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RFC Response: Development of a National Spectrum Strategy

for

National Telecommunications and Information Administration

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and is approved for release from Digital Global Systems by

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on 17 April 2023

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Background and Overview

Spectrum is a valuable finite resource that has fueled the wireless telecommunications industry over the past 100 years. The FCC manages spectrum utilization for commercial applications while the NTIA manages its utilization for government applications. In the last 8 years, the US government has reviewed its spectrum utilization needs in order to free up more for commercial applications, in response to an ever-increasing need for more spectrum to address emerging new wireless services like mobile streaming, VR training, mobile logistics, anything-to-anything connectivity, low latency, and high reliability, all promised by advanced 4G and 5G telecommunication systems. This resulted in the auction of several hundred MHz of spectrum traditionally used by the government to be licensed for commercial applications. These auctions have collected over $200 B USD from commercial companies, demonstrating the spectrum's importance to the commercial telecommunication industry. However, the spectrum auctioned so far is not sufficient for the high mobility, low latency, and high-reliability services envisioned to be enabled by new telecommunication networks like 5G and beyond. Additional spectrum is needed at the appropriate frequency bands in order to make the deployments of these services economical. Unfortunately, there is no more spectrum available at those frequency bands that can be managed with the current spectrum utilization management approach used so far by the government. Nor can the needs of new emerging commercial services be met by taking the spectrum assigned to government services and reassigning or compressing the government spectrum to make some spectrum available. An alternative way of allowing disparate services (current and emerging ones) to use the spectrum simultaneously is needed.

Alternatives have been investigated and proposed by the government over the past two years. These alternatives call for more efficient usage of the spectrum, where several services with different requirements can simultaneously exist thus sharing the available spectrum. Several sharing alternatives are being investigated and are the subject of much debate between government agencies and commercial industries. Most of the approaches so far are based on the scheduling of spectrum access by different services, where the schedule is either known beforehand or where users access Web portals to identify their intended services, their network location, and how they intend to use the spectrum. Propagation models are created to estimate the level of interference by the requesting services in order to grant access to the spectrum. An example of this approach is CBRS, used for sharing the bands between 3550 and 3700 MHz.

Unfortunately, these approaches fall short in providing spectrum access for networks with mobile components and/or intermittent needs of the spectrum with short requests. Approaches based on *actual measurements of the current spectrum utilization* are better at dealing with these problems and can provide dynamic spectrum access to multiple services in a more efficient manner, especially for those desirable “sweet spot” frequency bands where network deployments are more economical. This approach of true dynamic access based on current environmental feedback requires new spectrum management tools and policies which enable *dynamic spectrum sharing*. Especially for services requiring low latency and high reliability, continuous measurements of spectrum utilization are critical. DGS has developed the bulk of the tools necessary to build a system that would allow dynamic spectrum sharing that optimizes the utilization of the spectrum between disparate services. This includes current and emerging service for the government and commercial applications.

In the remainder of this document, we will discuss these tools and how they can be used to solve the dynamic spectrum sharing problem.

Dynamic Spectrum Management Using Real-time Observations

Current Spectrum Management Approach

To understand how agencies currently manage spectrum utilization, a brief review of how the spectrum is currently used to carry information wirelessly is worthwhile. In general, information is superimposed into an electromagnetic wave by a transmitter which travels wirelessly through the air (medium), and information is recovered from the electromagnetic wave at another point via a receiver. The first person to try to understand how much information can be transmitted reliably from one point to another was Claude Shannon. (https://people.math.harvard.edu/~ctm/home/text/others/shannon/entropy/entropy.pdf)

He calculated the capacity of a medium as the maximum information that the received electromagnetic wave contains about the transmitted information. He denoted this quantity as the *capacity* of the medium:

$$C = Max_{p(x)} I(X;Y)$$

where p(x) is the set of all possible mappings of the information to be transmitted into the electromagnetic wave X, Y is the received electromagnetic wave and I(X; Y) is the mutual information contained in X and Y. In general terms, the received electromagnetic wave Y is a version of X altered by the RRF environment between the two points (the transmitter point and the receiver point). The mapping of the information into X, p(x), and the extraction of the information from Y, p(y) are known as the modulation/demodulation protocol. Claude Shannon was able to prove that in the case where the Y contains X plus additive other signals, a reasonable case in real life (the worst-case condition is when the additive signal does not contain any information about the information stream embedded in X).

$$C = BW\ Log\ (1 + SIPNR) = BW\ Log(1 + \frac{Px}{Pn + Pint})$$

where BW is the bandwidth (amount of spectrum used) by the modulation protocol) used by the transmitter and SIPNR = Power in X / (power of the additive signals = Power noise + Power of interference signals) = Px / (Pn + Pint). We use Power noise as the component of the additive signal that is totally independent of any other transmitted signal, and Power of interference signals as the power of other transmitted signals present in the same spectrum or portion thereof.

Some observations:
The maximum amount of information carried is linearly proportional to the spectrum used and logarithmic proportional to the ratio of the power transmitted versus the power of the additive signals.

If you do not allow multiple signals to use the same spectrum and curtail the power used to transmit signals in adjacent spectrums to minimize the *Pint* component in the SIPNR for a particular transmitted signal you allow the maximum information to be transferred by that signal.

From these two observations, primarily from the second, a philosophy for the current spectrum utilization management emerged. This philosophy can be described as follows: First, a service that requires a particular information rate to be transmitted is analyzed to find out what suitable modulation protocol can be used economically (resulting in a number of bits of information per Hz of the spectrum), then a BW is requested so that information rate = BW (number of bits/Hz). Then a frequency range of the spectrum is allocated to be used uniquely for the service. Finally, a power profile (of allowed transmitter power versus frequency) for the transmission of signals associated with the service is imposed so as not to interfere with other services in adjacent frequency bands in the spectrum.

If the services requesting spectrum access are small compared to the spectrum available then this spectrum management philosophy is relatively easy to implement, and we only need to use power profiles to implement policies for the spectrum access and use simple tools like a spectrum analyzer to police those utilizing the spectrum in order to guarantee their adherence to management policies. This has been the case for the last 85 years in the United States. During this time, all services were allocated a particular spectrum band, and the industry concentrated on developing modulation/demodulation protocols that maximized the information they carried on the assigned spectrum.

Frequency Band Value

Each electromagnetic wave propagates differently based on the frequency band of the spectrum used, which in turn contributes to the complexity of the modulation protocol used and also more importantly to the cost of implementation. In general, the lower the frequency band used, the longer the electromagnetic wave needs to be to propagate the signal in the air before its power at the receiver point is too small to recognize. These longer waves require larger antennas and more powerful transmitters, driving up the implementation cost. This can be offset somewhat by more advanced modulation/demodulation protocols in the transmitter and receiver.

