A 5G Americas Briefing Paper
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SPECTRUM SHARING: CHALLENGES & OPPORTUNITIES

Introduction

The objective of this white paper is to describe spectrum sharing models applied today, give an overview of technology options and their limitations for spectrum sharing, highlight the complexities of accomplishing the goals of spectrum sharing to maximize the utility of the spectrum band, and highlight the need for spectrum sharing to consider the needs of both legacy users as well as the wireless industry.

While exclusive licensed spectrum is the best solution to provide appropriate incentives to support the vast investments, network densification and complex network management necessary to build and operation efficient 5G network and support increasing consumer demand, 5G Americas recognizes that, as spectrum becomes more scarce – particularly in the low and mid-band ranges – sharing models between disparate spectrum use cases may be necessary to expand to access to spectrum for commercial, mobile use.

In this context, *Dynamic Spectrum Sharing (DSS)* is a concept involving technologies that allow for the shared use of spectrum resources by enabling disparate use cases to the same frequency band, while striving to minimize interference and maximize spectral efficiency taking into account not only space and frequency allocation but also time. DSS, however, is a complex topic that may present opportunities for spectrum access by commercial services, for example in the 3.1-3.45 GHz range.

1. Overview of spectrum management models

1.1 Licensed spectrum model

Licensed spectrum has been the lifeblood of mobile networks. Cellular technologies, deployed globally, have used dedicated spectrum which allows to dimension networks effectively and align with traffic demands. The exponential increase in data consumption driven by data-hungry applications, the introduction of new mobile services, and the advent of new verticals have driven the need for additional spectrum. To address the growing demand, regulatory authorities have vacated and re-packed spectrum bands to provide the necessary spectrum resources. Consequently, each generation of cellular technology has relied on licensed spectrum to ensure performance requirements are met and deployments happen timely.

1.2 Unlicensed spectrum model

Unlicensed spectrum has historically been used to deliver Wi-Fi services in homes and offices. As home and office data traffic grew, the need for more spectrum to deliver higher data rates for a variety of new applications increased.

1.3 Shared spectrum models and mechanisms

1.3.1 Standardized same technology spectrum sharing

Standardized same technology spectrum sharing such as Multi-Operator Core Network is a spectrum sharing technique, in which the operators share their carrier frequencies over the same technology, such as 3G. The sharing mechanism is defined by the Third Generation Partnership Project (3GPP) and sharing proportions are agreed among operators. The technology has been successfully used for more than a decade across the globe, allowing mobile carriers to achieve more efficient cost deployments.

1.3.2 Standardized multi-technology spectrum sharing

Standardized multi-technology spectrum sharing such as 3GPP Dynamic Spectrum Sharing and Multi Radio Access Technologies Spectrum Sharing are defined techniques where a radio access can be re-used to transmit at the same time multiple 3GPP technologies over the same air interface.

The type of sharing had an objective of introducing new technologies over existing spectrum and facilitating spectrum re-farming.

1.3.3 Evolved Spectrum access system

The concept of having a coordination database was introduced to allow new services to share spectrum with incumbents.

Those databases have access to the incumbents' activities in time, frequency and space domain and determine what frequencies can be accessed by the newly introduced radio services based on spectrum sharing mechanisms.

2. Review of spectrum sharing models

2.1 Definitions of Dynamic Spectrum Sharing

Recently the term Dynamic Spectrum Sharing (DSS) has been frequently used with different meanings:

- 3GPP defines Dynamic Spectrum Sharing as a method to provide a migration path from Long Term Evolution (LTE) to New Radio by allowing LTE and New Radio to share the same carrier to facilitate rapid deployment of 5G by mobile operators.
- 5G Americas views Dynamic Spectrum Sharing as an approach whereby two or more disparate radio services (including incumbents and new entrants) adjust their respective operations to achieve efficient utilization of the same frequency range in time or space, such that they can each provide their intended service in a cost-effective manner with minimal performance degradation to their respective operations.
- On the other hand, NTIA has used the term to describe means that involve the operation of independent systems close enough together (in frequency, space or time) that dynamic access methods are required to prevent harmful interference.

