SCTE·ISBE CABLE-TEC EXPO 2018 ATLANTA, GA OCTOBER 22-25

2018 Fall Technical Forum SCTE·ISBE • NCTA • CABLELABS

CBRS Use-Cases With focus on Localized Indoor Mobile Access (LIMA), Mobility and Service Continuity

A Technical Paper prepared for SCTE•ISBE by

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Introduction

Citizens Broadband Radio Service (CBRS), is a 150 MHz-wide shared spectrum in 3.55 GHz to 3.7 GHz band. FCC spectrum sharing policy creates an innovative way for a lightly licensed tiered access that creates dynamic sharing of spectrum in real time. As a one of its kind spectrum sharing concept, CBRS aims to combine the best of traditional licensed spectrum (LTE) and unlicensed spectrum (Wi-Fi) by combining the best of both technologies.

Specifically, for MSOs, the CBRS band offers them a path to deploying their own LTE network without making significant investments for licensed spectrum acquisition.

MSOs can thus strategically utilize CBRS for diverse use cases like:

- Local Indoor LTE mobile access (LIMA) to augment Wi-Fi coverage to control quality of user experience and offload MVNO costs.

- Leverage the HFC plant and deep fiber nodes to deploy CBRS small cells for outdoor mobile access and as mobile backhaul.

- CBRS based Fixed Wireless Access (FWA) technology to provide broadband access in areas that don't have cable access.

- Help enterprises or venue owners deploy CBRS based *private LTE networks* to beef up in-building wireless coverage and capacity.

- Create new business models like *Neutral Host Networks* and *Industrial IOT* using this band.

MSOs are positioned very favorably to leverage the economics of FCC's CBRS initiative to deploy mobile infrastructure very cost effectively for various use-cases listed above.

In this paper, we describe those use cases, with a specific focus on LIMA (Local Indoor Mobile Access), which we have identified as - by a large margin - the largest opportunity for MSOs to capitalize on CBRS based mobile coverage. Indoors is where there are the highest concentrations of subscribers, as well as majority of time spent on mobile devices by users. The paper provides details on how MSOs can innovate with a hybrid indoor Mobile and Wi-Fi service that seamlessly integrates with the macro cellular network as well as extend service continuity to the MVNO network.

Content

1 Introduction

In 2015, the U.S. Federal Communications Commission (FCC) established the Citizens Broadband Radio Service (CBRS) for, a one of its kind and the first ever, shared wireless broadband use of the 3550-3700 MHz band (also referred to as 3.5 GHz Band). FCC also released the first public notice on protection of pre-existing 3650 to 3700 MHz licenses which were utilized by Department of Defense (DoD), and other incumbents. In 2016 the FCC issued a second report on rule making, position on methodology adopted on protection of pre-existing 3650 to 3700 MHz Band Licensees, and conditional approval of Spectrum Access Servers (SAS) administrators. In 2017 finalization of spectrum rule, which are contained in Part 96 of Title 47 of the Code of Federal Regulation (CFR), referred to as Part 96 in this document. Rules making is still in process for private licensing of CBRS band but should be finalized in 2H-2019 with a (Priority Access License) PAL auction.

CBRS (also commonly known as the 'innovation band') was envisioned to support a 3-tier shared spectrum model that required a detailed architecture to be standardized. The FCC has created a three-tiered framework to facilitate shared federal and non-federal use of this band using automated frequency coordinators, known as Spectrum Access Systems (SASs), to coordinate operations between and among users in different access tiers. The CBRS has three tiers of users: Incumbents, Priority Access Licensees (PAL), and General Authorized Access (GAA) users.

Citing the intent of this shared spectrum principle as stated by FCC:

"The Citizens Broadband Radio Service takes advantage of advances in technology and spectrum policy to dissolve age-old regulatory divisions between commercial and federal users, exclusive and non-exclusive authorizations, and private and carrier networks."

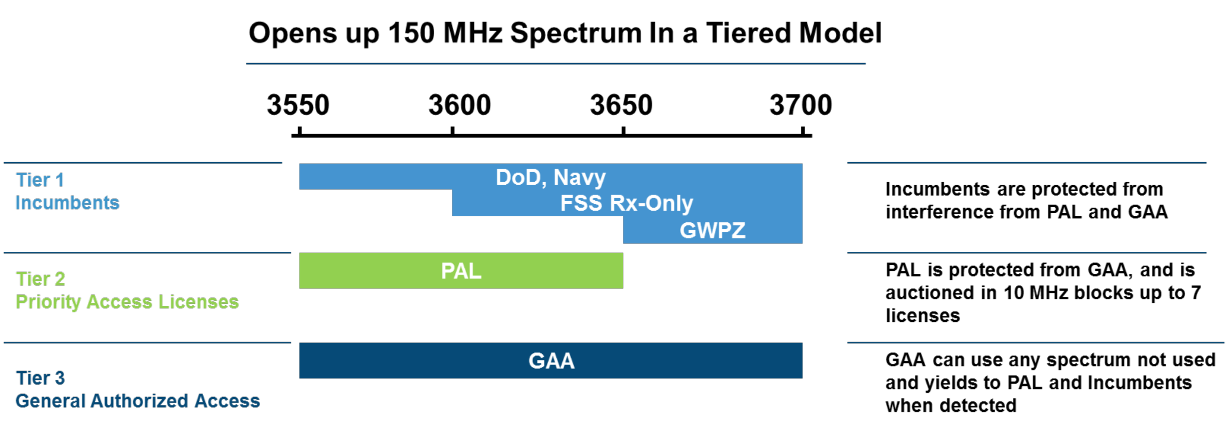


Figure 1 CBRS Spectrum Tiers

Given tremendous interest in this spectrum, the FCC decided to leverage the Wireless Innovation Forum (Winnforum) as a unifying alliance that brought government entities, regulators, service providers, industry associations and equipment providers together. Winnforum's goal is to standardize a technology neutral architecture that enabled a shared licensed access and protection for incumbents. As of end of 2017 the WINNFORUM has created 10 CBRS standards and many policies, databases and procedures.

While CBRS Spectrum and licensed shared access architecture are radio technology neutral, there was significant interest from LTE service providers, manufactures and standards bodies to integrated LTE in CBRS. In 2016 the CBRS Alliance was created to drive standardization of LTE use of CBRS in collaboration with Winnforum.

The FCC identified incumbent users for the CBRS band that fall into several categories:

1. The 3550-3650 MHz band is allocated to the Radiolocation Service (RLS) and the Aeronautical Radio Navigation Service (ARNS) (ground-based) on a primary basis for federal use. Both fixed and mobile high-powered DoD radar systems on ground-based, shipborne, and airborne platforms operate in this band. These radar systems are used in conjunction with weapons control systems and for the detection and tracking of air and surface targets. The U.S. Navy uses the band for radars on guided missile cruisers. The U.S. Army uses the band for a fire finder system to detect enemy projectiles. The U.S. Air Force uses the band for airborne radar Station Keeping Equipment throughout the United States and Possessions to assist pilots in formation flying and to support drop-zone training.
2. The 3600-3650 MHz band is also allocated to the Fixed Satellite Service (FSS, space-to-Earth) on a primary basis for non-federal use. Use of this FSS downlink allocation is limited to international inter-continental systems and is subject to case-by-case electromagnetic compatibility analysis. The Commission has licensed primary FSS earth stations to receive frequencies in the 3600- 3650 MHz band in 35 cities.
3. The 3650-3700 MHz band is also allocated for terrestrial non-federal Wireless Broadband Services. Such service is authorized through non-exclusive nationwide licenses and requires the registration of individual fixed and base stations. All stations operating in this band must employ a contention-based protocol. Base and fixed stations are limited to 25 watts EIRP per 25 MHz. Mobile and portable stations may operate only if they can positively receive and decode an enabling signal transmitted by a base station; airborne operations are prohibited.

1.1 SAS, CBSD, ESC

The core principle of CBRS is dynamic spectrum sharing in a tiered access. For that, a real-time spectrum coordination mechanism has been created to facilitate the required spectrum sharing. The spectrum coordination architecture for CBRS is based on a distributed system. At the top of the hierarchy is the FCC database which centralizes spectrum allocation. The next tier is the Spectrum Access System (SAS). The SAS is a third party certified vendor offering SAS services. The next tier is the sensor network referred to as the Environmental Sensing Capability (ESC). The ESC system detects and communicates the presence of a signal from an Incumbent User to an SAS to facilitate shared spectrum access. The next tier is the SAS user network which interaction with the SAS for PAL and GAA usage.

A block diagram of the CBRS Band spectrum sharing system is given in Figure 2: CBRS Band spectrum sharing system. At the heart of the system is the Spectrum Access System (SAS). It is the gatekeeper that takes information from the FCC Database, other SASs, Environmental Sensing Capability (ESC), and the CBRS Broadband Service Devices (CBSD). Then it applies the FCC rules to allocate Frequency and Power resource to each of the CBSDs.