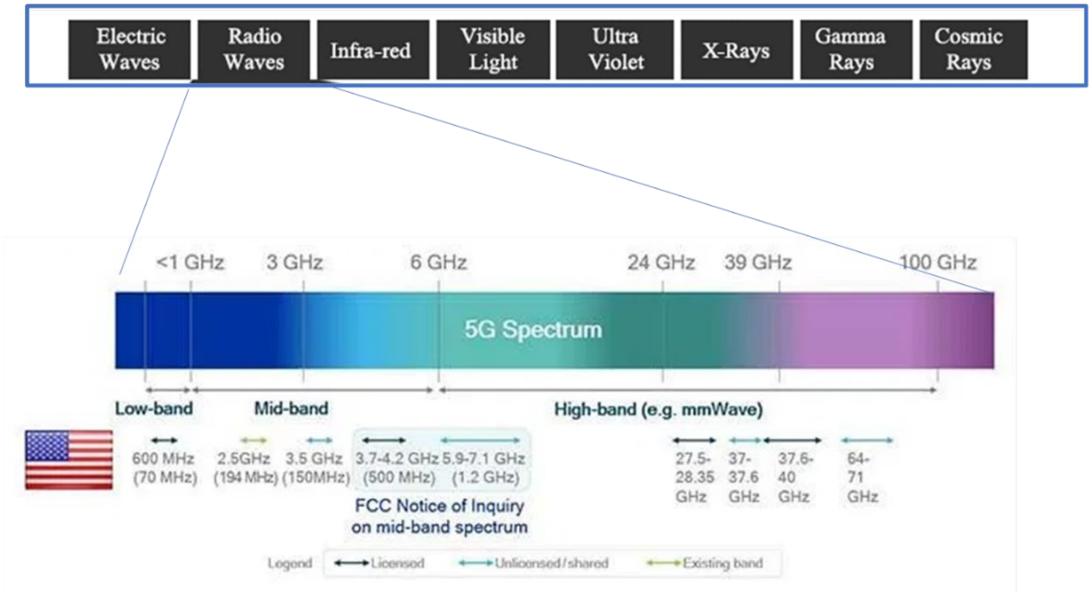

Figure 1: The "Sweet Spot" for Wireless Communications

This has resulted in preferred bands of spectrum for different types of services (see the figure of spectrum sweet spot for telecom as shown in the previous figure). For the telecom industry, the sweet spot is between 20 MHz and 8 GHz. Higher frequencies are being considered for backhaul applications due to their shorter propagation distances and the cost of their implementation (Note: The mass production cost advantage for these higher frequencies is not in place yet). Unfortunately, these "sweet spot" frequency bands are highly partitioned with multiple services competing for ever-decreasing slivers of the spectrum (see Figure 2). With the current spectrum management system, providing spectrum to new services in this spectrum band is impossible without displacing current services in the band.

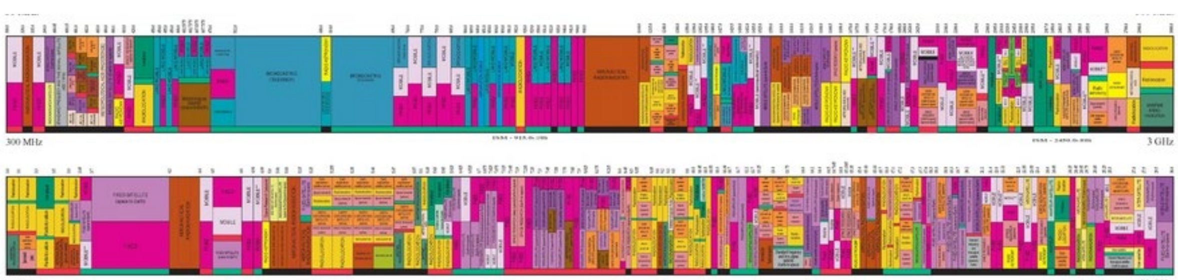

Figure 2

Also consider the delivery of high throughput services to users has become increasingly costly as the user application requirements have grown ever more demanding. Aggregating slices of bandwidths to create large effective bands requires complex software and hardware. Moving to higher frequencies where bandwidth is more available brings significant costs:

- Costs of transceivers grows rapidly with frequency, as we seen in the industry so far.
- Such transceivers are not widely available in the industry yet.

- Issues with range increases the cost of building, deploying, and operating a network. Shorter effective range for RF links implies more nodes, each of which requires infrastructure. The infrastructure could include towers, network access, cabling or microwave links, costs for rights of way, etc.
- Additionally, improving spectral efficiency and power utilization (both at lower and high frequencies), are using more advanced spatial technologies (such as, MIMO and beamforming). These add addition costs to the radios and apertures.

For these reasons, moving to higher frequency bands, where more spectrum is available is not the most economical solution until these costs are mitigated substantially.

Wireless Networks as Foundation to New Emerging Services

A useful analogy for the evolution of large-scale data communication networks is to compare with the evolution of electrical power networks in the last century. Ultimately the industries that provided most of the economic benefit were the developers of electrical devices that were attached to the network. Basically, the general attitude of innovators was that there is ‘electricity everywhere’. The wireless access innovations in 5G and 6G will be a significant step towards enabling the same attitude about data communication – data connection is everywhere. When we get to this state, the key information about the network will be on how well the service/application layer is operating, and the most useful discussions will be in terms of how well those services are working. There will always be a need to know how much bandwidth is being used, analogous to knowing how many kilowatts are needed from a power grid, but actual performance of interest to the service innovators will be in terms of things like error rates, user location accuracy, end user experience quality, etc. In order to make this a reality, spectrum needs to be manage and used dynamically by all services. This requires new tools that allow us to understand how the spectrum is being use by all services on a persistence basis and use this information to optimize the utilization of the spectrum by all service in an autonomous fashion, allowing all services the capabilities to share the spectrum.

After an internal evaluation of government services in the sweet spot of the spectrum, many government agencies simply relocated their services to other bands, while also investing in improved modulation protocols that allowed those services to run more efficiently (higher number of bits per Hz). Whenever that was not possible (due to national security or for economic reasons) the government agencies’ services made some frequency bands available using the co-primary or primary and secondary basis as described previously.

Initial Shared Spectrum Attempts

Initial Government Relocation of Some Services and Attempt to Share

The US government has evaluated its utilization of the spectrum over the last 8 years in the sweet spot used by the commercial telecommunications industry. They have made around 450 MHz of bandwidth available for auction in the sweet spot, generating over $180 B, by relocating some of their services to other spectrum bands, granting co-primary access to commercial services along with the government’s existing services, and granting secondary access to commercial services whereby some partition of a band is shared when the secondary users are not actively using the spectrum (this cover the AWS3 auction, the 3.4 to 3.55 GHz auction, and the 3.7 to 3.98 GHz auction, among others). The granting of co-primary access with the government's incumbent services has generated a lot of confusion and controversy due to the poor definition of co-prime utilization and the interference that one service imposes on the other. To combat this interference the affected government agencies opted to develop a measurement system to monitor the interference from the commercial services. Additionally, they established a portal to coordinate the deployment of commercial services while minimizing the resulting interference.

