability, high speed radio links, low to ultra-low latency, short to long range, and operation in cluttered environments.
- **Critical control of remote facilities and other mission control applications** (e.g., hazardous environments, rescue missions) requires ultra-high reliability radio links, high speed radio links, low to ultra-low latency, short to long range, operation in cluttered environment and ground/obstacle penetration.
- **Healthcare applications** like remote surgery would require ultra-low latency in addition to the same characteristics as mission control applications.
- **Self-driving vehicles** would require similar technical characteristics as the above ultra-reliable communications as well as operation near fast moving obstacles.

1.5.1.3 Massive Machine-Type Communications:
- **Internet of Things:** Smart home, smart grid, smart metering, smart shipping, etc. applications require lower bandwidth, lower power, long-range connectivity. Low power IoT devices and applications may more easily facilitate co-existence with federal users.
- **Sensor networks:** Industrial or commercial sensor networks would require short to long range connectivity and mesh networking.

1.5.1.4 Access/Backhaul Integration
In public WiFi or small cell (self-backhauling), networks can use the same spectrum bands for access and backhaul. In long range rural backhaul solutions, integrated

access/backhaul solutions can enable multi-hop backhaul to extend coverage further using non-line-of-sight connectivity.

- "Wireless Fiber" expanding multi-gigabit fiber capacity wirelessly as a cost-effective solution to extending fiber capacity to buildings especially in urban/suburban areas
- More agile and flexible technologies allow networks to better share spectrum within the same architecture and possibly more capable of federal sharing.

2 ACTIONABLE RECOMMENDATIONS FOR THE NTIA

2.1 Recommendation: Interference Mitigation Technologies to Facilitate Federal / non-Federal Systems Sharing.

The responses to the questions in this document represent a general overview of potential technologies, methodologies, and techniques for interference mitigation. Such mitigation technologies must be evaluated for suitability to facilitate spectrum sharing based on all relevant factors, including specific frequency band under consideration, nature and use cases of the federal and non-federal systems, and whether the interference to mitigate is a co-frequency or adjacent/near-adjacent frequency case. When considering compatibility, both receiver and transmitter characteristics must be considered as well as the system design and performance requirements. For these reasons and others, a specific recommendation on technologies to implement in federal systems is not possible.

Keeping this is perspective, CSMAC 5G subcommittee has following recommendations for NTIA:

1. Open one or a series of Notice of Inquiries (and/or Requests for Information) designed to collect information on potential spectrum bands that could be considered for sharing including proposals for how these bands could be shared with the incumbents. Develop a list of information that is needed for interference mitigation that would improve sharing. This list should include information about the legacy waveform and operation that is required to design and develop sharing approaches, and the information needed to co-exist.
2. Recommend that NTIA request that FCC consider a counterpart processes inquiry on which commercial bands and which technology steps should be considered for bi-directional sharing.
3. A review of the new technologies that are being developed in 3GPP that can address sharing between federal and nonfederal systems. For instance, 3GPP Release 14 incorporates means to reduce uplink interference at the receiver

by utilizing MMSE-IRC (minimum mean square error – interference rejection combining).

4. Beamforming, active antenna system (AAS), massive MIMO and network/cooperative MIMO can help reduce the effect of interference at the receiver and reduce interference in a shared environment. It is recommended that the task of utilizing these approaches be addressed in the Action Committee (see recommendation Action Recommendation).

5. NTIA should evaluate the technologies outlined above based on spectrum, technology, application, and functional requirements of the federal communication system that needs to share spectrum with a non-federal entity.

6. Expedite workshop on bi-directional sharing recommended in last round of CSMAC deliberations. (As proposed in WG Report dated June 2016 and by CSMAC at August 2016 meeting.)

7. Hold a workshop with the objective to establish a platform for an industry-led consensus on solutions to fundamental questions on sharing and interference mitigation.

8. Currently, there are no regulations governing the design of wireless receivers, or their performance. Protection from noise and interference is achieved through stringent requirements for the performance parameters like ACS (adjacent channel selectivity), blocking characteristics, spurious response, and intermodulation response. Propose NTIA examine receiver technology, in existing and future systems that could allow federal and non-federal systems to co-exist with minimal performance degradation in a spectrum sharing scenario.

2.2 Recommendation: Spectrum Management Utilizing Automated Coordination (database)

The use of database techniques to facilitate shared access to underutilized spectrum while providing interference protection has developed over several years starting with television white spaces, licensed shared access and more recently in the 3.5 GHz band. Specifically, spectrum sharing has been facilitated in these examples using automated techniques to permit disparate and separate services to co-exist in the same band without incurring interference from the other uses. Such techniques may not be appropriate in all cases and, in general, an effort should be made to minimize the complexity of the sharing arrangement. In general, co-existence of mutually exclusive spectrum use can be supported in some cases by geographical separation between the disparate systems to avoid interference. In other cases, the spectrum may be accessible only at certain times, at certain locations utilizing specific technical parameters for instance transmit power, etc.

A critical component in determining the appropriate sharing framework will be the degree of protection and the type of services involved. Spectrum sharing can be more challenging when use cases require low latency, high QoS or when

waveforms are undefined. Sharing may also be enhanced using new capabilities such as beamforming. However, the framework may not allow fast enough coordination to support spectrum sharing using dynamic beamforming. Ideally the sharing architecture should be as simple as possible to minimize cost and complexity.

