**COMMERCE SPECTRUM MANAGEMENT ADVISORY COMMITTEE (CSMAC)**

**5G SUBCOMMITTEE**

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# NTIA Questions

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

### Response

#### 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 NR (3GPP term for 5G), and in LTE rel 13/14 which are explicitly designed to reduce or cancel interference. For the most part, these techniques are intended to address intersite cell interference concerns.

#### Transmitter Techniques

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.

#### Receiver Techniques

On receiver side, advanced antenna technologies developed for NR such as 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 and thereby increase access to the spectrum. Both interference suppression and interference cancellation are possible. For interference suppression, you do not need to know anything about the interferer (let’s assume co-channel interference. Usually adjacent channel interference is reduced enough by filtering. If not, the same co-channel techniques would apply.)   On the receiver side IS, you will have to give up a MIMO degree of freedom to avoid admitting energy from a direction.

However, 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, matter. 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 but effectiveness vs. feasibility would have to be studied. Alternatively, if the direction and angular spread of the channel towards a federal victim receiver 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.

#### Inclusion in 3GPP Standards for 5G

##### 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 receiver, by utilizing MMSE-IRC (minimum mean square error – interference rejection combining) based eNB receiver. This technique is the un-assisted kind with no side information, and relies on blind estimation to autonomously model interference as correlated noise in space or frequency. It is the most robust in the sense that it estimates the aggregate correlation and tunes its processing to suppress it. Space, frequency, same network, other network, no difference. This receiver is one approach for disparate networks sharing the spectrum and having little to no coordination.

##### Interference Cancellation.

Cancellation across disparate systems is not likely assuming the information about federal systems will be secured. But in principle, nothing prevents a complete receiver for various federal systems to be incorporate into a 3GPP cancellation receiver. For instance, in some kinds of radars (say FAA), it may be possible to get detailed information about the signatures and waveforms. The issue really is the radar receiver. It is typically going to be incapable of doing much to cancel interference.

#### 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 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. 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. 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.

Different use cases may require different co-existence techniques but utilization of a database to automate coordination is for the most part frequency agnostic. The critical component in determining the appropriate sharing framework will be the degree of protection and the type of services involved. In some cases, spectrum sharing can be more difficult when use cases require low latency, or waveforms are undefined, but sharing can also be enhanced using new capabilities such as beam forming. Ideally the sharing architecture should be as simple as possible to minimize cost and complexity.

#### 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 2 300 MHz - 2 400 MHz band.

#### 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 FCC conditionally approved the initial (Wave 1) SAS administrator applicants in Dec 2016. All Wave 1 applicants (Google, Comsearch, KeyBridge Global, CTIA, Sony, Amdocs, and Federated Wireless) 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 applicants. Nokia, Rivada Networks, Red Technologies and Fair Spectrum LLC were the 2nd wave applicants.

#### Inclusion in Standards for 5G

The wireless industry (both terrestrial and satellite) still prefers the regulatory certainty that licensed, dedicated spectrum supports. However, it is not always possible that spectrum can be cleared in a timely manner or that the incumbents can be relocated. Therefore, spectrum sharing maybe necessary. Appropriate technologies and co-existence techniques can facilitate the shared use of spectrum depending on the waveforms and parameters of the networks. It is recommended that federal bands that are underutilized, and with incumbents that are unable to relocate in a timely way, to be considered as a candidate for spectrum sharing. These specific sharing scenarios can be included in a request for standardization in organizations like WinnForum and 3GPP.

### 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.

#### Response

Response

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

* 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-frequency or adjacent/near-adjacent frequency case.

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

When considering compatibility, both receiver and transmitter characteristics must be considered as well as the system design and performance requirements. For communications services and applications, including IoT devices, that are emerging now, it is important to evaluate protection and opportunities for sharing based on operational and design requirements, which vary from service to service, and system to system, , and 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 receive 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. Devices interference protection can be further improved through other means like diversity, multiple antenna techniques (MIMO), and beamforming.

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) and Enhanced Intercell Interference Coordination (eICC) 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, aims to turn the inter-cell interference 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 time- and phase-synchronization on a one millisecond (subframe duration) basis between all base station nodes within the same geographical area.

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 (feasible/economical) for relatively simple IOT devices. However, simplicity of the IOT devices results in their low power and low throughput requirement which results in lower overall cross interference among IOT devices and interference to other adjacent systems. Furthermore, IOT devices are expected to turn on only for short durations a few times during a 24-hour period which results in a much less interference than a typical mobile device. In deployments where a large number of IOT devices are in close proximity of each other, cross-interference among these devices can be controlled by having the wake-up times of each device scheduled through their associated network or via a central controller for devices connected to different networks.