2.2 Spectrum Sharing techniques

The selection of the right spectrum sharing technique should be determined on a case-by-case basis based on the nature of the incumbent(s), and should include consideration of the following:

- Spectrum partitioning
- Semi-static frequency selection:
  - » Fixed-Satellite Station where interference is avoided through the use of separation distances and the avoidance of radiations in certain directions
  - » Fixed Microwave where interference is avoided by using a database system and the repacking of links if possible

- Dynamic frequency selection:
  - » Radars where interference is avoided by using a database system
  - » Mobile Usage where interference is avoided by a database system
  - » Existing Commercial Experiences in the United States

2.3 Citizens Broadband Radio Service (CBRS)

CBRS shares the 3.5 GHz band with incumbent systems, notably Department of Defense radar and a few fixed-satellite service earth stations. Devices, which are licensed, must connect to a centralized Spectrum Access System (SAS) database to find which frequencies are available in the area for use without harmful interference to other systems. Mobile devices known as CBRS devices can access the spectrum in two tiers, a Priority Access Licensing tier that is licensed exclusively over a county, and a General Authorized Access layer that can access spectrum on a licensed by rule basis and on non-interfering terms with the incumbents and Priority Access Licenses.

The fixed-satellite service is essentially static in nature, while Naval activity in littoral waters and in ports is dynamic. A coastal sensor network senses dynamic radar activity and the SAS subsequently reconfigures devices in the area to avoid interference. The devices must check with a SAS every four minutes or less in case Department of Defense activity starts occurring in their area. CBRS considers aggregate interference, so every SAS must be aware of all devices authorized by it and every other SAS to perform the aggregation calculation, which is complex and is subject to an offline validation process that is carried out overnight.

2.3.1 Automated Frequency Coordination (AFC)

In the 6 GHz, the Federal Communications Commission defined three categories of devices:

- Standard power
- Low power
- Very low power

Only the standard power requires coordination with the AFC database.

Standard-power unlicensed devices in the 6 GHz band share spectrum with many fixed point-to-point links. Such devices are required to perform automatic frequency coordination by synthesizing incumbent usage information from public database sources. Commercial realizations of AFC systems are available that allow devices to determine which frequencies are available for use in their area on a daily basis. While new or temporary fixed service links may arise on occasion, the incumbent fixed service operations are relatively static in a given area.

2.4 Spectrum sharing in 3.1 – 3.45 GHz band

As an example of potential spectrum sharing approaches, the National Spectrum Strategy outlined the importance of 3.1 – 3.45 GHz band in advancing wireless communication technologies and addressing spectrum needs for various applications.

DSS is being contemplated in this frequency band as a method of spectrum sharing with incumbents by leveraging the advancement of effective sensing methods or alternative communication information from radar systems to enhance situational awareness within mobile networks. Additionally, DSS is envisaged to involve signal identification and analysis of various waveform categories in a manner that addresses operational security concerns. Following signal analysis, provable mitigation techniques are expected to be developed, incorporating strategies like adjusting transmission parameters, periodic signal muting, carrier aggregation with traffic diversion, or time-frequency-spatial domain suppression of mobile transmissions during radar activity. These techniques are likely to be tailored to deployment location, product capabilities, interferer characteristics, and proximity to the interferer, adapting to specific scenarios. Evaluating the viability of spectrum sharing will require an understanding of the impact on the ongoing operation of radars and the performance of mobile networks.

The accuracy of incumbent information is crucial for effective spectrum management. Outdated or inaccurate data could lead to inefficient spectrum allocation and coordination, which undermines the objectives of spectrum sharing initiatives.

Information sharing is critical between stakeholders to determine the effectiveness of methods possible to coexist. Studies should aim to maximize spectral efficiency and ensure that spectrum is used to its highest degree by all stakeholders.

A key consideration for sharing of spectrum is whether it is technologically viable and at what cost. Ideally, the sharing regime should maintain the performance of licensed spectrum with full power and broad coverage, offer global scale to products, and follow standardized solutions. Any sharing of spectrum must also recognize that mobile networks will need adequate guarantees of service continuity and to develop tools that enable actions taken by the network that are standards compliant and do not require changes to user terminals.