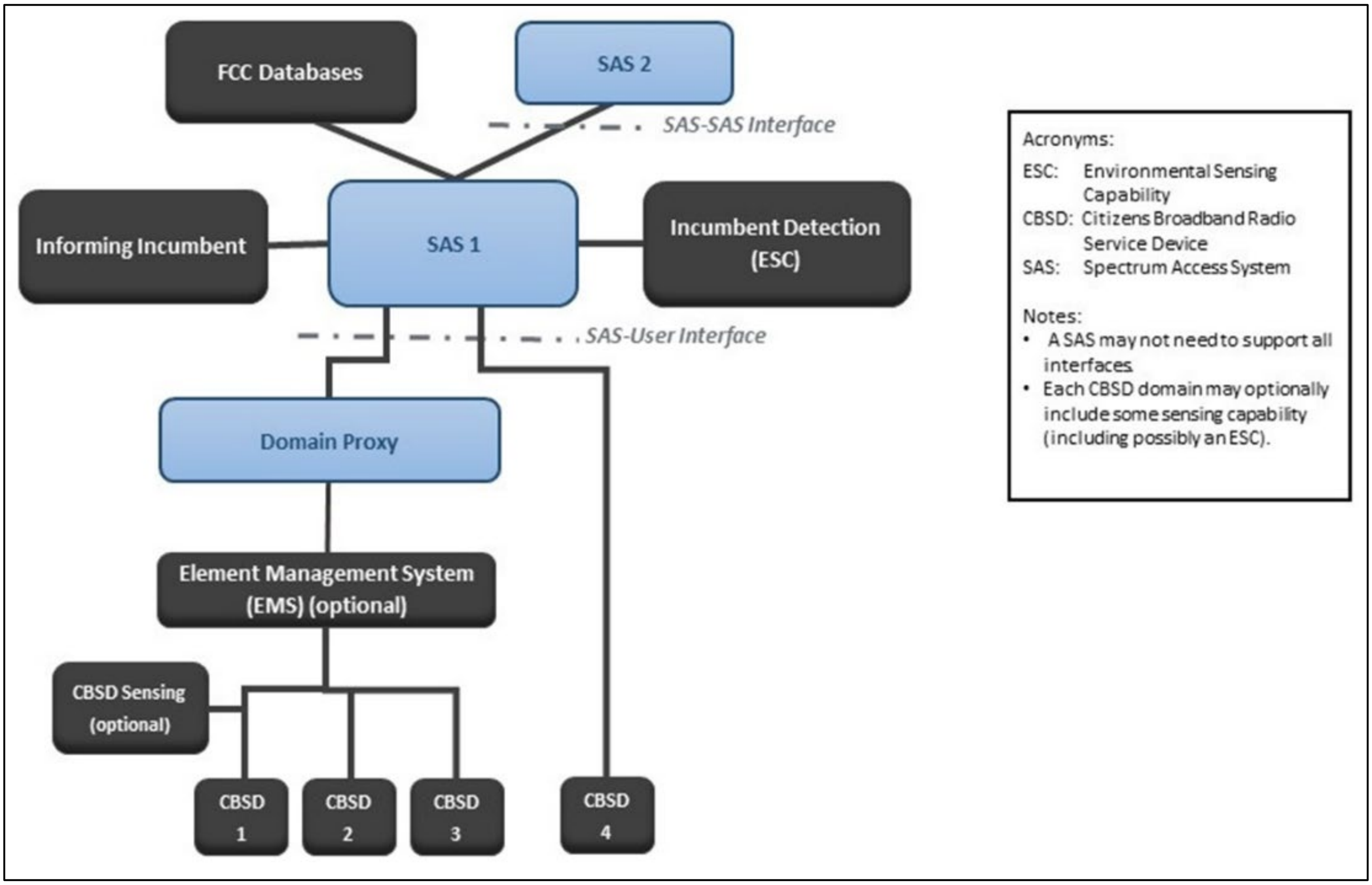


Figure 2: CBRS Band spectrum sharing system

- **FCC Database** is administered by the FCC. It is the repository of tracking information on CBSDs, Incumbents, and PAL licenses. FSS Earth Station incumbents must register with FCC yearly and must include geographic location, antenna gain, horizontal and vertical antenna gain pattern, antenna azimuth relative to true north, and antenna elevation angle. The SAS will communicate with the Database to get relevant information for CBSDs and Incumbents for its geographic area.
- **SAS Operators** are tasked with implementing the HW, Network, and operating the SAS according the FCC rules. SAS Operators must be certified by the FCC.
- **SAS-SAS Interface** will enable communication between SAS's to effectively administer rules across neighboring geographic areas. A group of CBSDs owned by a network operator may extend across SAS's thus requiring coordination between SAS's.
- **ESC** is required before SAS can enable CBSD to operate near DoD incumbents. Without ESC availability an Exclusion Zone of 80 km radius around federal radiolocation sites must be maintained. CBSD are not allowed to operate inside the radius of an exclusion zone. Exclusion Zones are converted to Protection Zones when one or more ESCs are used by the SAS. CBSDs may be authorized within these Protection Zones when ESC reports no incumbent operation. Within 60 seconds after the ESC communicates signal detection from DoD system in given area,

the SAS must either confirm suspension of the CBSD's operation or its relocation to another unoccupied frequency.

- **Informing Incumbent** block enables information gathering and communication between SAS and Incumbent equipment directly. Sensitive DoD incumbents will not be included.
- **Domain Proxy** is included in the SAS system to facilitate communication between groups of CBSDs and the SAS. A SAS operator may make this option available to groups of CBSDs to offload some of the bookkeeping functions and service CBSDs efficiently.
- **Element Management System** is optional block network operator can implement to centralize communication to the SAS network while also offloading and simplifying the individual CBSDs.

The SAS serves as an automated frequency coordinator across the CBRS band. Though the Spectrum sharing concept is similar to UNI-II DFS, the architecture for spectrum sharing in CBRS is very different than that of DFS. CBRS has a frequency coordination model wherein the centralized SAS nodes perform frequency coordination controller function and manage spectrum along with the CBSDs, while in DFS the spectrum coordination is done entirely by the Wi-Fi Access Points that support the UNI-II band. The role of the SAS is to protect the incumbents (higher tier users) from those beneath and optimizes frequency use to allow maximum capacity and coexistence for both GAA and PAL (Priority Access users). It provides dynamic allocation and management of spectrum resources that fall into 3 tiers:

1) Tier-1: Protects the incumbents such as DoD / Navy, Fixed Satellite Stations (FSS) which there are about 30 sites in US, and legacy license holders.
2) Tier-2: Priority Access operations receive protection from GAA operations. Priority Access Licenses (PAL), are defined as an authorization to use a 10 MHz channel in a single census tract for three years, except in the first auction bidders can request automatic renewal after the first three years for a total of six years. Priority Access License (PAL) licenses will only be assigned in up to 70 megahertz of the lower portion of the 3550-3650 MHz portion of the band. A single PAL holder can only get assigned total of four separate 10 MHz channels (40 MHz aggregation) in each census tract. If a PAL is not in active use, then it reverts to GAA use. It is expected that PAL licenses will be awarded through reverse auctions in 2018. There are still some open items, the most contentious topics are:
   a. PAL license term: 3 yrs. vs 10yrs.
   b. PAL block size (75k Census Blocks vs 3142 counties vs 404 PEA).
3) Tier-3: General Authorized Access (GAA) which allows opportunistic use of the full 150 MHz CBRS band on a shared basis. GAA has no expectation for interference protection. GAA users must not cause harmful interference to and must accept interference from PAL and Incumbent Users operating in accordance with the rules. GAA deployments will be gated by CBSD certification which is anticipated for Q4'18.

While indoor and outdoor CBRS base station devices (CBSDs) can be assigned to either GAA or PAL, more indoor GAA deployments are expected until ESC certification and PAL auctions get finalized.

The SAS maintains a database and tracks a host of information needed to execute its function.

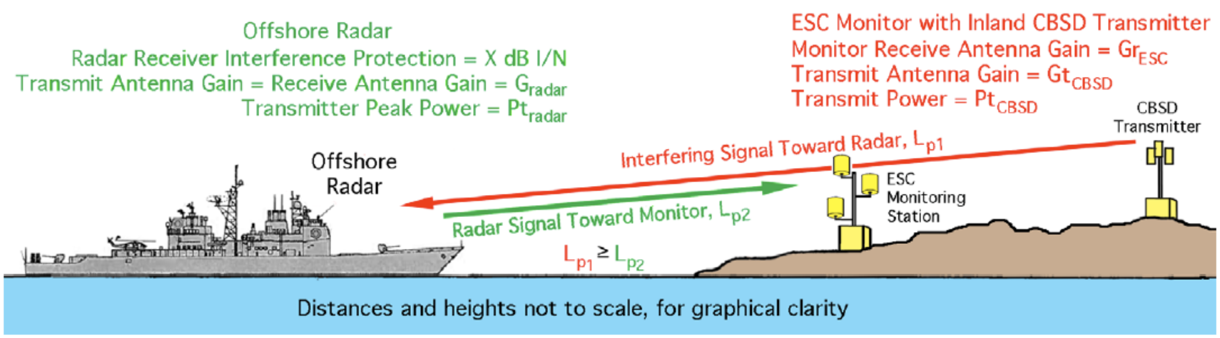
1. Information of all CBSDs in it controls; Tier status (Tier 1, 2, 3), Geographical location and antenna height within 50 meters (horizontal) and 3 meters (vertical). Such geographic coordinates is reported by the CBSD to the SAS at the time of first activation (e.g. from a power-off to power-on condition). CBSDs also report their location to the SAS within 60 seconds of a

change in location exceeding the accuracy requirement. SAS uses this information to determine frequency availability and maximum power limits for CBSDs.
2. Incumbents in the geographic area under its control. The incumbents can be DoD radar, FSS or WISPs (Part 90).
3. It queries data from the FCC database for list of incumbents in the geographic area under its control.
4. It also audits/logs ESC information related to incumbent activity.

The FCC has set aside a transition period of 5 years, or the expiration of the incumbent FSS license, whichever is longer. During the transition period the incumbent users can operate as they normally do under the old part 90 rules and get full protection from interference of the CBRS network deployments. CBRS deployment in this 50 MHz portion of the band (3650 to 3700) will not start until the rules are finalized. The Incumbents who are eligible to be grandfathered are those that were registered with the FCC Universal Licensing System (ULS) as of April 17, 2015; the date the FCC issued new rules creating the CBRS band. After an incumbent grandfather period has expired they can continue using the band 3650-3700 band or the wider 3550-3700 band for that matter but must follow the new part 96 CBRS rules.

CBRS Devices (CBSD) are certified radio base stations that radiate CBRS 3.5GHz band. Before transmitting the CBSD must contact the SAS. The SAS assigns authorized CBSDs to specific frequencies, which may be reassigned by that SAS. There are two categories of CBSD. Category A CBSD is a lower power base station indoor, and outdoor (6 meters or less in height) and can be self-installed. Category B CBSD is a higher-powered base station for outdoor use only and must be installed by certified installer. Lastly, there are the End User Devices (EUD) that connect to the CBSD and are under the attached CBSD control (e.g. Power Control).

Protecting incumbents (DoD, Navy) is important aspect of sharing this spectrum. As described the sensor network is key aspect of protecting DoD and Navy use of the spectrum. It has been estimated that use of this spectrum is less than 1% of the time but is critical to national security. Shown below in Figure 3 is a depiction of how the sensor network will operate.



Basic geometry of the reciprocal-propagation monitoring approach

Figure 3 ESC sensor network operation

As per the Part 96 rules, a CBSD has 300 seconds to cease transmission and move to another frequency range or change its power level once it receives a command from a Spectrum Access System (SAS) alerting it to a federal system emitting an interfering signal nearby. Per FCC Part 96 *"Within 300 seconds after the ESC communicates that it has detected a signal from a federal system in a given area, or the SAS is otherwise notified of current federal incumbent use of the band, the SAS must either confirm suspension of the CBSD's operation or its relocation to another unoccupied frequency, if available."*

There are specific radio emission requirements such as transmit power, for each category of device as follows from FCC Part 96.

CBRS Device	Geographic Area	Output Power (dBm/10 Mhz)	Max EIRP(1) dBm/10MHz	Max Conducted PSD (dBm/10 Mhz) (2)	Height Limit
End User Device	All	n/a	23	n/a	n/a
CBSD Cat. A	All	24	30	14	<6 Meters
CBSD Cat. B	Non-Rural	24	40	14	
CBSD Cat. B	Rural	30	47	20	

(1) Where an FCC rule specifies limits in *radiated* terms such as EIRP or ERP, the limits apply to the maximum emission that would be observed by a linearly polarized measurement antenna. For radiated measurements, the maximum need be performed only over two polarizations for the receive antenna—horizontal and vertical.
    a. If one of the transmitter outputs is a 90-degree phase-shifted replica of the other and the phase centers of the two antennas are co-located (as would be the case when creating a circularly polarized transmission using linearly polarized antennas), then the each of the two EIRPs or ERPs (total or spectral density) must individually be below the limit
(2) Where an FCC rule specifies limits on antenna-port conducted power or *conducted* power spectral density (PSD), the rule applies to the total power or PSD delivered to the two antennas (i.e., the sum of the two powers or PSDs).

Another deployment limit is Received Signal Strength Limits within a PAL and GAA users. Part 96 states *"For both Priority Access and GAA users, CBSD transmissions must be managed such that the aggregate received signal strength for all locations within the PAL Protection Area of any co-channel PAL, shall not exceed an average (RMS) power level of −80 dBm in any direction when integrated over a 10 megahertz reference bandwidth, with the measurement antenna placed at a height of 1.5 meters above ground level, unless the affected PAL licensees agree to an alternative limit and communicate that to the SAS."*

Aggregate Interference Consideration

For non-federal-government protection, it considers aggregated CBSDs within 40-150 km, depending on protected entity and type of CBSD. Federal government protection distances are still being finalized as of May 2018.

