DYNAMIC SPECTRUM SHARING FOR PRIVATE CELLULAR

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DGS

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INTRODUCTION AND MARKET OVERVIEW

The world has experienced significant turmoil the past few years, with the COVID-19 pandemic, the Ukraine-Russia war, geopolitical tensions, and rising inflation challenging consumers and enterprises alike. Many companies are now reassessing their future financial guidance to be more moderate and in-line with these ongoing challenges. Regardless of these challenges, a stable foundation for the operation of both consumer and enterprise markets has been telco networks, which operated flawlessly throughout the pandemic, during the period when most employees had to work from home. Since then, there has been renewed national interest in maintaining high-quality telco networks, while ensuring that communications—both wired and wireless—continue to create opportunities in both consumer and enterprise domains.

In the enterprise domain, private cellular is a relatively new value proposition, which allows enterprises to deploy mission-critical wireless networks on-premises to enable existing and new types of use cases. Indeed, many enterprises have now deployed these networks to improve existing use cases and enable new ones, including the below examples:

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1) **Existing Use Cases:** Large enterprises and entities with large campuses have deployed private cellular networks to overcome Wi-Fi's security and coverage limitations. Manufacturing plant owners have deployed private cellular networks for better connectivity for their Automated Guided Vehicles (AGVs), resulting in faster AGVs and significantly improved operational efficiency.

2) **New Use Cases:** Mining companies have deployed private cellular in their open pit mines, allowing for completely automated operation for their equipment, including trucks and digging equipment. This has improved human safety considerably, especially in areas where blasting takes place.

These two examples are but a few success cases in the private cellular market. In the United States, the Citizens Broadband Radio Service (CBRS) spectrum has created the biggest private cellular market in the world, with hundreds of thousands of access points already deployed.

STATE OF THE PRIVATE CELLULAR MARKET AND ENTERPRISE 5G USING CBRS

Private cellular networks are a recent market development that combines the carrier-grade nature of cellular networks with the localized deployment that Wireless Local Area Networks (WLANs) offer. Moreover, the access point and device ecosystem for cellular is very well-established, allowing enterprise users to take advantage of these economies of scale and reduce the cost of deployment and operation. There are several shared spectrum initiatives around the world, giving enterprises access to cellular-grade spectrum. The most of popular, successful, and coordinated of these initiatives is in the United States.

The CBRS is a 150 Megahertz (MHz)-wide frequency band in 3550 – 3700 MHz in the United States. In 2017, the Federal Communications Commission (FCC) created a process to share this band between incumbent users (e.g., the U.S. Navy), Priority Access License (PAL), and General Authorized Access (GAA) licensees. Priority of communications across this band is with incumbent users, then PAL, and finally, GAA. A handful of Spectrum Access System (SAS) providers are managing this spectrum and have deployed Environmental Sensing Capability (ESC) sensors on U.S. coastlines to ensure that CBRS systems do not interfere with U.S. naval radar.

According to the latest data collected and analyzed by the National Telecommunications and Information Administration (NTIA) (Technical Report TR-23-567), CBRS Devices (CBSDs) were in the range of 287,000 as of January 2023, while this number is expected to have increased to 330,000 by 3Q 2023. Of these devices, 70% have been deployed in rural areas, meaning there is a need for connectivity in underserved areas, for both consumer and enterprise use cases. For example, several rural operators are using CBRS spectrum for Fixed Wireless Access (FWA) services, while enterprises like John Deere tractors have invested in PALs to improve operational efficiency.

Despite the success and global leadership of the CBRS ecosystem, there is still room for improvement. Spectrum management is one of these areas of improvement, where ESC is being discussed, as well as the process of detecting interference and informing relevant parties to change frequencies to mitigate this.