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

#### Response

5th Generation systems are expected to have diverse deployments; 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, in particular for 5th generation wireless systems’ radios: 3GPP via its 5G NR standard Rel. 15 and 16, and IEEE via its 802.11ax standard. 3GPP has extensive set of features that could explicitly address interference management.

##### 3GPP

3GPP’s standardization efforts in 5G encompass both low and high 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.

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.

###### Interference Prevention

5G networks will focus heavily on adopting virtualization techniques to perform majority of processing needed to run commercial networks, via virtual network functions. The virtualization allows 5G Radio to schedule users effectively and simultaneously reduce interference significantly. Network Function Virtualization (NFV) specifications define software-based processes running on commercial off-the-shelf hardware to run virtual network functions, rather than use specialized hardware processes.

###### Context-Aware Networking

NFV supports virtual functions that can be tied to operate many different wireless topologies and technologies – like small-cells, macro-cells, wifi, and legacy networks using a centralized architecture that uses 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, and 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.

###### 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 the area of 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, 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.

###### Beamforming

Beam forming technologies also provide an inherent mechanism that can prevent interference to an extent. Although applicable to low frequency bands too; 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.

###### 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 network. This allows devices to use lower power than they would have used if they were to communicate via network. In downlink it 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 network.

###### Selective Retransmissions

5G supports both: ultra-reliable low latency (URLLC) traffic as well as high throughput enhanced Mobile Broad-Band (EMBB) traffic. In order to satisfy very low latency requirement of low latency traffic, 5G allows short low latency packets to pre-empt transmission of very 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 results in possible transmission errors. The conventional hybrid -ARQ utilizes one bit acknowledgement to indicate whether the transmission was successful or not and this requires re-transmission of the whole packet. 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 to be 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 can cause reduction in interference by reducing the amount of air-interface resources required for re-transmission. This helps to significantly mitigate the impact of the interference created by short bursty traffic or frequency localized interferer.

###### 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.

###### 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.

##### Interference Detection

###### Transmission of Special Signals

Channel sensing mechanisms: using sensing based schemes; both base-station and UE can perform measurements to detect and/or identify an interfering signal. 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.

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

###### 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 high probability of interference. This mechanism will require definition of information exchange mechanisms, definitions of exchanged formats, and a centralized processing server that can perform analysis in real time and enforce rules.

##### Interference Resolution

###### 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: base-station can avoid allocation of uplink resource grants to a UE if, nearby base-stations report increased uplink interference via Xn link.

###### Resource Blanking

An alternate 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.

###### Flexible Control Channel Broadcast

Base-stations may use optimal mechanisms to reduce frequency of always ON transmissions like broadcast signaling that cause 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, transmission frequency, or power of such signals when periods of high interference are detected. 3GPP standard allows configurable ranges for changing these aspects. Most of these techniques can be automated.

###### Network Assisted Mechanisms

Network assisted mechanisms (NAICS: network assisted interference cancellation and suppression) can help UEs to reduce or cancel interference. For eg: a base-station may send information on CRS of neighboring base-stations to a UE so that UE can use advanced receivers to cancel this interference.

###### 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.

##### IEEE

IEEE has largely focused on interference management.

###### Channel Assessment and Power Control

To improve the system performance in dense environment, a dynamic Clear Channel Assessment (CCA) (also known as listen before talk (LBT)) is adopted that increases the special reuse to determine transmission opportunity with CSMA and manages the interference. The CCA threshold used in original CSMA is fixed, but studies are performed to check whether the CCA threshold should be dynamic.

In IEEE 802.11ax, dynamic CCA and transmission 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 minimize the interference, but this could also reduce the number of concurrent transmissions. On the other hand, an aggressive configuration of CCA threshold and TPC level increases the number of concurrent transmissions at the cost of increasing collisions and interference. Hence, a distributed and dynamic algorithm, which can appropriately tune the CCA threshold, and TPC level based on run-time measurement, is the key to reach an optimal trade-off between collision probability and transmission opportunities. Both research groups and standard bodies are studying the optimal CCA threshold and TPC level based on multiple factors, such as frequency, topology, transmission power, even coexistence with legacy IEEE 802.11 stations.

###### 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 802.11 ax allows the APs to interfere with each other to improve the overall system throughput. Another way to improve the spatial reuse in 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.

###### 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 particularly known as the LAA-WiFi hidden terminal problem. Therefore, interference management between LAA and IEEE 802.11a/ac/ax is important.

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

* Listen-before-transmission (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 different carriers on a relatively slow time scale, so as to avoid interference to/from weather radar systems.
* Dynamic carrier selection (DCS). Since there is a large available bandwidth on the unlicensed spectrum, this function enables an LAA network to select a carrier with a lower 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.

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

## 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)?

# Conclusion

# Actionable Recommendations for the NTIA

# CSMAC future work