Aggregate interference calculation must ensure a result that is at least as conservative as a Monte Carlo method defined in the Requirements, where, essentially, the random variable is the Irregular Terrain Model (ITM) reliability factor (for the ITM model) or the situation-depended log-normal distribution (for the eHata model). ITM model is always used in rural markets. For zone-based protection of non-federal incumbents, the aggregate interference is computed across a standard 2” grid (even arc secs in lat/lon).

For protecting (dynamic) federal incumbents, a move list is generated per channel. Generally speaking, CBSDs are rank-order by their impact on interference, and the fewest number/greatest contributors to interference are the ones targeted for re-accommodation to mitigate predicted interference in a channel when federal incumbents are active.

The DoD has divided the offshore area to roughly 200 Km off coast, and roughly 50 areas called Dynamic Protection Areas (DPAs). Each DPA is monitored by one or more ESC sensors. When the federal incumbent activity is detected in the DPA, the entirety of the DPA is protected from aggregate interference to a pre-defined level. CBSDS that may impact interference in the DPA are reconfigured accordingly. DPAs may be used to protect some inland sites.

1.2 Priority Access License (PAL)

It is expected that PAL will currently be auctioned in 2H 2018 or 1H 2019 and will provide the holder 3+3 years initial license term on a per census block (~74,000) then 3 years thereafter. However, the FCC is considering changing some aspects of the PAL tier per (Docket 17-258) such as considering expanding the license term, expanding geographic area, modifying auction rules etc., but none of the other rules in Part 96. Only 70 MHz is available for PAL and this is carved from the lower block (3550-3650 MHz). Current FCC part 96 rules allow each PAL to be authorized for 10 MHz channel, and up to 7 license holders in any given census block.

An important consideration for PAL license holders which will utilize CBSD Cat B base stations is the Exclusion Zones areas (*ntia.doc.gov/category/3550-3650-mhz*). *“Exclusion Zones shall be maintained for an 80 km radius around the federal radiolocation sites listed in 47 CFR 90.1331 and 47 CFR 2.106, US 109. These Exclusion Zones shall be maintained and enforced until one or more ESCs are approved and used by at least one SAS, in accordance with §96.67. Thereafter, Exclusion Zones shall be converted to Protection Zones.”* The Exclusion Zone for DoD, Navy is the blue line in the diagram below which was reduced after NTIA studies in 2015/16 (*NTIA Report 15-517*).

Figure 4 Original exclusion zone scheme

As of May 2018, the FCC has temporarily waived static exclusion zone restrictions based on a new DPA (Dynamic Protection Zone) scheme based on DPA enabled SASs. DPAs and DPA enabled SAS function is shown below:

- Offshore region is divided into “Dynamic Protection Areas” (DPAs)
- Each DPA is monitored by one or more ESC sensors
- When federal incumbent activity is detected in a DPA, the entirety of the DPA is protected from aggregate interference to a pre-defined level
- CBSDs that may impact interference in the DPA are reconfigured accordingly
- DPAs may be used to protect some inland sites

Figure 5 New DPA based scheme

There are also Wireless Protection Zones to protect incumbent fixed wireless operators, that are provided protection until their license sunsets by 2020 to 2023. This for 50 MHz of spectrum that falls in the 3650 – 3700 MHz band.

- Grandfathered Wireless Protection Zone (GWPZ) highlighted in red are protected until their licenses are sunset by 2020-23 timeframe
- Protected in all or portion of 3650-3700 MHz spectrum
- Protections based on aggregate interference, propagation model, and 2" grid per spec
- All CBSD as far as 40 Km from the GWPZ are considered

Figure 6 GWPZ map

1.3 CBRS (3.5 GHz) relative to Unlicensed 5GHz

LTE deployment in the CBRS band can be augmented with LTE in unlicensed 5GHz spectrum which has made significant progress with the support of LTE-U in release 12, LTE Assisted Access (LAA) release 13 and LTE Wi-Fi link aggregation (LWA) in release 13. LTE-U, LAA and LWA however require licensed anchors. The development of MulteFire which does not require a licensed anchor can be considered by NSPs who don't operate Licensed (exclusive use) spectrum.

Unlicensed 5GHz band in US is available for FWA point-to-point and point-to-multipoint which has some potential application. 5GHz UNI-3 and UNI-4 defined in FCC Part 96 can provide a number of enhancements to FWA deployment such as Mesh networking of Small Cells, and point-to-point backhaul.

1.4 Key Industry Groups Affecting CBRS Deployment

Many Standards bodies as well as industry groups are working together and alongside the FCC for development and deployment of services in the CBRS band. The two main active bodies doing most of the work are

- WInnForum
- CBRS Alliance

The responsibilities of these two bodies are described and compared below:

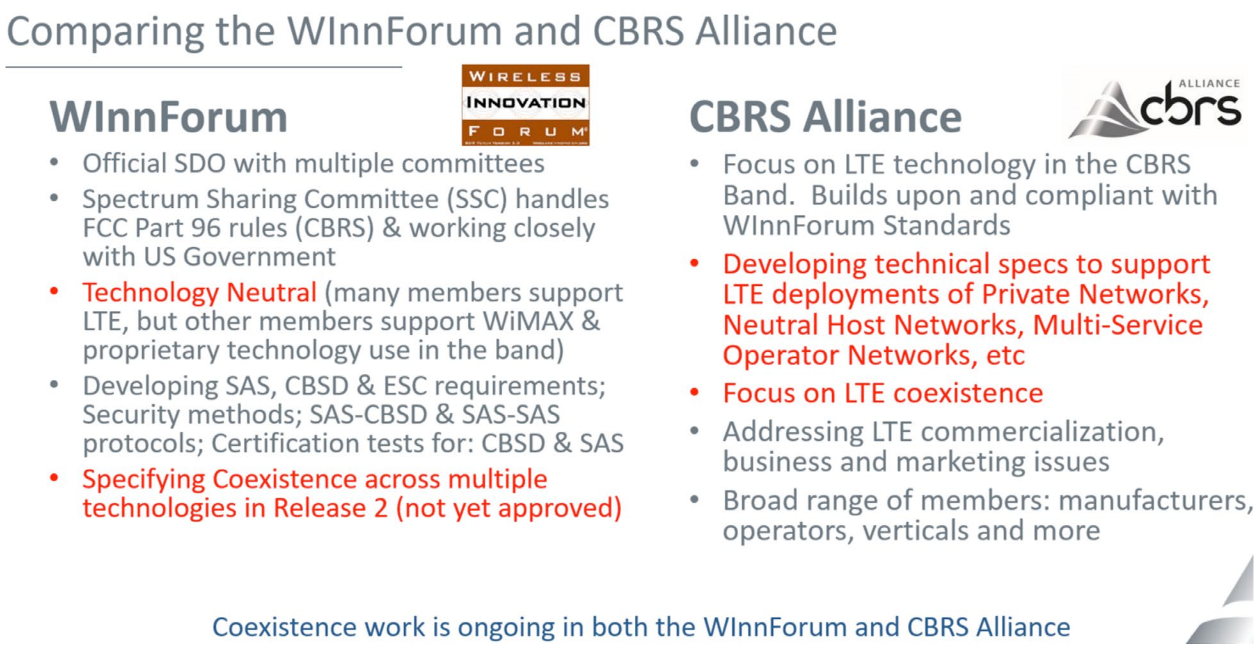


Figure 7 Main CBRS standards bodies and their roles

These two industry bodies interface with many other bodies e.g. Incumbents, Govt., Standards etc. that pertain to various technologies being developed for the CBRS band. As an example, the CBRS alliance works closely with 3GPP. 3GPP organization is a standards body that is responsible for creating specifications related to LTE.

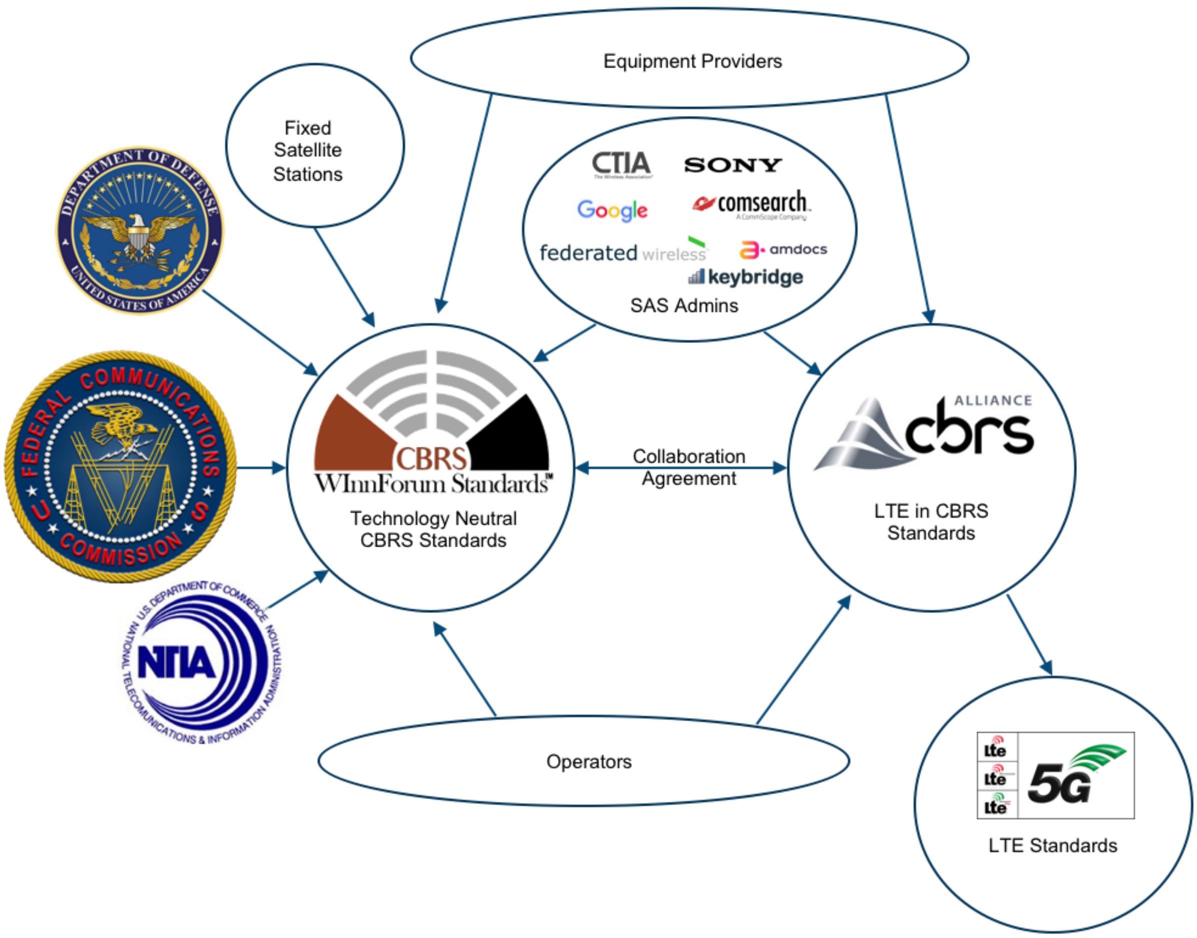


Figure 8 CBRS standards bodies and their interactions with related industry bodies

2 CBRS Use Cases for MSOs

Historically, licensing spectrum for exclusive use (Licensed Spectrum) has been very expensive to acquire, costing billions of dollars and representing a majority of the cost of a mobile wireless network. Such an upfront and sunk-in spectrum cost (again in billions) was considered cost prohibitive as it created a barrier to entry for non-traditional cellular operators.