SHARED SPECTRUM AND DYNAMIC SPECTRUM SHARING

Spectrum has traditionally been either licensed or unlicensed, both of which have several pros and cons. Licensed spectrum can enable high-quality, carrier-grade services, but Mobile Network Operators (MNOs) have had to spend billions of dollars in acquiring spectrum licenses, which often came with stringent coverage requirements, translating to billions of additional costs to deploy nationwide networks. On the other hand, unlicensed spectrum is completely free to use, and is widely used by Wi-Fi networks. There have been telecoms technologies using unlicensed spectrum, including MulteFire and License Assisted Access (LAA), but neither has reached large-scale use. Shared spectrum falls in between these two categories and combines the best of both worlds: the robustness and ecosystem of licensed spectrum without hefty fees to access it.

There are several national shared spectrum initiatives, including in the United Kingdom, France, Germany, Japan, and the United States, which pioneered the CBRS system, the most comprehensive framework in the world.

STATE OF PRIVATE CELLULAR USING SHARED SPECTRUM/CBRS

The CBRS framework is a complex system that ensures that no interference occurs between tiers and, most importantly, that the CBRS system does not interfere with naval radar across the U.S. coast. However, CBRS is not true spectrum sharing, but rather an allocation of licensed and unlicensed channels. Operators do not occupy the same channels, even if their service profile would allow it. The spectral efficiency afforded by a more dynamic approach to spectrum sharing is not leveraged in the current CBRS framework.

The frequency band CBRS operates in is a popular one for 5G, and is the most efficient band for the deployment of Massive Multiple Input, Multiple Output (mMIMO) radios, which are the key component of the new generation. These allow a leap in terms of capacity, using beamforming, while allowing the deployment of 5G on top of an existing 4G cellular network. Thus, it is natural that PALs have been popular acquisitions across the United States, with an estimated total cost of US$4.6 billion. Networks operating in PALs also take priority over GAA deployments, meaning that private cellular networks deployed in the latter band may need to be retuned or use another frequency to not interfere with PAL networks.

There is also the case where multiple GAA networks may be interfering with each other, while not necessarily using the same frequency band. In fact, there is no guard band between GAA frequencies and C-band (3.7 – 3.98 Gigahertz (GHz)), meaning that there may be communication degradation if a proper guard band is not implemented. Managing spectrum and interference is a complicated matter, and the role of SAS providers has been shown to be a good first step toward managing multiple network coexistence, but an incomplete framework if large-scale deployments continue.

There are discussions that the role of ESC equipment is not the most efficient, due to concerns that CBSDs themselves may trigger ESC sensors. There are "whisper zones" where interference may be detected from lawful devices. Several parties have proposed the Incumbent Informing Capability (IIC), with the government notifying CBRS network users if a naval radar or other incumbent system is in the area and CBRS networks need to power down or change frequencies.

DRIVERS, APPROACHES, AND THE ROLE OF SAS PROVIDERS

The discussion above illustrates that the CBRS system is far from perfect and requires continued improvement to ensure no interference is caused between incumbent, PAL, and GAA users. SAS providers operate comprehensive databases of devices active in their coverage areas and oversee calculating potential interference when a new network is applying for a license and award or decline a license accordingly. SAS providers exchange hundreds of megabytes of data every day and run heavy computational workloads to estimate if interference takes place across the areas they operate. It is impossible to calculate if a new network will interfere with existing systems in real time and this process often takes 24 hours.[1]

There are several discussions in the industry—and proposals to the OnGo Alliance—to update the role and functionality of SAS providers to enable real-time acceptance of new systems, minimize interference, and even enhance the efficiency and capacity of CBRS systems.