NTIA should:

1. Monitor the activities with regards to the SAS in the 3.5 GHz to determine how effective the regulatory framework allows spectrum sharing while at the same time managing interference.
2. Investigate participation in standards organizations where technology developments to facilitate sharing are discussed. Sharing scenarios can be considered for standardization.
3. Open one or a series of Notice of Inquiries (and/or Requests for Information) designed to collect information on potential spectrum bands that could be considered for sharing including proposals for how these bands could be shared with the incumbents while minimizing the burden and complexity of the sharing arrangement.
4. Establish a formal working group with the FCC (under existing MOU?) to target relevant bands for sharing and develop specific, actionable goals and objectives.
5. Develop a list of legacy information that is needed for database sharing approaches and the potential challenges to this approach. This list should include information about the legacy waveform and operation that is required to design and develop sharing approaches, and the information needed to operate a sharing system.
6. Use probabilistic risk assessment (i.e. calculating likelihood-consequence distributions for multiple hazard scenarios) rather than worst-case analysis (i.e. focusing on the one hazard with the most severe consequence, regardless of its likelihood) as the basis for determining sharing frameworks.

2.3   Recommendation: Standardization Changes for Sharing

Introducing sharing mechanisms in SDOs needs technical analysis, industry partnerships, and due process by the SDO. This process could take years and it would also need to be monitored and updated as technology evolves. Therefore, it is important for NTIA to view this as a long-term engagement, which would require a different resource requirement at different times and depending on the activity. NTIA should investigate the possibilities around this engagement and perhaps leverage groups such as ITS which have done similar work in the past. This group and/or individuals may also additionally:

1. Hold workshops: to gather contributions from a wider group representing the industry, including manufacturers, network operators, academic institutions, industry verticals and research firms, to address standardization changes. Since some contributors may also participate in various standardization forums, this workshop will provide an important platform for an industry-led consensus on solutions to fundamental questions on sharing. The workshops could also be used to educate the broader industry of inherent challenges in spectrum sharing and invite ideas on how these challenges can be overcome either through 5G standards or via other methods that are feasible to implement.

2. Consider liaising with industry trade organizations such as NGMN and 5G Americas, or alliances such as ATIS. These groups advocate for better features and functionalities of next generation wireless technologies. These industry organizations influence what use cases need to be addressed by standard bodies and address related spectrum requirements and policy.

3. Consider working with other administrations, through ITU, CITEL or others, to develop a unified view on spectrum sharing requirements and asking the standardization bodies to address them. For example, 3GPP has a direct liaison with the ITU.

3   RECOMMENDATIONS ON CSMAC FUTURE WORK

Over the past several decades, GPS-based (and GNSS) technology has enabled farmers to achieve ever greater levels of productivity. In short, in less than 20 years, GPS technology went from being an emergent technology to a robust, mature technology that has optimal capabilities for production agriculture. Agricultural machinery now also comes with installed modems that are designed to communicate with each other, the owners, operators, dealers, and agricultural consultants with the goal of making farmers more productive. Bringing all this M2M data together requires additional communications capacity and the importance of ensuring and considering the tradeoffs that systems, including receivers, are designed to operate in an increasingly congested and dense communications environment must be recognized.

Mobile broadband (LTE) is the key enabler today and 5G IoT systems operating in low band spectrum will be a future key enabler in the 2020 timeframe. Today, vital economic (and high-technology) activity is occurring in less populated rural areas, where more and more food is being grown on high-value cropland to meet world demand. As global population growth continues, ever larger harvests must be produced, both safely and securely, to meet the growing demand for food, fuel, and fiber and to contribute to improved living standards globally.

Also, considering that First Responder Network Authority (FirstNet) is an independent authority within NTIA to provide emergency responders with the first nationwide, high-speed, broadband network dedicated to public safety, expansion of rural broadband for FirstNet to help close the digital divide and for agriculture must therefore be a priority for federal policy makers.

Broadband deployment in unserved and underserved croplands and ranchlands is critical to continued U.S. leadership in global food production. It is also essential to the rural communities where agriculture provides an economic foundation for rural education, healthcare, cultural institutions, and local infrastructure.

Question. The Infrastructure Bill from this Administration is expected to include state block grants for improved rural coverage. Therefore, what rural coverage policies are needed to consider public safety, industrial and consumer needs for rural broadband?

Finally, as part of CSMAC future work, it is recommended that consideration be given on whether determining operational compatibility requires a consideration of both transmitter and receiver characteristics, and whether that is required for regulatory compatibility. Current spectrum management methods specify device characteristics (*e.g.,* transmit power ceilings, and receiver interference protection criteria). It may be possible to decouple them by focusing on the signal strength resulting from transmitter deployments, and the radio signal environment in which interfered with systems must operate. Examples of such approaches could include Ofcom's spectrum user rights (SURs, defined as a statistical limit on the resulting signal level that a licensee can deliver in the same and neighboring bands) and the FCC TAC's harm claim thresholds (HCTs, in-band & out-of-band interfering signal levels that must be exceeded before a system can claim that it is experiencing harmful interference).

Question. The question is to consider whether determining operational compatibility requires a consideration of both transmitter and receiver characteristics, and whether that is required for regulatory compatibility and how that may be applied to sharing between communications systems?