The FCC's choice of (first ever) spectrum policy innovation, through creation of shared spectrum rules for CBRS, significantly lowers the barriers to entry for non-traditional wireless carriers. The flexible three-tier licensing framework lowers the barrier to spectrum and promotes success-based investment for new entrants. Due to significantly lower cost of PALs compared to exclusive use licensed spectrum costs, the FCC has leveled the playing field by democratizing LTE networks. MSOs specifically stand to gain substantially from this CBRS initiative.

Considering that a typical traditional Tier 1 US mobile operator holds, on average, about 130 MHz of licensed spectrum for exclusive use, in contrast, 150 MHz of favorable mid-band spectrum in the CBRS band is a significant resource for MSOs to provide LTE based mobile capacity to compete with traditional Mobile operators. CBRS thus offers cost-effective LTE solutions for both indoor and outdoor applications; opens up new use cases; and, encourages new revenue generating business innovations for MSOs.

CBRS Service Model

Shared Spectrum democratizes LTE network services where, depending of the business model, the LTE Radio Network may be offered only as a transit access or a vertically integrated mobile services like the ones offered by the cellular operators using licensed spectrum. Such decoupling of access and services makes it possible for the service providers to perform roles as shown in the figure below:

1. **CBRS Network Operator (CNO)**

CBRS Network Operator deploys a CBRS/LTE Radio Network at a venue or across a geographical footprint with the intention to provide mobile connectivity using LTE. Typically, a CBRS Network Operator does not have a direct business relationship with the end user or device. CBRS Network would have business relationship with the Participating Service Providers that have direct relationship with the end users. For example, if a mall owner deploys a CBRS LTE network in a mall to provide better indoor mobile coverage to mall patrons; the mall owner will allow access to subscribers of 'Participating Service Providers' that have business relationship with the mall owner. Participating Service Providers in this case are the Tier 1 Cellular operators.

2. **Mobile Service Provider**

Mobile Service Provider provides mobile services to end users. They have a business relationship with the end user and provide them valid SIM cards that let the end users get authenticated and authorized for mobile services. Mobile Service Provider may also assume the role of CBRS Network Operator (CNO) if it also operates a CBRS access network.

3. Subscriber

End user or device that is requesting mobile services.

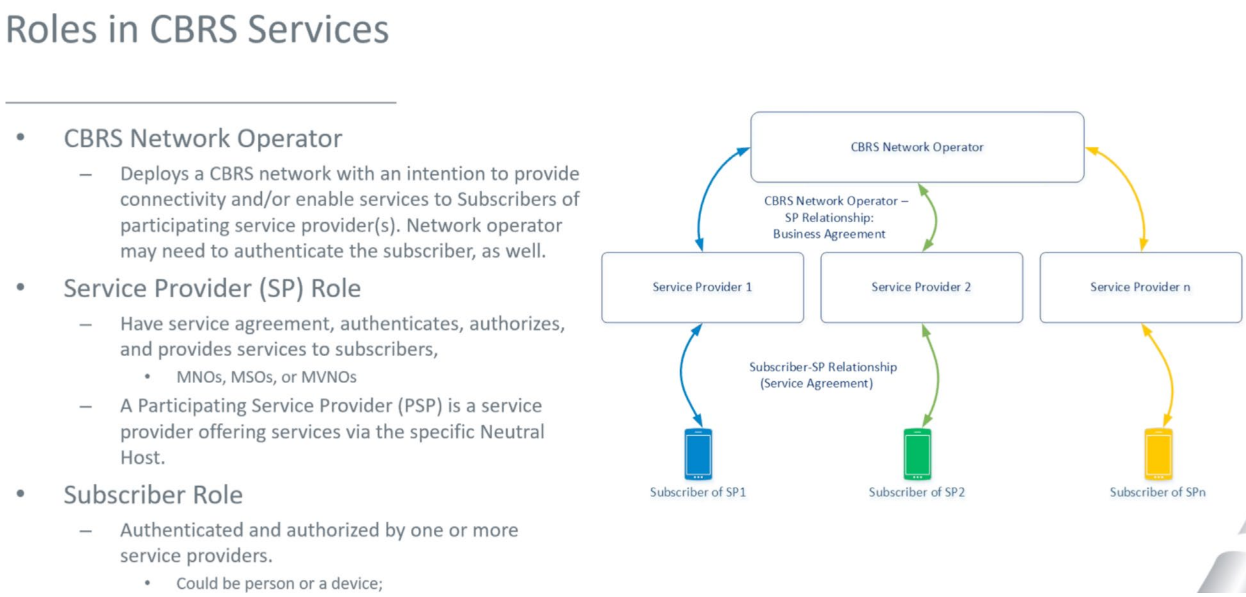


Figure 9 CBRS participant network roles

While there are a number of application MSO CBRS use cases, the major ones are covered here for review in this paper:

- **Indoor Mobile Access**
- **Outdoor Mobile Access**
- **Private LTE Networks**
- **Neutral Host Networks**
- **Industrial IOT networks**
- **Fixed Wireless Access (FWA)**

2.1 Inside-Out: Localized Indoor Mobile Access (LIMA)

Most industry statistics state that an average of **80-90%** [2] of mobile sessions happen indoors while the rest occur outdoors. MSOs currently have the lion's share of Fixed Broadband and an elaborate DOCSIS broadband capable network that reaches **85%** [1] of US residential and enterprise locations and offers High Speed internet connectivity of upto a theoretical max of 10 Gbps DL and 2 Gbps UL. Leveraging such a deep cable network, MSOs can employ a novel *inside-out*[3] strategy where the MSOs can build a massive LTE network by initially focusing on advanced wireless LTE solutions inside the residential and enterprise, and eventually expanding outdoors (hence *inside-out*). As an example, if an MSO has 10 million broadband cable subscribers, they could convert all the broadband subscribers into a 10 million LTE cell towers by incorporating CBRS/LTE base station (eNB) function in the DOCSIS modems. Such an *inside-out* strategy leverages deployment of indoor CBRS small cell radio in the home or business. A small cell is a low power radio node that connects to a mobile Evolved Packet Core (EPC) and/or IP Multimedia Services (IMS) An indoor CBRS small cell provide indoor mobility initial then moving to outdoor.

Such an indoor mobile network will cover 80-90% [2] of the mobile sessions on the indoor network, the remaining 10% of the mobile sessions originated by their subscribers outdoor 'on the go' may be offloaded to the MVNO partner network (i.e. a Tier 1 cellular operator partner).

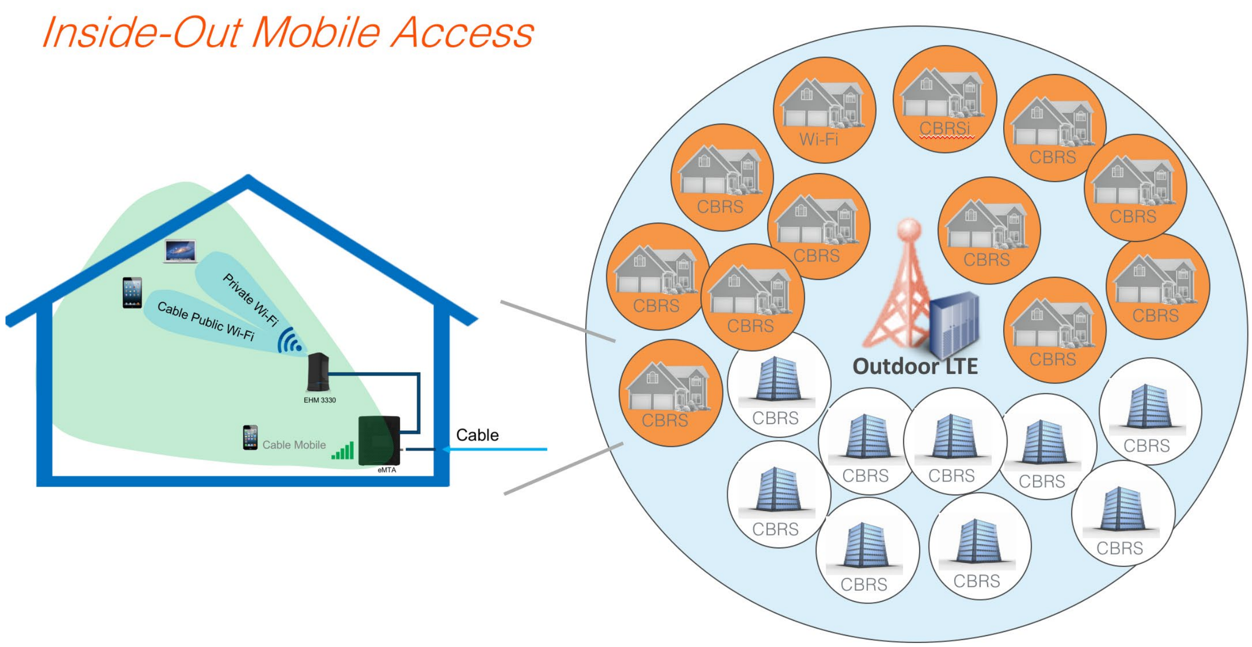


Figure 10 CBRS Inside-Out Mobile Access

Reduced CBRS shared spectrum acquisition cost along with an *Inside-Out* enables MSO to launch a ***near*** ubiquitous market wide LTE network at a fraction of the cost of a traditional macro cellular network AND at a fraction of the cost of being a pure MVNO. This can lead to an enablement of a very competitive mobile service offerings to compete with the traditional Tier 1 Cellular Operators and create a profitable and sustainable mobile wireless business for the MSOs.

2.1.1 Inside-out Mobile Access economics

Mobile wireless subscription services provide a great new source of revenues. In fact, users spend an average of $45/month/device, hence a family of four spends around $180/month on mobile subscription plans. *As an example, an MSO with 20 million broadband subscribers stands to gain* ***$43.2 Billion*** *of TAM in its served market*. This is approximately 2x of what a household spends on average on residential cable broadband and Linear broadcast TV subscription combined, which is approx. ~$80/month. MSOs already have a Triple play service offering (Voice/Video/Internet), and with a mobile wireless they can more than double their revenues by becoming a Quad play provider. Historically however, building and operating a wireless with traditional approach (Macro cellular) was a barrier to entry for MSOs. Firstly, there were huge spectrum acquisition costs associated with licensing wireless spectrum for exclusive use. Then, deploying a macro cellular network using 200+ feet towers, as well as hiring a trained workforce of radio network planners who could install and maintain such a complex radio network was a very difficult task as well. All in all, MSOs found it near impossible to enter and compete in wireless service market with a tradition network build approach [5].

MVNO based mobile service gets MSOs into the mobile business quick, however the MVNO terms were negotiated years ago, with certain fixed costs between $5 to $10/GB (close to $8/GB [7]) , and it's likely that the MNO host operator wouldn't be eager to give better MVNO deal anytime soon due to competitive reasons. With an average mobile data usage of approx. 11.9 GB / month [6] , a pure MVNO deal would require the MSO paying close to $95/month per mobile device to their MNO host. Clearly, such a business model is not sustainable in the long run if the MSO unlimited plan subscriber (majority of the subscribers) only pay $45/month to the MSO [8] .

However, with CBRS/shared spectrum, an innovative *inside-out* out strategy coupled with opportunistic Cable Wi-Fi offload and a modest outdoor MSO owned outdoor CBRS/LTE network in strategic densely populated areas (hot zones), the MSO can minimize the amount of wireless traffic that flows over the MNO host cellular network. This is the inflection point that creates a very powerful competitive advantage for the MSOs.