IMPACT ON ENTERPRISES AND FUTURE ACCELERATION

A more efficient manner of managing interference and new systems will be necessary in the future, when enterprise adoption of CBRS systems will accelerate. Indeed, all collected data from the market indicate that CBRS deployments are accelerating, with more than 300,000 CBSDs already deployed in the market today. ABI Research expects that the CBRS system will accelerate, with the following enterprise verticals and use cases being the most prominent across the United States:

- **Energy Generation and Utilities:** Energy generation sites, such as mines or oil & gas fields, are vast areas. Furthermore, use cases like the condition-based monitoring of oil & gas fields are highly critical and require maximum network integrity. Consequently, providing connectivity to these areas can become costly and difficult to ensure. As 5G network infrastructure can cover a larger area than other wireless connectivity technologies, deployments will be easier and more economical. Furthermore, energy generation will rely more and more on renewable energy resources, and more innovative technologies and increased connectivity will be needed throughout the utility network to monitor supply and demand levels.

- **Industrial Manufacturing:** As manufacturing processes are becoming more and more complex, production lanes are becoming an increasingly stressful environment. Exposing manual workers to this increases the velocity of fatigue, as well as their error rate. Consequently, factories will look at flexible production layouts and more opportunities to remotely operate and monitor production workflows. This increases demand for connectivity, especially with regard to high availability and reliability, as well guaranteed network integrity.

- **Ports and Airports:** Similar to energy generation and utilities, ports and airports are often characterized by a very large area that requires reliable and robust levels of connectivity. Furthermore, the loading and deleting of cargo is a particularly hazardous operation and labor-intensive work. This increases the demand for remote operations and, therefore, increases the connectivity requirements.

Furthermore, the more widespread adoption of machine vision and generative Artificial Intelligence (AI) will increase the demand for high bandwidth for enterprise connectivity, which 5G will be able to support.

[1] *Recommendations to the Federal Communications Commission Based on Lessons Learned from CBRS*

SPECTRUM MANAGEMENT CHALLENGES

As previous sections have highlighted, the CBRS spectrum management process is neither perfect, nor finalized. Table 1 summarizes a few challenges and what their implications are in terms of CBRS system performance.

Table 1: CBRS System Performance Challenges and Their Implications

(Source: ABI Research)

CHALLENGES	TECHNICAL AND COMMERCIAL IMPLICATIONS
A propagation model in the CBRS framework uses the Irregular Terrain Model (ITM), which does not consider clutter, such as buildings and foliage.[1]	Interference levels are overestimated, meaning that network planning and dimensioning typically lead to **higher deployment and equipment costs** than necessary.
Interference calculations and planning take place over a 24-hour period, meaning that potential interferers can remain unidentified even days after their appearance.	Using the current scheme of CBRS deployments, it is **not possible to guarantee mission-critical use cases** due to the lack of real-time understanding of the radio channel.
A new device appearing in the network asking for access can be permitted to transmit the following day and only after SAS providers have calculated potential interference levels.	New devices can only be permitted to the network after a day at best and SAS providers are required to perform complex, intensive calculations daily. .
There are no coexistence guidelines for GAA license owners, meaning that SAS providers cannot distinguish between license owners in the same coverage area, unless one of them is identified as harmful interference.	GAA licenses operate on a first-come, first-served basis and interference-free operation is not guaranteed. At the current mode of operation, there are no conflicts between 2 GAA networks in the same vicinity, but this may change once private cellular accelerates in the market.
Radio Frequency (RF) awareness is coarse and non-real-time for CBRS networks at the moment due to lack of RF measurements built into the standard.	New networks—especially for mission-critical use cases—will not be able to do adequate planning to forecast capacity and congestion challenges. Most often, this inadequacy results in higher costs.
Interference management needs to be more nuanced, including what is referred to as "whisper zones," exclusion zones, and GAA licensee coexistence.	Inefficient interference management results in deployed systems that include significant overhead.

The examples in Table 1 illustrate that spectrum and interference management in CBRS is currently a coarse process that takes days to complete and allow new devices in the network. Moreover, networks with a GAA license cannot guarantee the uninterrupted and interference-free operation of a network, meaning that mission-critical use cases using Ultra-Reliable Low Latency Communication (URLLC) and deterministic networking are not probable and perhaps not even possible in CBRS GAA spectrum. Thus, it is necessary to adopt a real-time spectrum management approach, which will allow more granular and detailed interference management.