The initial portal approach was deemed infective by the government agencies sharing the spectrum. This was the first case that clearly indicated the current spectrum management system is not adequate to allow any spectrum sharing on a co-prime or secondary basis. For the 3.4 to 3.55 GHz band, the government service was established as the primary service. Therefore, when the government is using this spectrum nobody else can use it. The commercial industry invested around $24 B to be a secondary user of the spectrum, with a portion of the 150 MHz auctioned (around 70 MHz) allocated for sharing between commercial and government services and the balance dedicated to secondary (commercial) users whenever the primary (government) user is not present in the spectrum. This arrangement resulted in the creation of a third organization, independent from the FCC and NTIA, to manage access to this shared spectrum. In the CBRS bands (3550 to 3700 MHz), the Spectrum Access System (SAS) utilizes a network of special sensors to detect the presence of high-priority signals and informs all secondary users to vacate the spectrum accordingly.

Spectrum sharing is managed by slicing the 150 MHz into 15 channels of 10 MHz each. When a user requests access to the spectrum the SAS analyzes the request and provides grants for each channel. The granting of requests is currently implemented using a method similar to the portal for co-prime services mentioned above, where the prospective services register their transmitters and receiver locations as well as their intended usage of the spectrum (transmitted levels and antennas for EIRP estimates) and the SAS uses propagation models to simulate the level of interference that each service will cause to other services using adjacent channels. If no interference is generated, the request for channel access is granted. Details of this implementation can be found on the OnGo Alliance (formerly CBRS Alliance) website: https://ongoalliance.org/

In summary, the CBRS approach to spectrum sharing:

- Defines three tiers of spectrum users with relative priority of spectrum usage.
- Utilizes a centralized Spectrum Access Systems to grant spectrum requests based on demand and priority.
- Uses a sensor network to detect the presence of Incumbents, the highest priority tier, and uses.
- Relies upon a rather centralized approach to granting spectrum.
- The synchronization of data between SAS is regular, but not instantaneous. Grants and PAL with government.

- Relies upon propagation modeling to protect the PALs and does not rely upon measurements to allow or disallow, making this approach unscalable as the number of users grows and time consuming, unable to support dynamic requirements.
- The specifications do not include a method to detect, identify, and resolve interference between GAA users, the lowest priority tier, not measurements of the actual utilization of the spectrum are used making a fair and transparent dynamic assignment of spectrum impossible.

The government is currently investigating its ability to share more frequency bands with commercial entities in the spectrum sweet spot, but only using *true dynamic sharing*. For example, in the 3.1 to 3.4 GHz band the government services use large amounts of radiated power, and the users are not static in time and space. Because of these characteristics, scheduling a timeslot or service via a portal is impractical (if not impossible).

The Modulation/Demodulation Protocol Front

As mentioned before, the modulation/demodulation protocols are used to map information to be transmitted by the electromagnetic wave X and recovered from Y, respectively. From 1910 to 1979 most communication systems were between pairs of transmitters and receivers and the research was focused on modulation theories to find a modulation/demodulation protocol that maximizes the number of bits per Hz that can transmit for a given transmitter power level. Modulations protocols like FM, QAM, QPSK, PSK, Trellis Coded Modulation, and Turbo Codes were developed first for applications at lower frequency bands and then transported to other frequency bands. When transported to higher frequency bands, they started to exhibit a lot of fading. Therefore, multicarrier modulation schemes were developed, such as code-division multiplexing (CDMA) and orthogonal frequency division multiplexing (OFDM). Most current modulation protocols are very efficient and capable of transporting multiple bits of information per Hz across the sweet spot of the spectrum.

Once multiple receivers and transmitters are clustered together in a region, a communication network is developed. In these networks, the information to be transmitted can come from different locations and is mostly organized in packets of data. Therefore, these networks need to synchronize the utilization of available power, spectrum, and information to be transmitted among others but offer the capability to handle multiple streams of information from different points in the network. The transmitted packets could be from different applications at different locations. A new level of management was required to manage the transportation of these packets through the communication network. The Open Systems Interconnect (OSI) model defined additional layers beyond the physical layer to facilitate the transportation of information from multiple points in the network and became the standard framework for all communications networks. The adoption of the OSI model for wireless communication networks was utilized beginning with the first generation of wireless communication networks (GSM).

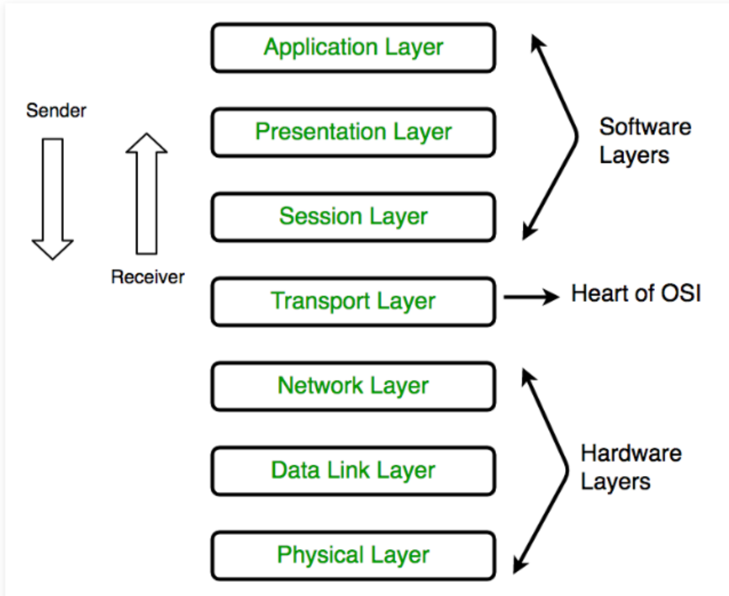

Figure 3: The OSI Model

In this model, the hardware layers and the transport layers are different between wired and wireless networks. The hardware layer contains most of the traditional point-to-point modulation/demodulation protocols as well as extra layers to deal properly with traffic management throughout the network. One thing to notice is that most other network transport issues are managed in the upper layers independent of any issues associated with the physical layer. This facilitates the management of the network by software from a central location, regardless of how large the network is, instead of at every transmitter-receiver location. This provides a clear advantage, especially when the service provided by the network only depends on the information rate that the modulation/demodulation protocols can provide, and no other physical layer properties are required for the service (e.g., the latency associated with the propagation of signals or interference reduction).

In the last 20 years, protocols that support different information data rates and levels of reliability have been developed (e.g., UMTS and LTE) which allow the network to provide different levels of service. This brought the flexibility to support high mobility with higher data rates for services in the network. In turn, this has made it possible for the network to support a large number of applications, making the resulting wireless network the primary mode of communication and information. One of the disadvantages of this is the reliance of all services to be covered by the properties supported by the modulation/demodulation protocol and associated network management. Thus, other services that might be better implemented using other data rates cannot be implemented without being forced to the data rates the protocol supports (requiring all services to use a homogenous foundational protocol).

Services that require not only a high data rate but also quick response and/or reliability of the information communicated through the network are difficult to support on the current network with centralized management functions. To resolve this deficiency, 5G network slicing was created whereby the network management for slices of the network can be pushed down to a regional point in order to minimize network response time and its associated latencies. A pictorial representation of this new 5G architecture is presented in Figure 4.