CBRS/LTE based Cable Gateways in particular (*inside-out*) provide the greatest advantage as MSOs now have close to 75% Cable broadband penetration in US [9]. This provides the opportunity for the MSOs to turn each one of such locations as a turnkey CBRS/LTE cell tower to create a near ubiquitous indoor LTE network to provide the much-needed critical mass of coverage for their mobile wireless network.

The chart below shows costs associated with delivering a wireless service for various network deployments types [10] .

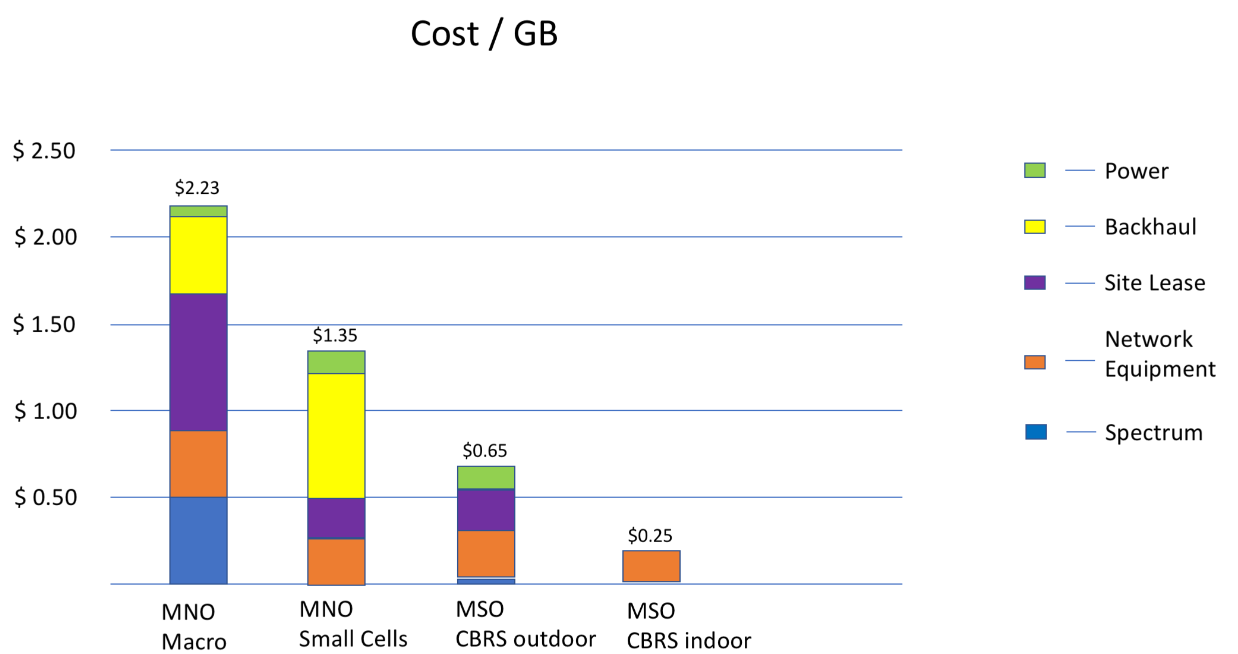


Figure 11 CBRS network economics

Given that 80% - 90% [2] of the wireless sessions originate indoors, it is highly likely that an MSO network planned around *inside-out* strategy could reach a traffic distribution pattern that, for a typical user, might like as follows:

- 50% of the monthly LTE data on MSO owned indoor CBRS/LTE network based on LTE enabled Cable Gateways; i.e. 5.95 GB/month/device

- 20% of the monthly LTE data on MSO owned outdoor CBRS/LTE network based on LTE small cells at their outdoor fiber optical nodes of their fiber deep HFC plant; i.e. 2.38 GB/month/device
- 10% of the monthly LTE data strategically offloaded to the MSO owned Cable Wi-Fi network; i.e. 1.19 GB/month/device.
- Rest, 20% of the monthly LTE traffic would use the MNO host's macro LTE network; i.e. 2.38 GB/month/device

For such a monthly traffic profile, the MSO can provide a profitable wireless service @ a cost of $22.25 / month / device, which leads to a sustainable business since such a network costs only 1/4th of the, otherwise, cost of $95/month/device associated with a "pure" MVNO business model.

2.1.2 Licensed Assisted Access (LAA)

Since licensed spectrum is a scarce resource, a number of radio innovations have been adopted by LTE standards to use unlicensed spectrum with LTE radio. The first innovation was LTE Unlicensed defined in 3GPP release 13.

LTE-U and LAA protocols will be utilized in the 3.5 GHz band. LTE-U and LAA are desirable technologies, because they will allow carriers to expand their capacities while still ensuring that they can rely on stable licensed spectrum for high quality service. Current versions of LTE-U and LAA operate with an anchor licensed carrier's channel and use carrier aggregation to integrate licensed and unlicensed spectrum, while utilizing coexistence mechanisms to avoid interference, ensure fair sharing with other unlicensed technologies, and enable flexible spectrum use.

LAA (Licensed Assisted Access) is a standardized version of LTE-U as governed by 3GPP. In certain markets such as the United States a protocol called Listen-Before-Talk (LBT), which was designed to address fair coexistence, is not a necessarily implemented in all solutions since it is not a regulatory requirement.

LWA stands for LTE WLAN Aggregation. LWA configures network to allow use of both Wi-Fi and LTE network simultaneously. Unlike LTE-U and LAA which requires hardware changes to co-exist with WLAN networks, LWA relies on aggregation of the Wi-Fi and LTE traffic in the core network w/o any explicit hardware modifications / requirements on radio nodes.

LAA, LWA and LTE-U can enable the MSO to combine and better utilize the Wi-Fi and CBRS/LTE spectrum and provide their users a much superior Quality of Experience asr a managed end to end wireless service.

2.2 Outdoor Mobile Access

MSO have invested in deep fiber (HFC plant) successfully for the last 20 years to support the high speed DOCSIS 3.0 broadband access to their subscribers. MSOs can now leverage the dense HFC plant in general, and the fiber nodes in particular, to strategically install outdoor CBRS/LTE metro cells to further densify MSO mobile access (beyond indoor densification using the *inside-out* strategy).

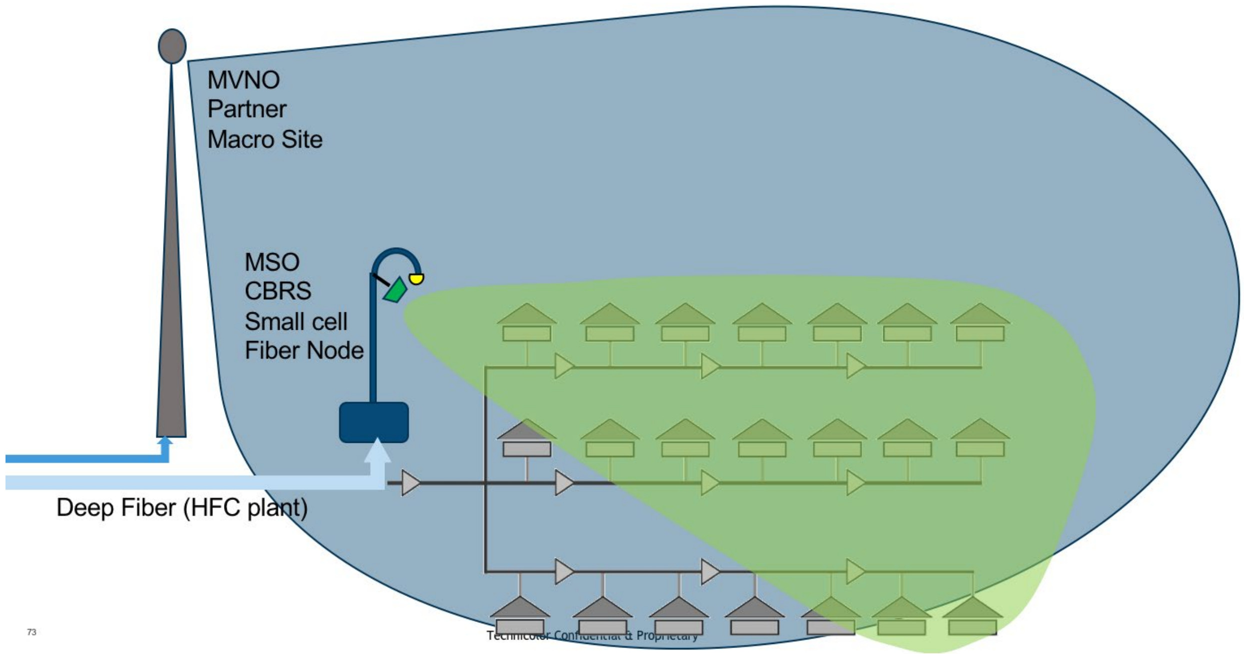


Figure 12 CBRS strategic outdoor mobile access

Leveraging HFC / fiber nodes to provide outdoor CBRS/LTE mobile coverage is a great option for MSOs to build out an LTE network and make the Mobile Virtual Network Operator (MVNO) economics work in their favor. LTE service across both host macro network and owned CBRS small cell network may simplify network integration efforts and will likely result in more predictable user experience than offloading to Wi-Fi. Since US cable operators do not yet own much licensed spectrum, this is a big upgrade from Wi-Fi. MSOs can capture additional subscriber mobile traffic on the 3.5 GHz band with LTE and 2.4/5 GHz bands with Wi-Fi to reduce the amount of charged traffic going over to the host mobile operator network. The profitability of a MVNO business case is heavily dependent on lowering the amount of traffic going over to the host mobile operator network. Since an MVNO pays a mobile operator for traffic going over the host operator's network, higher subscriber usage directly translates to higher network cost. Hence, for the cable operators, this means offloading subscriber traffic over to owned networks as much as possible.

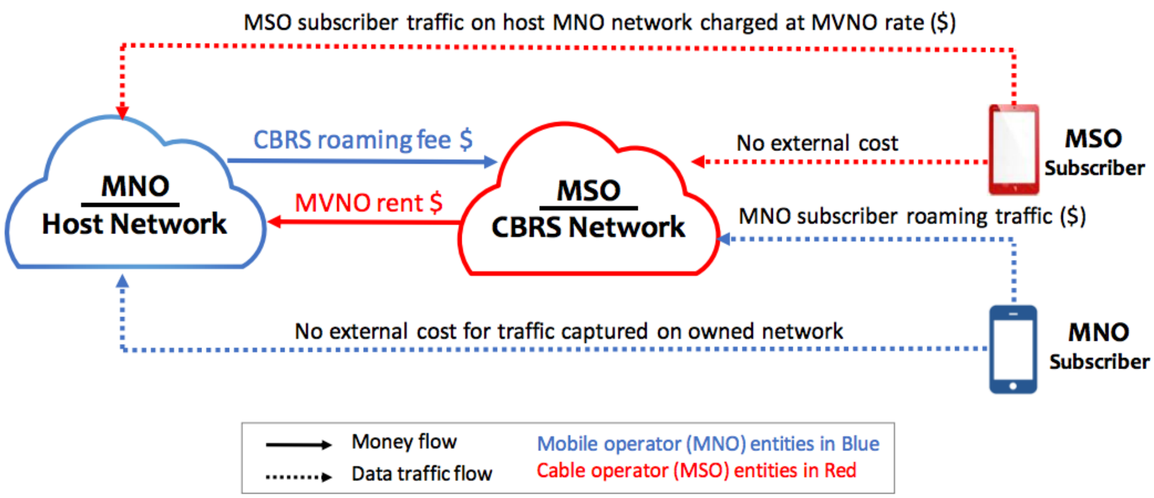


Figure 13 CBRS MVNO economics

Another business model involves a bilateral roaming arrangement with the host mobile operator to allow MNO subscribers to roam onto the MSO's LTE small cell underlay network in exchange for a lower MVNO terms. Having owned LTE-based network in strategic places where most of subscriber traffic is generated or consumed, affords additional optionality for the cable operators. Besides reducing MVNO expenses through traffic offloading, the cable operators can negotiate for better MVNO terms involving a potential "swap" deal.