DYNAMIC SPECTRUM SHARING: A NECESSITY FOR THE FUTURE

The discussion outlined above illustrates that better spectrum management needs to take place for CBRS and shared spectrum, in general, for multiple reasons. At the moment, it is not possible for SAS providers to understand the RF environment across the areas they connect without measurements directly from CBSDs or end devices. The company Digital Global Systems (DGS) has developed an approach that does exactly this: collects measurements from the radio channel

and combines them to understand the state of interference, spectrum use, and multiple other parameters in detail. These data can then be used to make the communication channel more efficient and improve various other parameters. However, DGS's dynamic spectrum sharing should not be confused with The 3rd Generation Partnership Project's (3GPP) dynamic spectrum sharing, which are two completely alien concepts:

1) **DGS' Dynamic Spectrum Sharing:** This technology combines comprehensive RF capture, performs analysis of these data at the edge, extracts insights, and optimizes processes to improve the RF environment and other parts of the network.

2) **3GPP's Dynamic Spectrum Sharing (DSS):** This allows Long Term Evolution (LTE) (4G) and New Radio (NR) (5G) radio networks to use the same spectrum and coexist without interfering with one another. This is deployed in the market, but inflicts significant overhead, so it is used only where necessary.

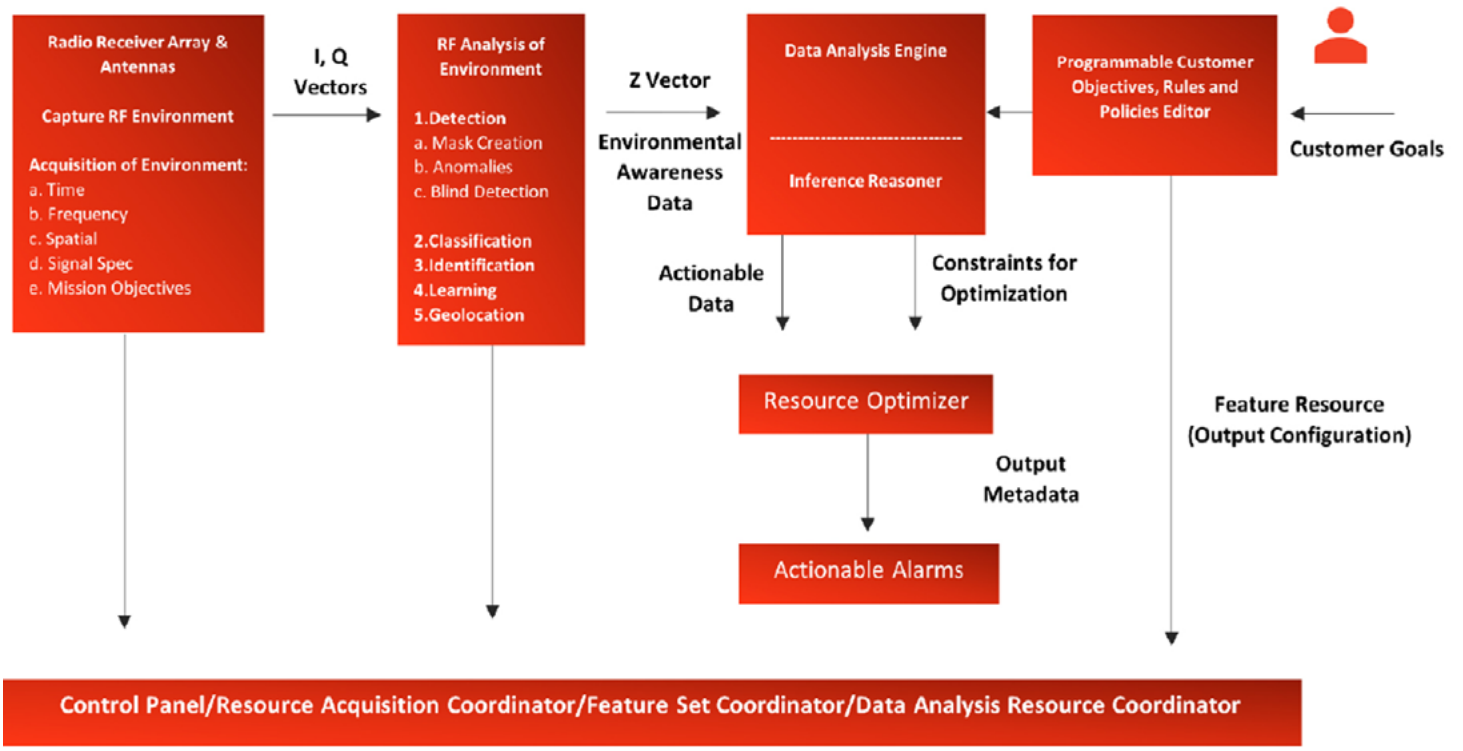
The focus of this paper is DGS's solution, which aims to optimize the shared spectrum channel, with a particular interest in CBRS in the United States. It is important to identify which new features and what level of efficiency improvement dynamic spectrum sharing will introduce, particularly in the context of enterprise wireless networking.