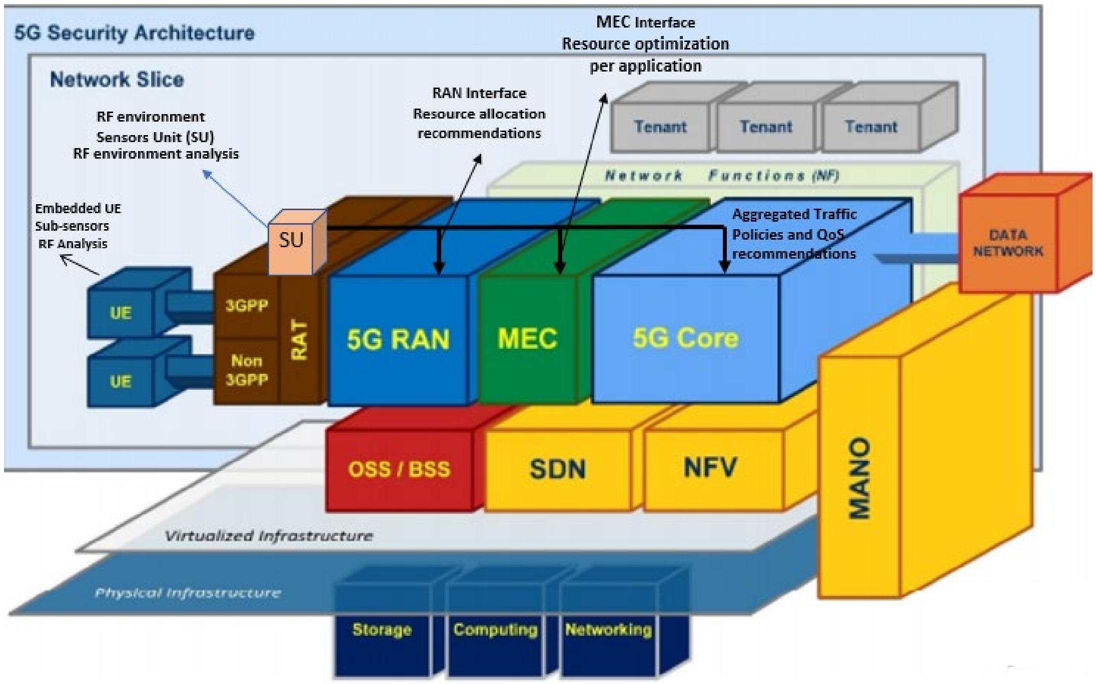

Figure 4: 5G Architecture Block Diagram

In this architecture, concepts like edge computing were implemented through the incorporation and usage of the MEC function (Multi-Access Edge Computing), where computation and storage capabilities can reside to help make decisions affecting the management of the traffic in each slice of the network. Although this can minimize the network response to services performing at each network slice, there is no consideration for physical layer conditions whose sources are external to the network (like interference from other services in congested spectrum environments). These external conditions might require readjustments of modulation/demodulation protocol parameters to guarantee reliability since it might take several milliseconds to discover the condition (if even possible using conventional performance key measurements for such networks) and calculations for the new MEC parameters. It is estimated that by the time the condition is identified, and appropriate parameters are selected to compensate, several tens of milliseconds of processing will have passed in the RAN-MEC-Core processing chain within the slice. Therefore, even though this architecture represents an improvement to handle low latency requirements, it is most likely not sufficient and new improvements are needed. Specifically, improvements that provide statistically sufficient measurements of the RF environment that can be used in a distributed processing fashion and allocate the right network resources to support these services are required.

Proposed Solution: Dynamic Shared Spectrum Management

A description diagram of the proposed solution is depicted in figure 5. The RF environment is sampled continuously and then analyzed to extract available information about all signals associated with services using the spectrum. Samples collected from the RF environment should cover the spectrum band of interest plus adjacent frequency bands, at a minimum. The analysis of the sampled environment should include detection, classification, and identification of all signals present in the environment. It should also include geolocation of signals and pattern identification of the signal behavior and interactions.

This information provides RF awareness of all the signals associated with services using the spectrum. This information is further analyzed in combination with spectrum management policies to satisfy service requirements and optimize the spectrum utilization of all services *dynamically*. Using a semantic engine and inference reasoner, this information can also be analyzed based on customer goals to provide statistically significant actionable data to the customer to realize their goals.

Notice that this solution will allow for the implementation and monitoring of spectrum sharing, policies, rules, and agreements in a dynamic fashion, something not previously possible with the current spectrum management approach. Also, since service requirements other than data rates can be taken into consideration, such as latency and information reliability in congested service environments, it will allow for dynamic optimization of the network resources to support low latency and high reliability services with a modest modification of the network architecture proposed for 5G networks.

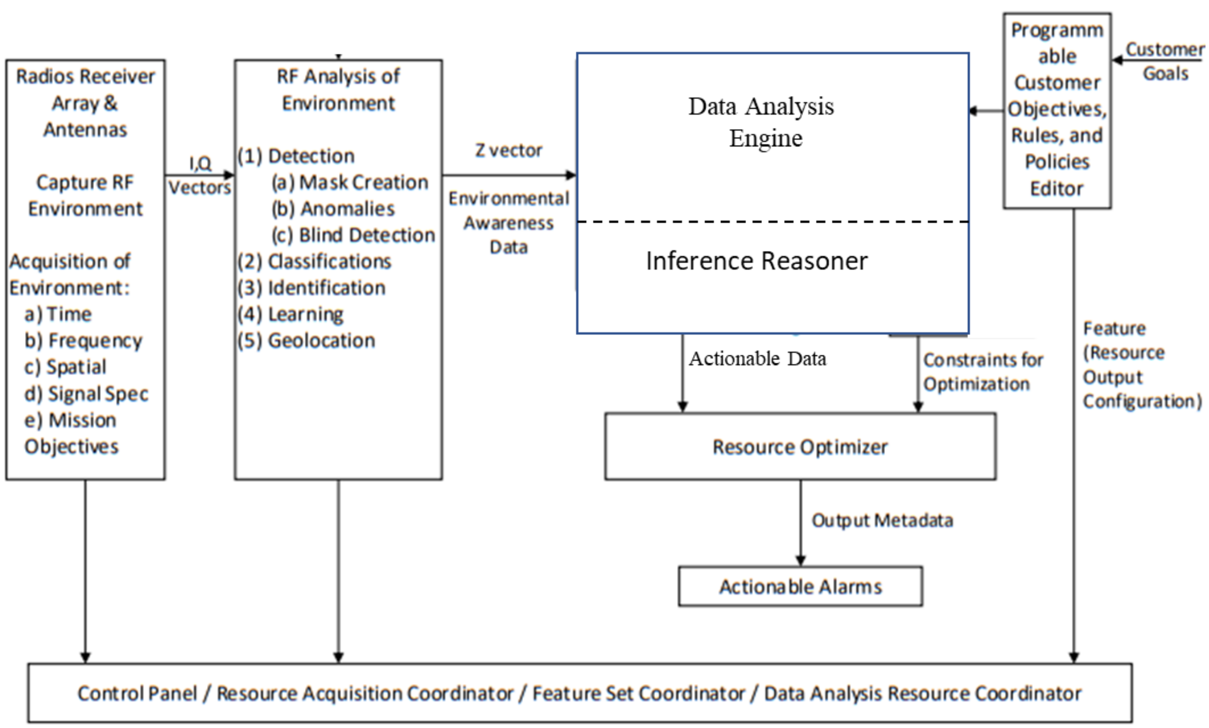

Figure 5

The proposed solution can be implemented in several ways: as an independent dynamic spectrum management system with its own network of sensors or as embedded software within a wireless network communication system such as 5G.