2.3 Private LTE Networks

Large enterprises have traditionally deployed Wi-Fi networks to satisfy the growing wireless data demand. However, it has been a poor substitute for critical mobile wireless internet or seamless mobile voice services indoors. The FCC has democratized LTE by making CBRS/LTE a shared spectrum as opposed to exclusive use licensed spectrum that Tier 1 operators use. Like Wi-Fi access points, Enterprises and venues can run seamless LTE services and create a private LTE network, in a similar manner as Wi-Fi, to run enterprise- or venue-specific applications on mobile devices of consumers or workers, enabling tremendous flexibility; it also allows enterprises to tap into broader device and app store ecosystems that already exist. For instance, a large corporation can run secure enterprise CRM and communication tools on workers' mobile devices through a private LTE network at enterprise campuses. In another example, a heavy industry company can set up a private LTE network at a remote mining site and run industrial IoT applications on LTE devices.

MSOs can create new revenue streams by creating turnkey Private LTE solutions for Enterprises.

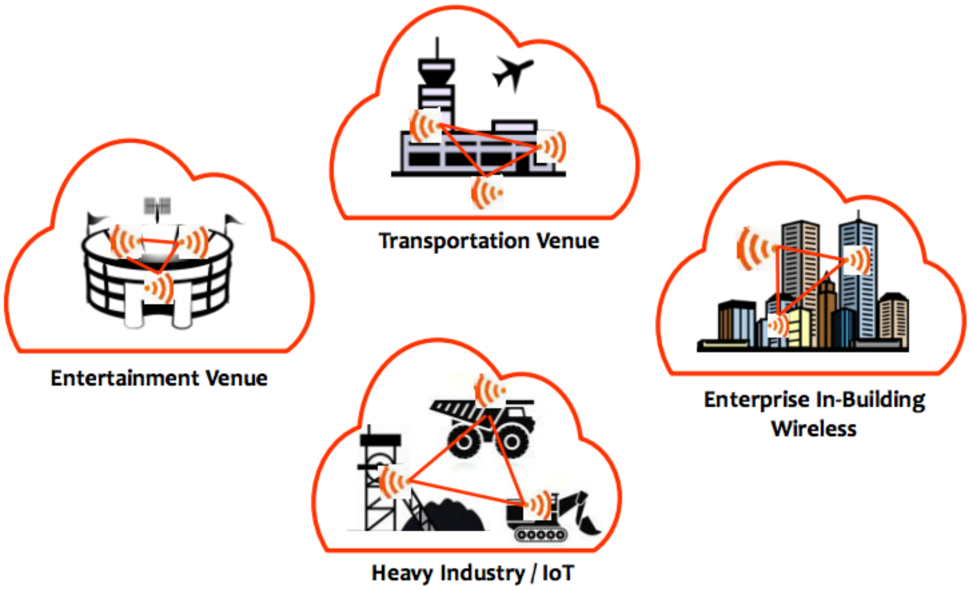


Figure 14 CBRS private LTE networks

2.4 Neutral Host Networks

There is a growing need for neutral host providers to bridge the gap between very large projects with direct mobile operator involvements and large numbers of smaller projects that are too small for mobile operators to consider, but too complex for enterprises to handle on their own. There is an opportunity for MSOs with CBRS/LTE deployments that involve SAS coordination and managing core network integration with mobile operators. Beyond the obvious large public venues such as stadiums and airports, hi-rise buildings, large hospitals, and university campuses are well suited for neutral host providers to address a growing, pent-up demand for in-building wireless coverage and capacity expansion. For enterprises with limited IT/telecom resources, a neutral host provider can take over the technical work and coordination with the operators. About 30 billion square feet of US commercial floor space has poor mobile coverage. With broad support from all four major operators and leading device platform vendors, neutral host providers can create a major new category of mobile coverage, funded by the enterprise or property owner.

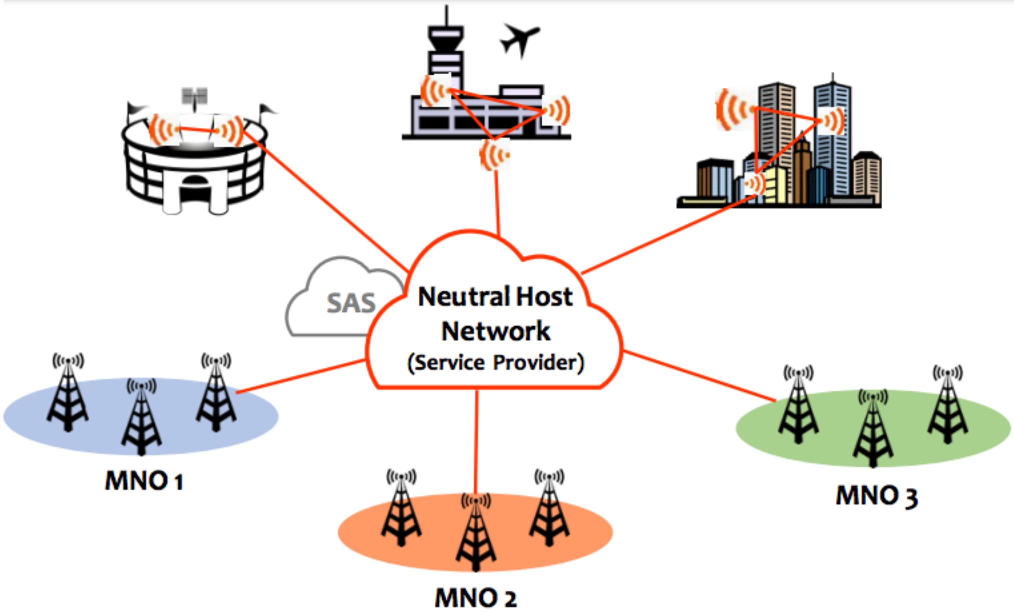


Figure 15 CBRS Neutral Host Networks

2.5 Industrial IOT Networks

As the FCC democratizes LTE in 3.5GHz (CBRS) band, it also paves the way for using private LTE for mission / business critical Industrial IOT applications. Unlike licensed spectrum based IOT that is operated and managed by the cellular operators, CBRS based Industrial IOT networks are owned by the enterprise, managed locally, using dedicated network LTE RAN that can be optimized for the specific Industrial process.

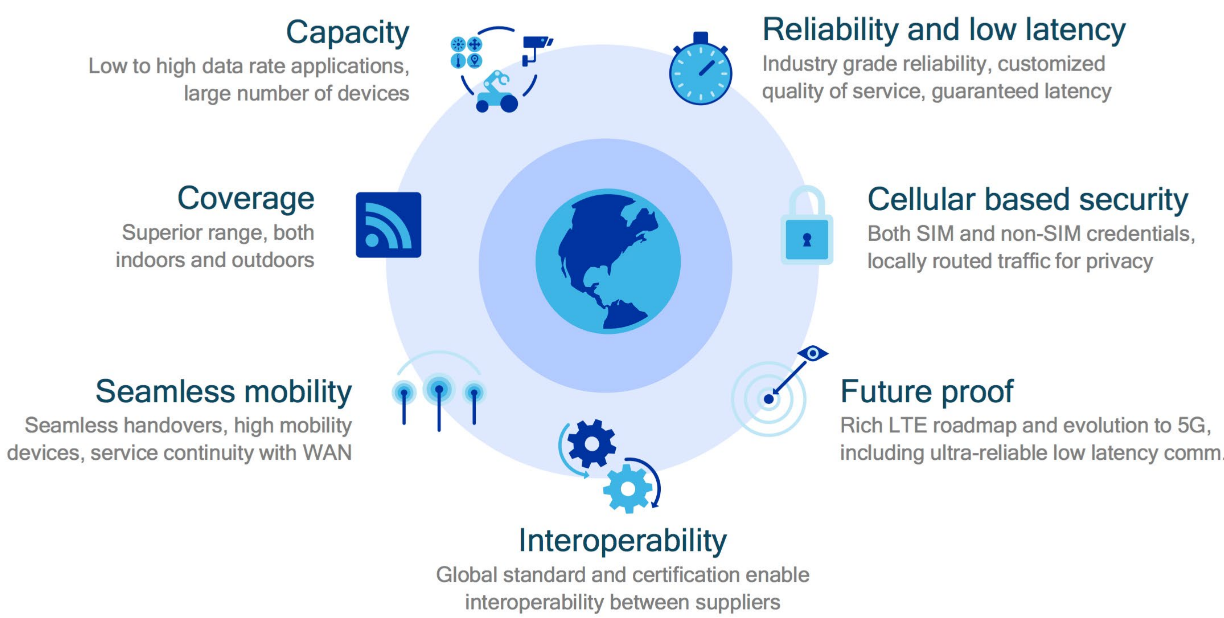


Figure 16 CBRS Industrial IOT networks

2.6 Fixed Wireless Access (FWA)

Within the US, the fixed broadband divide is significant. According to the January 2016 Federal Communication Commission "2016 Broadband Progress Report", 34 million (10 percent of all Americans) do not have access to broadband service at current FCC minimum standards of 25 Mb/s download and 3Mb/s upload speeds for fixed services; 23 million people (39 percent of rural Americans) lack access to broadband; and 1.6 million people (41 percent of Americans living on tribal lands) do not have access to broadband. Rural communities are any geographic census block with 25 or fewer homes per square mile. These areas have a high cost to deliver broadband service with the FCC defines at 25 Mb/s Downlink and 3 Mb/s Uplink.

Note: Globally the digital divide is a significant issue even in developed countries in EU, Latin America and Asia. According to the WBA July 2017 report (source) approximately 1.75bn citizens in the world's 8 richest countries remain unconnected. Please see report Global Fixed Wireless (TBD) Technicolor white paper.

The significance of this digital divide in the US has resulted in government incentive programs to bring broadband to rural America. The first program developed was the Connect America Fund (CAF) established in 2014 which provided, and the second and much larger program was the Connect America Fund phase-2 (CAF-II) which allocated $1.675 Billion per year for 6 years.

With CBRS spectrum availability in rural markets for GAA in Q2-2018, and the eminent auction of PAL in Q3-2018, CBRS leveraging LTE technology becomes a viable option for CAF-II service providers to deliver their broadband coverage commitment.

2.6.1 Connect America Fund

2.6.1.1 Connect America Fund II

In August 2015, price cap carriers either accepted or declined "statewide commitment" to provide voice and broadband in their study areas. Of the $1.675 billion per year available from 2015 to 2020. Price caped carriers elected to receive $1.5 billion of the annual fund. The 4 biggest recipients where CenturyLink, AT&T, Frontier (included Verizon original CAF locations), and Windstream.