DYNAMIC SPECTRUM MANAGEMENT SYSTEM: PRINCIPLES OF OPERATION

Figure 1 summarizes the DGS process for its Dynamic Spectrum Management System (DSMS), which includes the continuous measurement of the RF environment to detect signals.

Figure 1: DGS's DSMS Block Diagram

Source: DGS



A brief description of this framework is as follows:

1) DGS collects comprehensive measurements from the RF channel in multiple dimensions, including frequency, time, space, signal characteristics, and customer goals. This is achieved via two main ways:

    a. Software installation in the Radio Access Network (RAN).

    b. DGS sensing device that consists of multiple sensors, which can be a drone with multiple sensors onboard.

2) DGS then combines all of this information at the edge and trains AI/ML models that factor in customer objectives and priorities.

    a. The company has also created a template that can be used to share these data with SAS providers and inform them of any potential interference detected.

3) This is then processed in a resource optimizer that provides actionable alarms.

The DSMS approach is a much more comprehensive solution compared to what is available today in the CBRS domain. This can potentially enable new types of use cases and applications in near real time and goes beyond the capability of SAS providers.

WHAT ARE THE ENTERPRISE REQUIREMENTS AND HOW CAN DSMS MATCH THEM?

Enterprises that deploy private cellular networks have specific requirements, many of which are closely related to their own priorities and challenges. For example, no enterprise is going to deploy a private 5G network because it offers high-capacity, low-latency connectivity, but the same enterprise will be highly interested if a private 5G network can help reduce operational complexity, streamline operations, and reduce running costs. DSMS can augment and improve enterprise use cases enabled by CBRS in many different manners.

Reliable and Deterministic Networking and New Use Cases

A key feature introduced with 5G is the URLLC use case that enables deterministic and reliable networking. In this mode of 5G operation, the communication link is configured with stringent parameters, where communication packet loss and jitter (the packet arrival interval) are clearly and accurately defined. It is not absolutely necessary to provide ultra-low-latency communications in most scenarios—except in use cases that require near-real-time control—but the ability to enable a robust and reliable link can enable new types of use cases. For example, a private 5G network providing URLLC capabilities can enable remote control of machines and equipment, ensuring that humans are removed from potentially harmful environments without sacrificing operational efficiency. Previously, this was only possible using communications using cables or optical fiber.

However, the CBRS spectrum available to enterprises today through GAA licenses cannot guarantee an interference-free operation because SAS providers take a day to estimate the possibility of interference and two networks operating at once in the same area. Moreover, there is no guard-band between GAA licenses and C-band spectrum, meaning that an adjacent carrier cell site may interfere with an enterprise deployment. Moreover, SAS providers do not possess the data or capability to detect the location of a potential interferer, meaning that an in-person site survey will be necessary to find and remove the interfering culprit device. These are insurmountable challenges for an enterprise to address for a communication link.