To do this for a wireless communications network, it is very beneficial to have as accurate an understanding of the state of the various emitters (and receivers) in the environment and their expected state in the near future. Thus, let us briefly discuss how this architecture allows to acquire the information which we call "RF Environmental Awareness". This starts with collecting as much information as we can about the environment. RF sensors can be deployed, and the RF energy digitized for analysis. Broad spectral coverage and good resolution (in time, frequency and spatially) should be traded off versus cost.

Detection: The first step in the analysis is detection of the various signals active in the environment. Detection generally involves some level of thresholding which can be (dynamically) set to provide the appropriate rates of Type 1 and 2 errors. Since one of the main issues with spectrum sharing is interference mitigation, it is important to include blind detection techniques when searching for signals, since interference can come from unexpected sources.

Classification: Detected signals can be matched with various known emitter-types using matching of extracted characteristics with database information (SOI matching). The simplest matching can be done using envelop characteristics (center frequency, bandwidth), but matching can also be done using other extracted characteristics such as modulation method.

Identification: Matching estimates of the emitter's location with a priori information, or using information extracted by demodulating and decoding the signal can precisely identify the emitter.

Other: Over time, various characteristics of each emitter can be collected and knowledge of the environment can improve. More precise estimates of such things as location, duty cycles, patterns of use, correlations among emitters, can be developed to give a robust understanding of the use of the RF spectrum both for individual emitters and for the collective set of emitters. Modelling of the expected demand for spectrum can then be done more precisely over various time scales, including near real-time prediction of spectrum utilization that can significantly improve the efficacy of dynamic spectrum allocation decisions.

Policy Analysis and Comparisons with Environmental Measurements

The efficiency and fairness of spectrum utilization of a network is driven by the speed and quality of the decisions that are made to allocate resources to meet user needs. The decisions depend on several factors: requests for resources from users (including the time for which those resources will be needed), state of allocated and available resources during the time periods of each request, and the policies to use for allocating the resources. The decision quality improves with more and better details for each of the factors. Having a key spectrum usage parameter based on a measurement a fraction of a second ago is better than an estimate of that parameter based on a model that extrapolates measurements made months ago. Similarly, the policies can be made more precise by adding additional aspects of the request (for example more spatial details, or more nuanced aspects of priorities or QoS). In all cases, the models of how the state of the RF environment affects the user need will be more accurate when they are based on recent, even real time, data.

Historically, there has been a presumption that real time data is too expensive to obtain, but with the decline in costs for RF hardware and the increase in processing that can be integrated into sensor systems, the availability of data is certainly feasible and the benefits in network performance can be significant.

Optimization Recommendations Based on System Parametrization and SLA Policies Supporting a Strategic Policy

The policies that are selected and implemented can change over time, or even be dynamic, depending on current needs of the policymakers, needs of the users, and availability of measurements. Given the growing availability of computing power at the edges of the network, we recommend a hierarchical and distributed policy for allocating RF resources. The improve fairness and the overall effectiveness of policies, we also suggest that the parameter set for driving decision be taken more from the application and service layers of the network. The user experience will be less about the physical layer parameters (such as bandwidth) and more about service layer parameters, such as lag and data loss. QoS metrics will depend on the particular service being requested, and so there should be more effort to analyze applications to deduce the key parameters affecting the user's experience. These can be worked into a dynamic policy framework. The use of near real-time measurement will improve the fidelity of these service-layer performance parameters. Additionally, keeping track of historical measurements of data will inform optimization of the policies and provide compliance data.

Implementation and integration into 5G and 6G networks

In a network system like those described in the current implementation of 5G, the sample RF environment can be integrated into the RU unit of the RAN and the analysis of the sampled environment can be implemented in a distributed fashion among the DUs and CU or the RAN in each slice of the network. The particular implementation will vary according to the RAN functional partition being considered by several standards bodies. Figure 6 shows the typical function implemented in a RAN and the associated partitions currently being discussed in several study group committees.

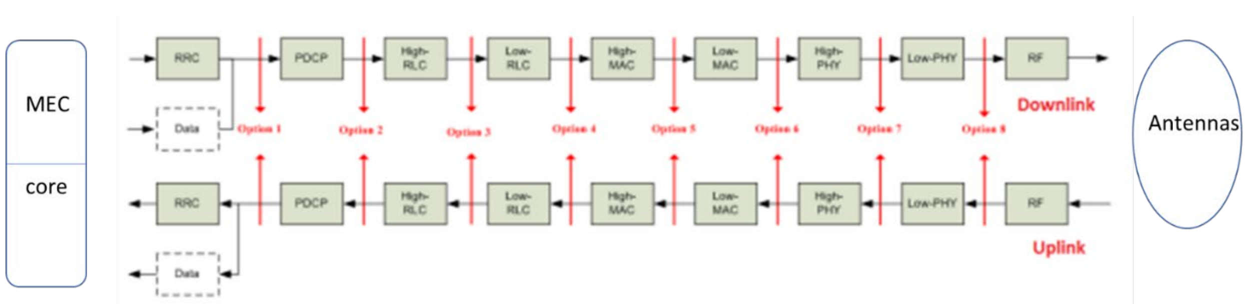

Figure 6

The partition options for these processing functions are listed below:

Here we show all the options proposed in 3GPP release 15 to possibly decompose the RAN's functions:

- Option 1 (RRC/PCDP 1A like split, RRC in CU while PDCP, RLC, MAC, Phy, in DU and RF in RU)
- Option 2 (PDCP/RLC split User plane only (like option 3) RRC, PDCP are in CU. RLC, MAC, and Phy in DU)
- Option 3 (High RLC/Low RLC split two sub approaches based on real-time need vs non-real-time, segmentation, or ARQ)
- Option 4 (RLC-MAC split, RRC, PDCP, and RLC in the CU and MAC, PHY in DU)
- Option 5 (Intra MAC split, Phy and Lower MAC in DU while High layer MAC RLC and PDCP in CU)
- Option 6 (Mac-Phy split, RRC, PDCP, RLC and MAC in CU, Phy in DU, RF configuration data pass to CU)
- Option 7 (Intra Phy split, There are three distinct possible implementation. The jury is still out)
- Option 8 (Phy RF split RF in RU, Phy in DU and all other functions in the CU)

The favored recommendations are shown below:

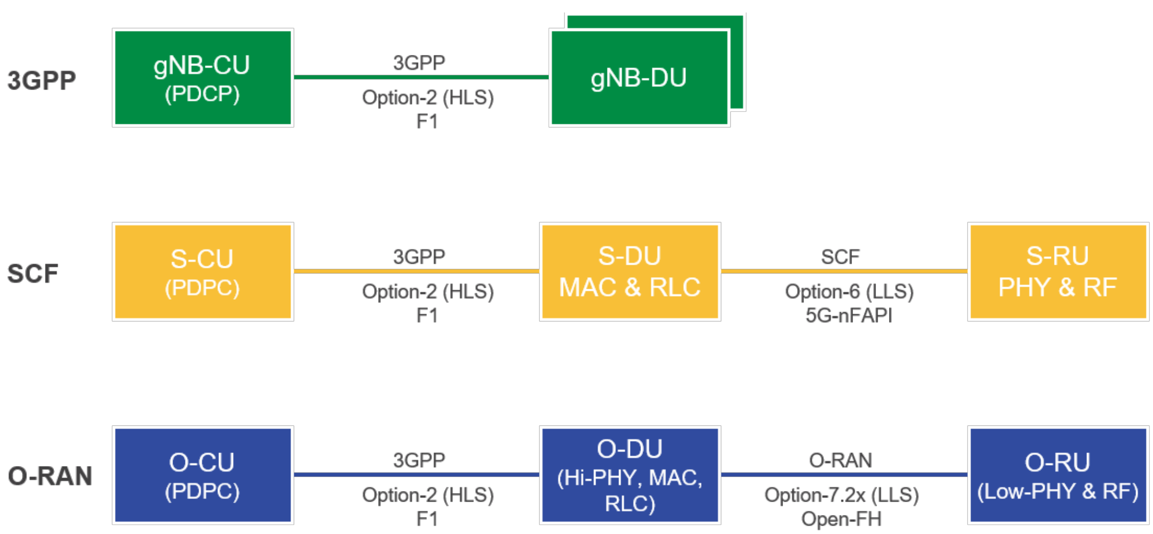

Figure 7

Independent of the actual partition of functions adopted by the industry, the proposed solution can be implemented as software features in the RU, DUs, and CU of the RAN for each slice in the network. The data analysis can be also implemented as a software feature in the Core or MEC of each slice.

Question Response: Implications for Pillar 1, Pillar 2, and Pillar 3

Implications for Pillar 1

Question 1

- *What are projected future spectrum requirements of the services or missions of concern to you in the short (less than 3 years), medium (3–6 years) and long (7–10 years) term?*
    - **The need for spectrum sharing in the "sweet spot" is evident to support new emerging services in the next three years (for all the emerging commercial services as well as the current government services). An example that emerged recently is the deployment of private wireless networks by enterprises to carry their internal IT services as well as other communications services including customer service. This need will continue to increase even if higher frequency spectrum is made available in an economical way. Therefore, the current need to maximize spectrum utilization is really the foundational requirement for spectrum sharing, as mentioned in section 2 of the background.**
- *What are the spectrum requirements for next generation networks and emerging technologies and standards under development (e.g., 5G Advanced, 6G, Wi-Fi 8)?*
    - **The network standards mentioned above are changing to focus on services that the network is required to support. These services are not homogenous and often require difference spectrum utilization and quality. Thus, technology must address the issues of efficient spectrum utilization in an autonomous and dynamic fashion. This cannot be accomplished without a system to manage the utilization of the spectrum by all services which leverages persistent RF environmental awareness and then uses this information to autonomously and dynamically optimize the network resources to facilitate optimal utilization of the spectrum by all services.**
- *Are there additional or different requirements you can identify as needed to support future government capabilities?*
    - **New policies must be put in place by the government that allow for autonomous verification of sharing agreements between disparate services based on current utilization of the spectrum by all services as opposed to prioritization of utilization.**
- *What are the use cases and anticipated high-level technical specifications (e.g., power, target data rates) that drive these requirements? How much, if at all, should our strategy by informed by work being performed within recognized standards-setting bodies (e.g., 3GPP, IEEE), international agencies (e.g., ITU), and non-U.S. regulators or policymakers (e.g., the European Union)?*

- **All the use cases require high reliability and low latency as well as connectivity where very high device density exists with different services and requirements. Since the 3GPP group is shifting focus from protocols to use cases that the network needs to support, we recommend that the government take an active role in these standards discussion.**

- *What relationship (if any) should our strategy have to the work of these entities?*
  - **We recommend that the government dedicate continuous funding to allow its participation in the commercial standards but also to fuel industry collaboration and research to address efficient spectrum utilization. Further, new network designs are required to serve these emerging commercial services while continuing to support the government missions. This funding should target industry rather than academia or research institutions (as done by NSF, DARPA, etc.).**
- *Are there spectrum bands supporting legacy technology (e.g., 3G, GSM, CDMA, etc.) that can be repurposed to support newer technologies for federal or non-federal use?*
  - **Regardless of how spectrum is repurposed, we believe dynamic spectrum sharing is needed to support current and future wireless communication networks.**

Question 2

- *Describe why the amount of spectrum now available will be insufficient to deliver current or future services or capabilities of concern to stakeholders. We are particularly interested in any information on the utilization of existing spectrum resources (including in historically underserved or disconnected communities such as rural areas and Tribal lands) or technical specifications for minimum bandwidths for future services or capabilities. As discussed in greater detail in Pillar #3, are there options available for increasing spectrum access in addition to or instead of repurposing spectrum (i.e., improving the technological capabilities of deployed systems, increasing or improving infrastructure build outs)?*
  - **The limited availability of mid-band (sweet spot) spectrum in the U.S. is widely accepted. Spectrum bands above 8 GHz can be accessed to address shortfalls in spectrum. However, these solutions remain less competitive than mid-band options forcing a focus on spectrum management techniques that can free up mid-band spectrum. DGS maintains the spectrum strategy approach that should be embraced focuses on delivering improved spectrum utilization in all bands. Achieving higher spectrum utilization in all bands is critical to our global competitiveness.**

Question 3

- *What spectrum bands should be studied for potential repurposing for the services or missions of interest or concern to you over the short, medium, and long term?*
  - **No comment**

- *Why should opening or expanding access to those bands be a national priority. For each band identified, what are some anticipated concerns? Are there spectrum access models* *(e.g., low-power unlicensed, dynamic sharing) that would either expedite the timeline or streamline the process for repurposing the band?*

- **The focus should not be on opening new frequency bands but rather on developing a system that optimizes the utilization of the spectrum by all services on a dynamic sharing basis with autonomous confirmation of sharing policies to detect and resolve conflicts in near real-time. This focus will result in larger allocations of spectrum being made and expedite availability.**

Question 4

- *What factors should be considered in identifying spectrum for the pipeline? Should the Strategy promote diverse spectrum access opportunities including widespread, intensive, and low-cost access to spectrum-based services for consumers? Should the Strategy promote next-generation products and services in historically underserved or disconnected communities such as rural areas and Tribal lands? Should the Strategy prioritize for repurposing spectrum bands that are internationally harmonized and that can lead to economies of scale in network equipment and devices?*
  - **The focus should be on implementing tools to maximize spectrum utilization rather than on repurposing bands.**