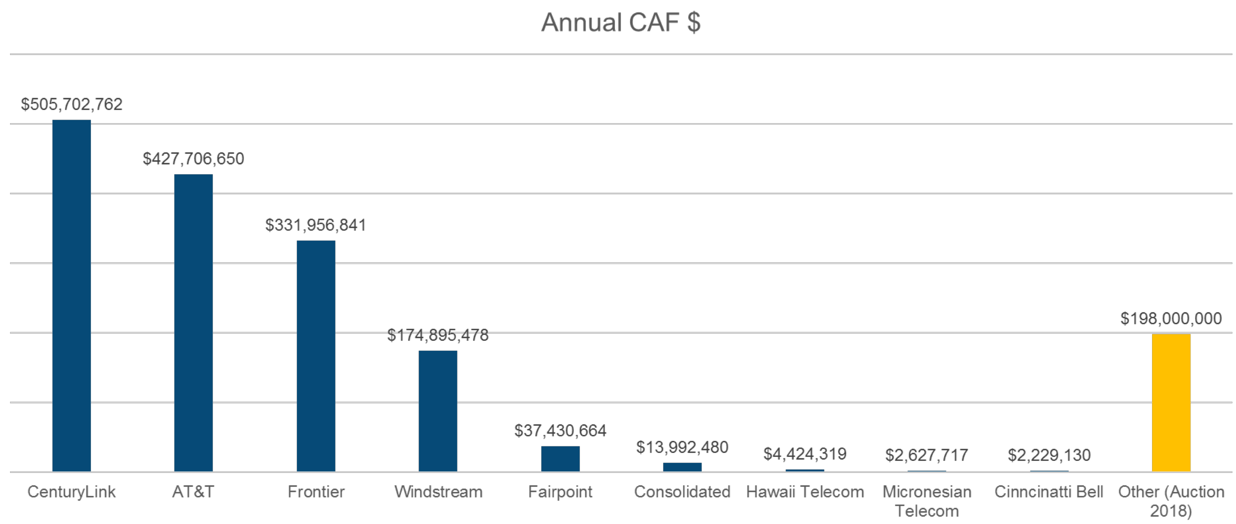


Figure 17 CAFII Award amount

The award of this funding covered

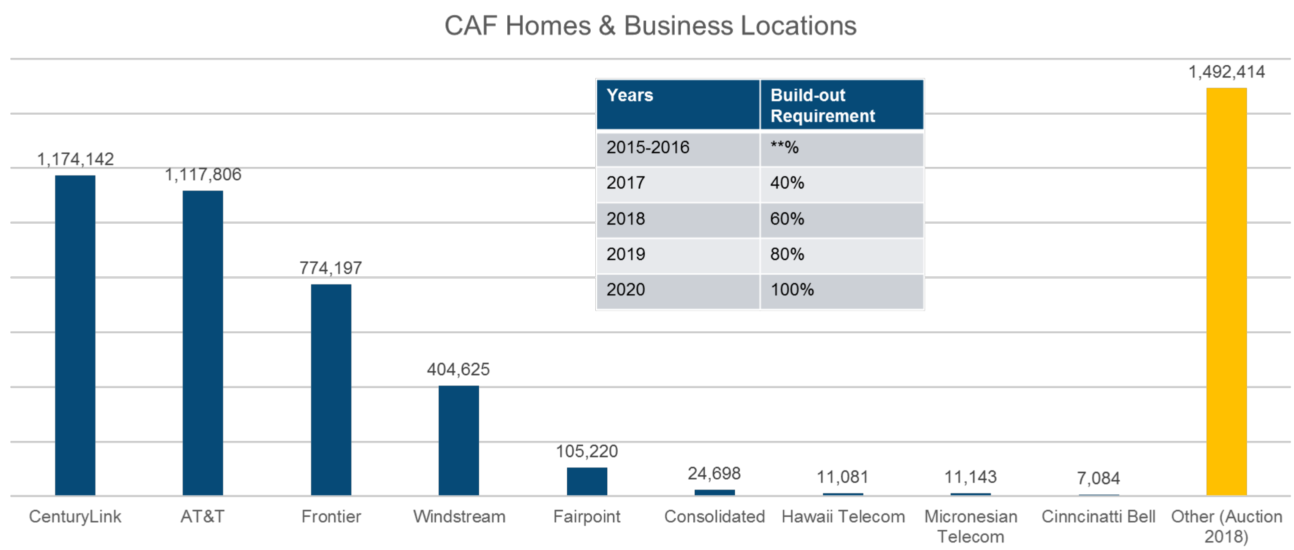


Figure 18 CAFII target number of households

Over 3.6 Million locations will receive broadband service based on FCC buildout requirements starting at 40% in 2017 and completing 100% of locations by 2020. Multiple service tiers can be offered as long as they offer at least one standalone voice plan and one service plan that meets the performance and latency requirements. The baseline tier is 25 Mb/s, with 10Mb/s being the minimum, higher tiers are and classified as above 100 Mb/s and Gigabit if 1 Gb/s. Latency is either Low < 100 ms, or High <750 ms & Mean Opinion Score for voice of >4.

2.6.1.2 Connect America Fund II Phase 2

As you can see in table figure above all most 1.5 Million locations did not get allocated in the 2015 CAF-II auction. In 2017 the FCC decided to have a new auction for these unallocated locations and create more lenient requirements for bidders. The new action # 903 is schedule for some time in 2018 based on eligible census blocks, where filing for eligibility of short-form application is due on March 30, 2018. The funding for these CAF-II Phase 2 locations will be $198 Million over 10 years, or approximately $2 Billion over the course of 10 years.

2.6.2 Broadband Technology Considerations

The technologies available to close this gap are Copper, Fiber, Cable or Wireless. Advancements in VDSL2, G.Fast make copper a low cost alternative but many rural markets do not have good copper plants and investments have limited upside in terms of capacity growth over the longer term. Ideally, Operators look to Fiber to the premise due to the long-term investment benefits, but the initial cost is very high with average distances to each home or business much higher than suburban/urban applications. Cable DOCSIS 3.1 can achieve Gigabit speeds but are high cost with requirements for deep fiber for backhaul and civil engineering costs to bring coax to homes. Alternatively, LTE wireless presents a compelling technology option to address the most challenging and high cost regions of the rural market.

Wireless broadband access offerings in unlicensed (5 GHz), Microwave (or lightly licensed (3650 – 3700 MHz) have been available for some time in the US via Wireless Internet Service Provider (WISP), however these networks remain fragmented today. There are over 300 WISPs serving US customers mostly in high cost rural areas. Most of these fixed wireless solutions utilize closed ecosystem solutions from the likes of Canopy, Ubiquity, Motorola Solutions (others). Product offerings range from point-to-multipoint and point-to-point.

With the introduction of LTE-A and LTE-A pro performance enhancements such as:

- Carrier Aggregation
- MU-MIMO
- Virtualization of LTE core network

And a healthy ecosystem driving the economics of LTE to Wi-Fi and IoT economics in wider band Licensed and Unlicensed spectrum, LTE has become a viable fixed broadband access technology competing with Cable and Fiber.

LTE is now capable of utilizing Unlicensed spectrum in 5Ghz band, in addition to new shared licensed spectrum CBRS 3.5Ghz band in US. Wider spectrum bands such as 3.5 GHz and existing LTE mid bands (e.g. B40, B41) can leverage TDD and LTE-A optimization for FWA scale. Of interest is the technical viability and business case for utilizing LTE for FWA in high-cost rural markets where Fiber is too expensive and copper not viable as a long-term asset.

Mid to longer term 5G technology and spectrum options are emerging quickly, thus increasing the value of Service providers implementing a Fixed Wireless alternative or augmentation to their broadband service offerings. However, to meet the CAF II requirements, 5G mm-Wave technologies might be too expensive to deploy v/s CBRS/LTE wireless as LTE is a mature and well-established technology with economies of scale.

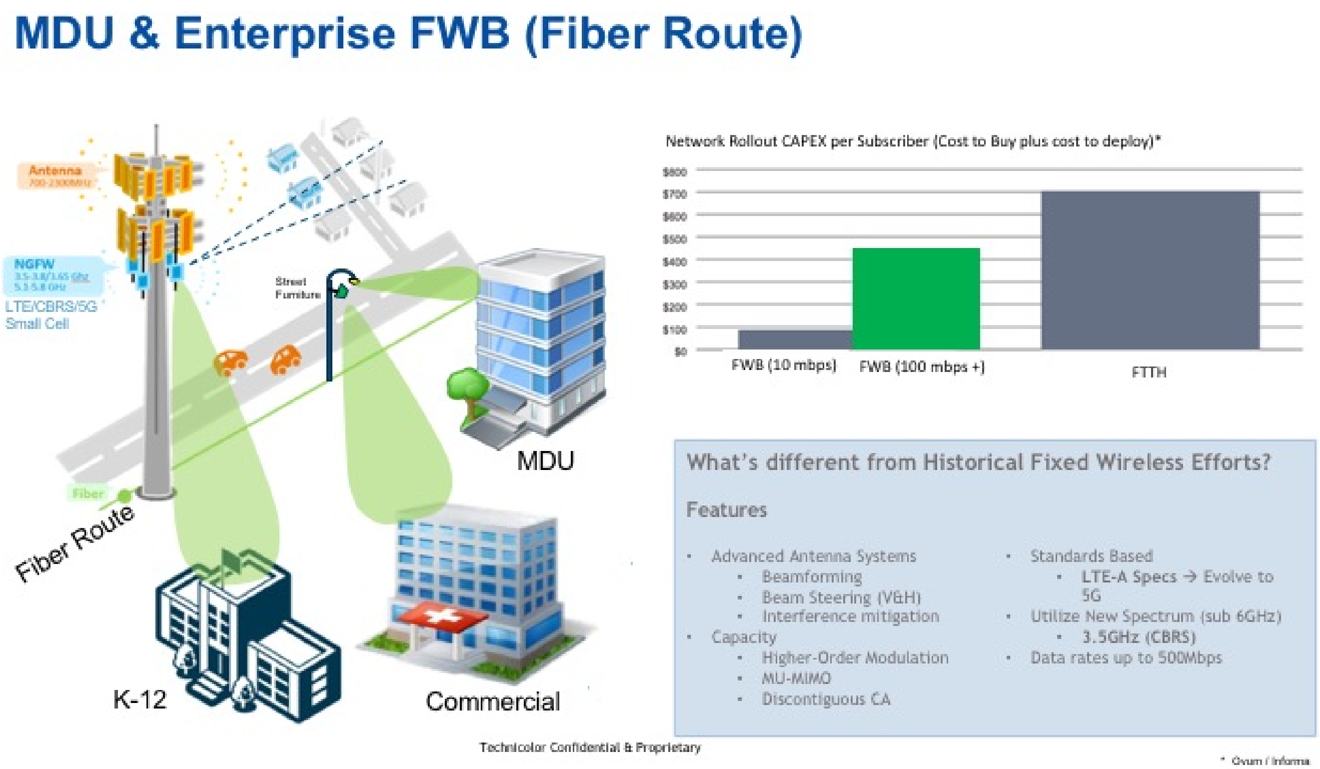


Figure 19 CBRS economics for green field broadband

3 CBRS/LTE FWA Network Design & Deployment

The design considerations for a FWA deployment will need to address the following aspects:

Radio Network Design: Radio network design is the most challenging part of any FWA solution and requires many factors both technical and economical to be considered. While each NSP will have different environments, this paper selects some generic use case and take a wide brush look at this aspect of the solution. Factors such as customer premise equipment, radio node placement, service tier performance and capacity, radio node lease and backhaul costs must all be factored into the decision.

Service Integration in Core Network: Depending on NSP type there can be significant differences. For example, a Mobile Networks Operator (MNO) may have more emphasis on following 3GPP standard integration of the FWA service into their Mobile Packet Core and IP Multimedia Services (IMS) platform where FWA is a network slice leveraging same Mobile assets but with less complexity. Conversely, a Telco NSP may want to further simplify the Packet Core network and integrate into existing Fixed Line core network where FWA looks like just another fixed access.