DSMS Solution: The DGS solution enables measuring the channel in near real time and reconfiguring the communication link to address potential interference and other mitigations. For example, DSMS can detect communication anomalies and interference, can factor in full environmental data for deployment, and considers customer rules and goals to assist in decision-making for the communication link. In addition, DSMS can combine near-real-time data collected from the RF environment with historical data to predict how the channel will behave and perform near-real-time optimization.

An important barrier for new services on CBRS spectrum has been this lack of reliability and near-real-time awareness of the channel, meaning that enterprises and the CBRS supply chain have been reluctant to enable new use cases using this shared spectrum. On the other hand, the ecosystem will likely create new use cases and applications if this capability appears in the market. The DSMS concept can turn CBRS GAA spectrum licenses into a carrier-grade, mission-critical tool for enterprises.

BETTER SPECTRUM AND INFRASTRUCTURE USE

A far bigger improvement is that a near-real-time awareness of the RF channel can make the entire process of CBRS planning more efficient and streamlined. The CBRS framework currently uses the ITM—or the Longley-Rice model—which was conceived in 1968. This is a path loss model that is widely used in academia and in the industry but it does not take into account several important factors, including the terrain near the receiver and buildings, foliage, and multipath. The latter is a very important aspect that creates degradations in wideband propagation channels, to which CBRS also belongs. Multipath refers to multiple transmission paths from transmitter to receiver, which are combined to construct the received signal. If the environment is full of obstructions, which may also move around (e.g., cars), then the channel becomes very difficult to predict and model.

The effect of using this model in CBRS has resulted in under-estimating path loss, while over-estimating interference. This results in larger guard-bands and more powerful CBSDs than are needed for any given scenario, translating to more equipment and a more costly deployment than necessary.

DSMS Solution: Near-real-time RF awareness with rich data that include time, frequency, spatial, and signal characteristics can improve CBRS network planning in many ways. This can reduce infrastructure Capital Expenditure (CAPEX) in many ways:

1) Protection zones can be minimized when RF awareness is possible. In current CBRS deployments, protection zones are enforced to minimize interference to incumbent users and PAL networks. With the DSMS solution, it is possible to perform this functionality in near real time.

2) By understanding the channel in near real time and being able to measure the propagation channel accurately, it is possible to manage spectrum in a much more efficient and accurate manner. This will result in a better framework for managing CBRS spectrum for all interested parties.

Overall, the dynamic spectrum sharing concept developed by DGS adds the ability to understand the propagation channel and RF environment in a much more granular and consistent manner. This can improve business opportunities for many interested parties.

THE COMMERCIAL VALUE PROPOSITION OF DYNAMIC SPECTRUM SHARING FOR PARTNERS

The DSMS has commercial and technical implications for the entire supply chain and can improve the value proposition for multiple stakeholders. The following sections summarize the benefit of the DSMS to different parties.

SAS PROVIDERS

SAS providers have the difficult task of performing heavy calculations to estimate if a new device or network will interfere and harm other incumbent, PAL, or GAA networks. However, this is performed daily without the SAS provider being fully aware of channel, environment, or potential interferer positions. Full RF channel awareness can improve the efficiency and value proposition of SAS providers significantly.

Table 2: DSMS Benefits for SAS Providers

Source: ABI Research

Value	**SAS providers will possess much more granular and updated information about the propagation channel, environment, and levels of interference across the entire CBRS system. This can improve their operation across all areas, including protection zones, and will enhance the capabilities of ESC systems.**
Integration	**DGS already uses a template to send its data and insights to SAS providers. The potential integration of the DSMS in CBSDs can allow DGS to communicate directly with SAS providers and provide much more real-time channel visibility.**
Commercial Opportunity	**SAS providers can augment and improve their value proposition with RF awareness in many ways. For example, they can improve their ESC sensors significantly without major expenditure, while ensuring that incumbent access is protected. Moreover, they can integrate better spectrum management processes in their systems by understanding spectrum conditions better.**

RAN VENDORS

RAN vendors are competing fiercely in the market, with private cellular slowly becoming a formidable opportunity that can offset the slowdown in 5G CAPEX as nationwide deployments in developed markets are reaching maturity. The DSMS can provide a competitive advantage for RAN vendors that can integrate its software stack in their infrastructure.