3. Complexity of spectrum sharing

As the demand for spectrum increases, consideration of bands allocated to other services must be considered for spectrum sharing. Spectrum sharing is possible, but there are technical, regulatory, and economic challenges that must be considered. In contrast, when one entity has sole access to a frequency band, it can typically achieve higher spectrum efficiency as it can optimize its system design without worrying about interference from others or dealing with other design constraints.

In a shared system, the spectrum resources are used by multiple parties based on constraints that have been put in place to minimize interference to the incumbents. For the most part it is the responsibility of the new entrant to accommodate incumbent operations. These constraints can include restrictions on the types of technologies used, power levels, total spectrum resources available for instantaneous access, operational timings etc. Each of these restrictions has implications for the new entrants' network. For instance, sharing requirements may not be supported by new entrant equipment and may require expensive modifications. The following sections describe other spectrum sharing challenges from a technical, regulatory and economic challenge.

3.1 Technical Challenges for Spectrum Sharing

Given the following challenges, the overall spectrum efficiency in shared scenarios is often lower compared to the exclusive spectrum use case. These technical challenges include:

- **Protocol Overhead:** Shared systems require protocols for coordination among users, which consumes part of the bandwidth used to serve customer traffic demands.
- **Power Limitations:** To prevent interference, regulatory constraints may impose transmit power restrictions and thereby limit signal range and network capacity. This impacts network costs as a denser network of transmitters is required to achieve the same connectivity as networks operating at full power.
- **Access Uncertainty:** Given the dynamic nature of network access, spectrum may not be available when needed and users may experience intermittent service, leading to a degradation in Quality of Service (QoS). Sharing mechanisms may also permit pre-emptive mechanisms which would allow the incumbent to preempt access to the spectrum by the new entrant and thereby increasing the spectrum access uncertainty.
- **Sensing:** Sharing approaches that depend on sensors (for detection of activity from incumbents, such as radars or other operations) can vary in performance depending on sensor capabilities and accuracy. They may lead to additional or conservative restrictions on spectrum usage and access including the need to protect the sensors from interference.
- **Design Flexibility:** Design flexibility can be curtailed in many dimensions of design and operations for both incumbent and more likely new entrants. For example, the overall spectrum efficiency will likely be sub-par to exclusive use cases, assuming there is no inherent lack of demand or low duty-cycles in either, given challenges of sharing protocol overhead, power adjustments, access uncertainty, or other considerations.
- **Prime spectrum:** Spectrum access, that is preemptible or uncertain, is unable to support certain mission critical operations unless the network has access to exclusive access spectrum where operations may resume once access is denied on the shared spectrum.
- **Interference management:** Interference management is complex given the variety of technologies involved in co-existence detection in near real-time for the determination of mitigation techniques. Real-time detection increases the complexity of detection.

- **Fairness doctrine:** Any spectrum sharing framework should allow for fairness in sharing between incumbents and new entrants and have inherent methods to police the use of shared resources.
- **Fragmented Shared Spectrum:** Equipment designed for wide-band radios gets more complicated if shared bands are interspersed across wide swaths of spectrum.
- **Dynamic Spectrum Sharing:** Dynamic Spectrum Sharing can be distributed or centralized (e.g. SAS systems), each with pros and cons. The former can have implementation issues in overlapping areas and lack of a coordination mechanism, and the latter has complexity and latency issues for control and management.