Question 5

- *Spectrum access underpins cutting edge technology that serves important national purposes and government missions. Are there changes the government should make to its current spectrum management processes to better promote important national goals in the short, medium, and long term without jeopardizing current government missions?*
  - **A focus on implementing tools to maximize spectrum utilization will minimize any risk to current government missions.**

Question 6

- *For purposes of the Strategy, we propose to define ''spectrum sharing'' as optimized utilization of a band of spectrum by two or more users that includes shared use in frequency, time, and/or location domains, which can be static or dynamic. To implement the most effective sharing arrangement, in some situations incumbent users may need to vacate, compress, or repack some portion of their systems or current use to enable optimum utilization while ensuring no harmful interference is caused among the spectrum users. Is this how spectrum sharing would be defined? If not, please provide a definition or principles that define spectrum sharing. What technologies, innovations or processes are currently available to facilitate spectrum sharing as it should be defined? What additional research and development may be required to advance potential new spectrum sharing models or regimes, who should conduct such research and development, and how should it be funded?*
  - **We agree with the definition of spectrum sharing with an emphasis that whatever is developed needs to be based on persistent measurements of the environment to see how each service is using the RF environment. Also, a set of policies that enables autonomous deconfliction of interference between services is essential. We believe that a set of tools to acquire RF**

environmental awareness, persistent and in real time, is needed as well as policies that allow for dynamic verification of utilization of the spectrum by all services.

Question 7

- *What are the use cases, benefits, and hinderances of each of the following spectrum access approaches: exclusive-use licensing; predefined sharing (static or predefined sharing of locations, frequency, time); and dynamic sharing (real-time or near real time access, often with secondary use rights)? Are these approaches mutually exclusive (i.e., under what circumstances could a non-federal, exclusive-use licensee in a band share with government users, from a nonfederal user point of view)? Have previous efforts to facilitate sharing, whether statically or dynamically, proven successful in promoting more intensive spectrum use while protecting incumbents? Please provide ideas or techniques for how to identify the potential for and protect against interference that incumbents in adjacent bands may experience when repurposing spectrum.*
    - **See section titled "Initial Shared Spectrum Attempts" in Background and Overview for discussion of recommendation on this topic.**

Question 8

- *What incentives or policies may encourage or facilitate the pursuit of more robust federal and non-federal spectrum sharing arrangements, including in mid-band and other high priority/demand spectrum?*
    - **We recommend that the government develop sharing policies that can be used to optimize the utilization of the spectrum by all services. These policies should be the basis for sharing agreements between all services using the spectrum. These require the current policies (based on exclusive assignment of spectrum to new services based on non-interference with existing services) to a set of policies indicating how the spectrum should be shared.**

Question 9

- *How do allocations and varying spectrum access and governance models in the U.S. compare with actions in other nations, especially those vying to lead in terrestrial and space-based communications and technologies? How should the U.S. think about international harmonization and allocation disparities in developing the National Spectrum Strategy?*
    - **A broad range of spectrum sharing methodologies are under consideration by various countries. The approach we are suggesting, which leverages dynamic spectrum sharing based on persistent RF measurements, will ensure the United States leads in efficient utilization of spectrum. This can occur despite the level of incumbency present in the U.S. market in key spectrum bands.**

Implications for Pillar 2

Question 1

- *Who are the groups or categories of affected stakeholders with interests in the development of the National Spectrum Strategy and participating in a long-term spectrum-planning process? How do we best ensure that all stakeholders can participate in a long-term spectrum planning process in order to facilitate transparency to the greatest extent possible, ensure efficient and effective use of the nation's spectrum resources?*
    - **We recommend including the entire ecosystem that supports the roll out of new services, such as logistics, telemedicine, virtual training, etc., as well as emerging markets like private wireless.**

Question 2

- *What type of timeline would be defined as a ''long-term'' process? What are key factors to consider and what are the key inputs to a long-term planning process? What data are required for planning purposes? Do we need data on spectrum utilization by incumbent users, including adjacent band users, and, if so, how should we collect such data and what metrics should we use in assessing utilization? Do we need information from standards-setting bodies and, if so, what information would be helpful and how should we obtain such information? What is the appropriate time horizon for long-term spectrum planning and how often should we revisit or reassess our prior findings and determinations? How do we balance periodic review and reassessment of our spectrum priorities with providing regulatory certainty to protect investment-backed expectations of existing spectrum users? How can federal and non-federal stakeholders best work together?*
    - **Pay careful attention to shifts towards service functionality and key parameters related to service offerings (e.g., data error rates versus interference power levels). Generally more and current information is better than old, simplified data.**
    - **Reconsider the data requirements whenever a new service is introduced. Avoid the tendency to over-simplify. Power measurements alone are not sufficient in determining whether a spectrum allocation has successfully enabled a service.**
    - **Transparency is essential. All service providers and network operators should have access to information about the utilization of the network and the pattern of service requests that come from users. The parameters being used for policy implementation should be available in a transparent manner.**
    - **Use of licenses by service providers should be regularly (e.g., annually) and aggressively reviewed.**
    - **These policies should apply to all services as opposed to protocol or band assignment.**

Question 3

- *How can federal and non-federal stakeholders best engage in productive and ongoing dialogue regarding spectrum allocation and authorization, repurposing, sharing, and coordination? Learning from prior experiences, what can be done to improve federal/nonfederal spectrum coordination, compatibility, and interference protection assessments to avoid unnecessary delays resulting from nonconsensus?*

- **There is still significant R&D needed to improve the technologies for data collection, the models for the use of spectrum and the quality of services enabled, and on the effectiveness of more complex spectrum sharing policies, including hierarchical distributed policies. More government funding to support this R&D is essential, and it is important to involve the commercial sector as well as academic and governmental organizations.**

Question 4

- *What technical and policy-focused activities can the U.S. Government implement that will foster trust among spectrum stakeholders and help drive consensus among all parties regarding spectrum allocation decisions?*
    - **Inclusion of persistent and autonomous measurement capabilities embedded in the network will facilitate policy sharing, validation, and enforcement.**
    - **This measurement data, reflecting the utilization of spectrum, must be collected and shared. Also, additional information about the behavior of applications should also be collected and made available.**

Question 5

- *Are additional spectrum-focused engagements beyond those already established today (e.g., FCC's Technical Advisory Committee (TAC),2 NTIA's Commerce Spectrum Management Advisory Committee (CSMAC),3 and NTIA's annual Spectrum Policy Symposium) needed to improve trust, transparency, and communication among the federal government, industry, and other stakeholders (including Tribal Nations) and why?*
    - **Currently, the government is using the National Spectrum Consortium to help address some of these technical discussions. We recommend that this continues since it serves to provide a forum for all interested parties to explore solutions and discuss fomenting trust between all parties.**
- *What would be the scope of such engagements, how would they be structured, and why would establishing new engagements be preferable to expanding the use of existing models? If existing models are sufficient, how (if needed) should FCC and NTIA maximize their usefulness or leverage their contributions to enhance and improve coordination?*
    - **No comment**