Integration with SAS and CBRS spectrum coexistence is also a new spectrum sharing mechanism that relies on a close, real-time coordination between network nodes that would need to be proven to work at scale.

3.1 CBRS Radio Dimensioning

Dimensioning a 3.5 GHz Fixed Wireless Access network requires a detailed link budget analysis to answer how far FWA subscribers can be from the CBSD to achieve the performance of the service offering based on how many subscribers the NSP needed to support at different KPI levels. Bandwidth capacity of the radio is based on a combination of LTE-A radio performance, antenna power and technology, radio propagation characteristics of the deployment environment and receiving CPE capabilities.

While a detailed site survey and empirical test data can provide more accurate account of the deployment dimensioning there are several industry modules that utilize empirical data sets that can be used to baseline dimensioning.

The use of CBRS spectrum for a rural fixed broadband service is interesting as it offers better economics and performance than Fiber or Copper investments. CBRS also has the added benefit of time to service and flexibility of much easier network and technology upgrades.

The overall performance of an FWA deployment will depend on the following characteristics:

- Quality of the radio link (e.g. Path Loss, Interference)
- Spectral channel bandwidth
- Broadband service traffic model (UL/DL, QoS etc.)
- Base Station and Antenna characteristics
- Radio optimizations and efficiencies (e.g. MIMO, Carrier Aggregation)

Typical FWA deployments use one of the following options:

3.2 Mounting CBRS to existing Macro Cell structures

In this scenario, the Service Provider utilizes the existing tower infrastructure to add new CBRS macro base stations to provide FWA to households in the area. This approach is beneficial when the primary goal is to provide wide coverage e.g. in very sparsely populated rural areas; such a design is optimized for coverage but lacks capacity.

3.3 Low Power CBSD-B and ODU

In this scenario, the Service Provider adds new low power radio to a smaller tower or to existing street furniture like utility poles to add new CBRS small cells to provide FWA to households in the area. This approach is beneficial when the primary goal is to provide adequate capacity in semi-dense populated areas like suburban towns and cities; such a design is optimized for capacity, but has much smaller coverage radius (typically 25-30 houses per small cell).

The ODU (Outdoor unit) is a standalone external Active LTE antenna that is installed on an outside wall of the customer premise. ODUs are typically powered via a PoE interface. The ODU is installed and mounted directionally to the eNode-B and is connected via Power of Ethernet (PoE) to an indoor unit with PoE injector, or separate PoE injector. The height of the eNode-B and ODU antenna can make a significant difference.

3.4 Quality of the Radio Link

In CBRS deployment various factors like propagation, interference and other aspects of radio quality that can impact the performance of deployment.

3.4.1 Link Budget

Link budget is a measurement of the gains and losses from the transmitter, through the air to the receiver in a wireless communication system. It accounts for the attenuation of the transmitted signal due to propagation, as well as the antenna gains, feedline and miscellaneous losses.

A simple link budget equation is represented as follows:

$$\text{Received Power (dB)} = \text{Transmitted Power (dB)} + \text{Gains (dB)} - \text{Losses (dB)}$$

An example link budget for a sample Base Station and ODU deployment could be shown as:

$$\text{eNode-B to ODU Rx Power} = 33 \text{ dBm} + x \text{ dBi Tx Gain} + 12\text{dB Rx Gain} - \text{Losses (dB)}$$

$$\text{ODU to eNode-B Rx Power} = 23 \text{ dBm} + 12 \text{ dBi Tx Gain} + \text{dBi Rx Gain} - \text{Losses (dB)}$$

3.4.1.1 Losses

Assuming the antennas are in an acceptable Fresnel Zone and line of site ground clearance to the Free Spaces Link Budget, a least squares approximation can be used to factor in loss due to distance without obstacles. Path loss can be defined as the ratio of the transmitted to received power expressed in decibels.

If the estimated received power is sufficiently large (typically relative to the receiver sensitivity), the link budget is said to be sufficient for sending data under perfect conditions. The amount by which the received power exceeds receiver sensitivity is called the link margin.

3.4.1.2 Free-Space Path Loss (FSPL)

In a line-of-sight radio system, losses are mainly due to free-space path loss (FSPL). FSPL is proportional to the square of the distance between the transmitter and receiver as well as the square of the frequency of the radio signal. In other words, free-space path loss increases significantly over distance and frequency.

Other losses in a radio system to consider are due to antenna cabling and connectors. In the case of the high gain ODU there is negligible loss from antenna. In the case of the Base Station which has external antenna a rule of thumb is 0.25dB loss per connector and 0.25dB loss for every 3-ft of antenna cable should be included in the calculation. For a radio system with a 3-ft LMR400 cable and 2 connectors, 0.75dB loss should would be included.

FSPL equation is as follows for distance (d) in Km and frequency (f) in MHz:

$$FSPL(dB) = 20\log_{10}(d) + 20\log_{10}(f) + 32.45$$

The table below provides FSPL for 3.5 GHz from 1Km to 12Km

Table 1

Distance	FSPL (dB) @ 3550 MHz
1 Km	103.45
2 Km	109.48
3 Km	112.99
4 Km	115.50
5 Km	117.43
6 Km	119.02
7 Km	120.36
8 Km	121.52
9 Km	122.54
10 Km	123.45
11 Km	124.28
12 Km	125.04

Free Space Link Budget Calculation

Given a Small Cell and ODU assumption deployed in Line of Site the following link budget is possible from 1Km to 12Km..

Table 2

Distance	Tx Power (dBm)	Antenna Gain (dBi)	Rx Gain (dBi)	FSPL (dB) @ 3550 MHz	Link Budget dB
1 Km	33	12	17	-103.45	-41
2 Km	33	12	17	-109.48	-47
3 Km	33	12	17	-112.99	-52
4 Km	33	12	17	-115.50	-55
5 Km	33	12	17	-117.43	-57
6 Km	33	12	17	-119.02	-59
7 Km	33	12	17	-120.36	-60
8 Km	33	12	17	-121.52	-61
9 Km	33	12	17	-122.54	-62
10 Km	33	12	17	-123.45	-63
11 Km	33	12	17	-124.28	-64
12 Km	33	12	17	-125.04	-65

3.4.1.3 Link Margin

Fading due to multipath can result in reduced signal and should be included in the model. A rule of thumb is to maintain a 20 dB to 30 dB of fading margin to compensate.

3.4.1.4 Signal-to- Noise Ratio (SINR)

Higher modulation techniques such as 64-QAM, 256-QAM and MIMO require higher SNR to achieve higher bandwidth capacity on the same carrier. SNR is the ratio of LTE signal to background noise and based on modulation scheme can deliver different data rates.

Conclusion

The shared spectrum model is a first of its kind innovative dynamic, 3-tiered, shared spectrum approach adopted by the FCC for the Citizens Broadband Radio Service. It is a bold and historic shift in spectrum allocation that hopes to combine the best of unlicensed and licensed technologies together. Developing and deploying an effective spectrum sharing mechanism through CBRS would be a significant achievement. It is an exciting opportunity because it makes available a significant amount of spectrum without the need for expensive auctions and is not tied to a particular operator.

It is expected that CBRS will create many new opportunities and revenue sources for MSOs for the new business models and use cases described in this paper. Market analysis shows that MSOs could benefit significantly from the new, shared CBRS bands. 3GPP LTE evolution is the key software enabler while the regulatory framework supports the availability of more spectrum that create economic value for operators. CBRS is an opportunity for the US to demonstrate new technology, business models and inject regulatory innovation.

The proposed opportunities enable MSOs to retain their existing Triple play customers, as well as acquire new customers for a Quad Play service (mobile wireless) and strengthen their overall market position by offering a new and improved personalized mobile broadband data services. An important use case for CBRS is the improvement in building coverage and capacity increase, Local Indoor Mobile Access (LIMA) using LTE based *inside-out* strategy. It has the advantage of being a more Wi-Fi like business model and economics with the Quality of Service of the LTE network. CBRS, thus, opens new business models for in-building wireless solutions. Further, with relaxed the Base Station Transmission power requirements, FCC has helped MSOs to extend the business cases to use CBRS outdoors, leveraging their deep fiber HFC plant.

In terms of relevance to MSOs, this table captures all the specified new business models with their relevance to generate new profit pools for MSOs.

Table 3

Use-Case	Revenue opportunity	Time Horizon	Notes
Local Indoor Mobile Access (LIMA); Inside-Out	++++	2019	By far the most relevant opportunity for MSOs in near term
Outdoor mobile Access using fiber node assets	+++	2019	Leverage the deep fiber and deploy CBRS small cells at strategic optical nodes for outdoor coverage.
Private LTE Networks	++	2019	MSOs offer turnkey private LTE enterprise wireless networks for Medium to Large enterprises.

Use-Case	Revenue opportunity	Time Horizon	Notes
Neutral Host Networks	++	2019	MSOs offer turnkey LTE Radio Access network in the CBRS spectrum for large venues and neutral hosts like hospitality.
Fixed Wireless Access	+	2019	Though MSOs have deep fiber and a cable plant that covers 80% of US homes and businesses, CBRS based FWA can complement the cable plant to provide strategic broadband access in rural areas and the learnings can be extended to future evolution to 5G FWA in urban areas.
Industrial IOT	+	2020	Unlike IOT in unlicensed spectrum, Industrial IOT like in manufacturing plants, refineries, chemical plants etc. requires highly reliable / mission critical wireless communication that can only be provided by a QoS capable technology like LTE. Industrial IOT ecosystems provide MSOs to offer turnkey Industrial IOT networks to automate manufacturing and smart cities.

Abbreviations

CBRS	Citizens Band Radio Service
LIMA	Local Indoor Mobile Access
IOT	Internet of Things
LTE	Long Term Evolution
MVNO	Mobile Virtual Network Operator
FCC	Federal Communications Commission
DoD	Department of Defense
SAS	Spectrum Allocation Server
PAL	Priority Access License
GAA	General Authorized Access
FSS	Fixed Satellite Service
EIRP	Equivalent Isotropically Radiated Power
ESC	Environmental Sensing Capability
CBSD	CBRS Broadband Service Devices
DFS	Dynamic Frequency Selection
EUD	End User Device
PSD	Power Spectrum Density
ITM	Irregular Terrain Model
DPA	Dynamic Protection Area
LAA	LTE Assisted Access
CNO	CBRS Network Operator
ODU	Outdoor Unit

Bibliography & References

[1] https://www.ustelecom.org/sites/default/files/files/USTelecom-White-Paper-2.pdf

[2] http://www.analysysmason.com/

[3]https://ecfsapi.fcc.gov/file/12280695017091/Final%20Charter%203_5%20GHz%20NPRM%20Comments%20(12-28-17).pdf

[4]https://ecfsapi.fcc.gov/file/104190157420141/IIoT%20Coalition%20ex%20parte%20filed%2004191 8.pdf

[5] https://www.cnet.com/news/cox-hangs-up-on-cell-phone-service/

[6] https://www.statista.com/statistics/489169/canada-united-states-average-data-usage-user-per-month/

[7] https://www.multichannel.com/news/comcast-charter-benefit-scuttled-sprint-t-mobile-ma-talks-analyst-416755

[8] http://bgr.com/2018/06/04/spectrum-mobile-best-unlimited-plan-2018-vs-verizon/

[9] https://www.fiercetelecom.com/telecom/from-comcast-to-hawaiian-telcom-tracking-top-15-residential-broadband-service-providers-q3

[10] http://senzafiliconsulting.com/resources-2/the-total-cost-of-ownership-tco-for-fixed-ongo-in-the-3-5-ghz-cbrs-band/