3.2 Regulatory Challenges for Spectrum Sharing

Monitoring, policing, enforcing interference resolutions and ensuring fairness in sharing is a key consideration. These include:

- **Regulatory Flexibility:** Regulatory flexibility is needed to allow the spectrum sharing framework to accommodate changes in the nature of the operations, both new entrant and incumbent. The regulatory framework should consider incentives to ensure that the spectrum continues to be used efficiently, e.g. receiver performance benchmarks.
- **Coverage Optimization:** Full power macro cellular operation with power levels on par with allowances in the C-band (3.7-3.98 GHz) will allow the greatest flexibility for operators to optimize coverage and capacity needs to address current and future traffic growth in an optimized manner.
- **Simplest Sharing Frameworks:** The shared spectrum model can be static, semi-static or dynamic, with the latter involving more reliance on sensing or other near-real time adaptive technologies than ever utilized before (which is a challenge until such mechanisms are proven and verified). However, access to needed spectrum resources may require sharing. Whenever sharing is considered, the simplest form of sharing should be considered.
- **Flexible Use Regulations:** For identified available spectrum, the spectrum governance models include exclusive licensing, unlicensed, and shared spectrum. Combinations of these approaches may also be pursued.
- **Spectrum Inventory:** Spectrum inventory is necessary to determine what spectrum resources are not being used efficiently.
- **Incentive Sharing Mechanisms:** Developing incentive mechanisms to encourage entities to share spectrum following guidelines that are designed to allow high efficiency of shared spectrum can be challenging.

3.3 Economic Challenges in Spectrum Sharing

Motivating existing spectrum holders to facilitate spectrum sharing by either repacking or modifying their operations, relocating or giving up a portion of their spectrum is fraught with challenges. These challenges involve:

- **Financial Incentives:** Incentive mechanisms, such as financial benefits or priority access, will be needed to encourage entities to share their spectrum.
- **Shared Spectrum Valuation:** It can be difficult to assess the value of spectrum sharing for new services, especially when considering the potential impact on existing services and the need for investment in new technologies.
- **Transactional costs:** These are the administrative and technical costs associated with managing shared access which can be significant. These costs can include costs of implementing a spectrum sharing system or infrastructure, facilitating coordination for enabling sharing (which is additional overhead on spectrum resources), or even monetary costs for a system implementing spot pricing for a dynamic auction-based spectrum allocation system. Deciding whether that is spread across all users, or apportioned in some manner based on spectrum usage, or other variations has policy implications.
- **Network Cost:** Spectrum sharing models with mandated power levels that do not provide the same grid coverage as similar dedicated licensed spectrum make the band less attractive to mobile operators. Additional equipment and possibly new sites are needed to compensate for these spectrum access constraints that inflates the cost of mobile networks raising the price of connectivity in an age where digital access is increasingly seen as a necessity rather than a luxury.
- **Business Models:** The unpredictability of access to shared spectrum can make it challenging to build competitive business models that require a guaranteed service level of performance.

Conclusion

Exclusive spectrum for wide-area, full power licensed use is at the foundation of societal, economic, and national security benefits. In some cases, dedicated spectrum for commercial services is not possible when allocated services cannot be relocated or decommissioned. In that case, spectrum sharing can provide an opportunity to address the additional needs for spectrum by other wireless services.

Spectrum sharing is common and has been accommodated using existing mobile technologies that have inherent features that can be configured and repurposed to support efficient solutions. Dynamic Spectrum Sharing is being contemplated as a spectrum sharing solution with federal incumbents by leveraging the advancement radar sensing methods or alternative communication information from radar systems to enhance situational awareness within mobile networks. Any sharing solution has the potential to impact the availability of the spectrum.

This dynamic nature of network access has technical, regulatory and economic impacts as described in this paper. The viability of spectrum sharing must be considered on a per case basis, and spectrum sharing should consider the needs of both legacy users and the wireless industry. Each sharing scenario should target equivalent performance of licensed spectrum with full power and wide-area coverage, offer global scale to products, and follow standardized solutions. Spectrum access constraints can jeopardize the position of the United States as a leader in the global wireless ecosystem and impact U.S. economic and technological security interests. The key to successful commercial deployment in any spectrum band is competitive and cost-effective performance in terms of capacity, coverage, service continuity, and quality of experience.

Appendix

Acronyms

AFC: Automated Frequency Coordination
CBRS: Citizens Broadband Radio Service
DSS: Dynamic Spectrum Sharing
LTE: Long Term Evolution
SAS: Spectrum Access Server

Acknowledgments

5G Americas' Mission Statement: 5G Americas facilitates and advocates for the advancement of 5G and beyond toward 6G throughout the Americas.

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