Question 6

- *In considering spectrum authorization broadly (i.e., to include both licensed and unlicensed models as well as federal frequency assignments), what approaches (e.g., rationalization of spectrum bands or so-called ''neighborhoods'') may optimize the effectiveness of U.S. spectrum allocations? Are there any specific spectrum bands or ranges to be looked at that have high potential for expanding and optimizing access? Which, if any, of these spectrum bands or ranges should be prioritized for study and potential repurposing? Conversely, are there any bands or ranges that would not be appropriate for access expansion? What, if any, metrics are ideal for measuring the intensity of spectrum utilization by incumbents in candidate bands?*

- **Once dynamic spectrum sharing is embraced, then spectrum bands will be differentiated purely by economics since all bands will be optimized.**
- **In general, our proposed solution can be adopted to higher bands when the cost of the transceiver and the network deployment is substantially reduced (comparable to current costs).**

Question 7

- *What is needed to develop, strengthen, and diversify the spectrum workforce to ensure an enduring, capable and inclusive workforce to carry out the long-term plans (including specifically in rural and Tribal communities)?*
  - **No comment**

Implications for Pillar 3

Question 1

- *What innovations and next generation capabilities for spectrum management models (including both licensed and unlicensed) are being explored today and are expected in the future to expand and improve spectrum access (and what are the anticipated timelines for delivery)?*
  - **Development of a system that obtains RF environmental awareness and uses this information to dynamically optimize spectrum utilization is the key innovation that Digital Global Systems has and continues to develop. This optimization occurs in real time for multiple services. This type of system is in prototype testing and is expected to be available by the end of 2023.**

Question 2

- *What policies should the National Spectrum Strategy identify to enable development of new and innovative uses of spectrum?*
  - **See response to section Implications for Pillar 1, Question 8.**

Question 3

- *What role, if any, should the government play in promoting research into, investment in, and development of technological advancements in spectrum management, spectrum dependent technologies, and infrastructure?*
  - **In addition to the response to Pillar 2, we recommend that the government continue to actively provide funding to allow for new technology to be tested and optimized in conjunction with private industry and ensure results are discussed openly in technical forum and consortiums (such as the National Spectrum Consortium). This will facilitate rapid adoption of this new technology.**
- *What role, if any, should the government play in participating in standards development, supporting the use of network architectures, and promoting tools such as artificial intelligence and machine learning for spectrum coordination or interference protections? What technologies are available to ensure appropriate interference protection for incumbents in adjacent bands? What spectrum*

management capabilities/tools would enable advanced modeling and more robust and quicker implementation of spectrum sharing that satisfies the needs of non-federal interests while maintaining the spectrum access necessary to satisfy current and future mission requirements and operations of federal entities?

- **In addition to the government actively participating in standards bodies (like 3GPP, ITU, etc.), we recommend the government invest in tools that extract RF environmental awareness and use the information to help optimize the spectrum utilization for all services. These techniques can learn from the environment and be programmable enough to deal with competing service requirements, Also, investment in the development of sharing policies that can be acted on and verified autonomously by the services using the spectrum is also recommended. These new techniques can also enhance planning and modeling of new networks and their performance.**

- *How can data collection capabilities or other resources, such as testbeds, be leveraged (including those on Tribal lands and with Tribal governments)?*
  - **These data, if properly collected, can be used to emulate use cases in a controlled environment and to test this new technology in a more realistic manner before having to deploy costly new hardware and software in the network.**

Question 4

- *NTIA is pursuing a time-based spectrum sharing solution called the incumbent informing capability (IIC) to support spectrum sharing between federal and non-federal users.4 What are some recommendations for developing an enduring, scalable mechanism for managing shared spectrum access using the IIC or other similar mechanism, with the goal of increasing the efficiency of spectrum use? What challenges do nonfederal users foresee with potentially having limited access to classified or other sensitive data on federal spectrum uses and operations as part of the IIC or similar capabilities, and what recommendations do users have for ways to mitigate these challenges? What are the costs and complexities associated with automating information on spectrum use?*
  - **For any such techniques to work it will require knowledge of how all the services are using the RF environment (not only how they are intending to use the environment) in order to provide optimization of the spectrum usage while minimizing interference between services. This requires tools such as the one recommended by Digital Global Systems' proposed solution along with a set of service goals and sharing policies which facilitate the autonomous detection and resolution of interference events between services.**

Question 5

- *What other technologies and methodologies are currently being, or should be, researched and pursued that innovate in real-time dynamic spectrum sharing, particularly technologies that may not rely on databases?*
  - **Throughout our responses, DGS has described a system leveraging RF environmental awareness as an alternative to solutions relying on databases. This approach satisfies the protection requirements of incumbents while**

providing low-cost spectrum access to commercial operators. In addition, the information acquired to support this dynamic spectrum sharing system can be leveraged to support the performance requirements of new services (e.g., URLLC).

Implication to Current Operational Systems

Private Wireless Networks for Enterprises using CBRS

CIOs have lamented the shortcomings of Wi-Fi for many years, with a lack of security and inability to differentiate services across large campuses among them. The use of private wireless networks using either LTE or 5G protocols is the most popular alternative, as they provide substantial advantages over Wi-Fi 6 (such as extra security and QoS support for critical enterprise applications, among others). These private wireless networks could be implemented by current wireless service providers (such as AT&T, T-Mobile, and Verizon) using slices of their network. But since not all features supporting advanced services in network slices are fully implemented and unlicensed/lightly licensed spectrum in the 3.5 to 3.7 GHz band (CBRS) is available outside of the carrier ecosystem, many enterprises are not waiting for network service providers before they deploy private networks. These new private wireless networks are likely to introduce thousands to hundreds of thousands of new nodes and their associated requests for spectrum access. This represents a problem for the current spectrum granting process implemented in the SAS because the process is not using actual measurements of the spectrum utilization by the nodes to make grants, but rather depends on user-supplied information about how the nodes are planning to transmit signals in the spectrum along with propagation models to simulate the utilization of the spectrum at the requesting node's location. Notice that as the number of requests for spectrum increases, the computation requirements to simulate the spectrum utilization at each node location increases exponentially, severely limiting the response time for granting spectrum and the number of requests that can be handled simultaneously. Because the grant process cannot guarantee the degree of utilization of each channel in the spectrum, one of two scenarios are possible: either the SAS can grant access to a spectrum channel that is currently occupied by another signal (resulting in interference) or the SAS may be too conservative based on propagation models and deny grants when actual spectrum is available. The end result is low-quality spectrum sharing assignments, negating the benefits of sharing the spectrum between multiple services.

A possible solution for this problem is to use our proposed solution embedded into each network node, providing actual spectrum utilization information for each node making a request, negating the use of propagation models and improving the grant response time of the SAS. This solution also allows the private network operators to see spectrum utilization in real-time, allowing for optimization of their spectrum to support a higher quality of information transfer. This can then be used for SLAs for mission-critical applications in their networks (including future low latency/high-reliability applications). Another advantage of using this information to optimize the spectrum is the possible reduction in the number of nodes required to support mission-critical applications. Today, most private network deployments include too many nodes, as the industry standard is to use extremely conservative propagation models that "plan for the worse" instead of deploying based on actual knowledge of the RF environment.