Table 3: DSMS Benefits for RAN Vendors

Source: ABI Research

Value	**RAN vendors can gain market share by integrating a DSMS in their equipment. This will allow them to have a much better understanding of the RF environment, which will result in more efficient deployments and systems. This may also create competitive differentiation for them.**
Integration	**RAN vendors can integrate the DSMS software stack directly in their equipment and communication stacks.**
Commercial Opportunity	**By integrating DGS software in their equipment, RAN vendors can start offering advanced functionality to enterprises, including 5G deterministic networking and URLLC. This means that RAN vendors can start tailoring their value proposition to sell new types of services, rather than equipment or capacity.**

TOWER COMPANIES AND NEUTRAL HOSTS

Finally, tower companies and neutral hosts are an important part of the CBRS ecosystem, enabling the efficient deployment across multiple verticals and venues. By having better RF environment awareness, these companies can improve their value proposition for their tenants and neighboring systems.

Table 4: DSMS Benefits for Tower Companies and Neutral Hosts

Source: ABI Research

Value	**Tower companies and neutral hosts can potentially offer new types of services, especially if they host processing capabilities for the DSMS. This can potentially allow them to minimize multi-tenant interference and help clients optimize their equipment.**
Integration	**These companies can either host DSMS sensors themselves or partner with RAN vendors that have integrated a suitable stack into their system.**
Commercial Opportunity	**Neutral hosts and tower companies can provide detailed RF environment data to tenants, which will be able to optimize their equipment and minimize equipment and deployment costs. This is an example of a new type of service that will allow new forms of monetization.**

CONCLUSIONS

This paper has argued that despite the continued deployment and commercial success of the CBRS shared spectrum platform, there are considerable improvements that need to be made for large-scale deployments and to alleviate enterprise end-user concerns. Interference management and RF awareness are critical areas for improvement, and something the OnGo Alliance is continuously discussing. However, this issue can only be addressed by understanding the RF channel in near real time and ensuring that potential interferers are managed effectively, again in near real time. This is not possible given the status of the CBRS framework, and improvements suggested by the OnGo Alliance would have to be universally adopted and implemented to ensure that deployments are behaving in the same manner everywhere.

The dynamic spectrum sharing proposal suggested by DGS is a valuable and credible approach to understanding the RF channel and making sure that interference or channel impairments can be addressed in near real time. This will be a necessity to ensure that GAA networks remain interference free and do not depend on the draconian planning process used by the CBRS framework and SAS providers. Indeed, the channel and system-level models used by SAS providers are considered to be pessimistic, translating to a more conservative approach, which leads to lower power levels than necessary and, in effect, lower capacity and performance in each system.

A better RF interference visibility and management solution will be necessary for CBRS spectrum to fulfill its promise and deliver reliable and carrier-grade wireless networks to many enterprises. Mission-critical cellular systems need to be robust, not be interference prone, and surely not wait for tens of hours to reconfigure their power levels if an interferer appears in their vicinity. ABI Research expects that dynamic spectrum sharing will not only be necessary for the future of GAA deployments, but will also significantly augment its capabilities.

Beyond CBRS, enabling true dynamic spectrum sharing will help the telecoms industry use mobile network spectrum more efficiently and, therefore, become an important enabler of fueling an increasingly digital society. Especially with topics like sustainability and efficient use of resources growing in importance, dynamic spectrum sharing is expected to become an even more important building block in a comprehensive digitalization strategy.

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