Small Cell Deployment Strategies for Cable Broadband

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1. Introduction

Cable broadband and wireless operators are working together to create new revenue-generating partnerships and service offerings. While some cable operators are reselling wireless mobility as part of their bundled service offerings, others are selling mobile operators access to their infrastructure for cost-effective small cell connectivity.

Many broadband operators also plan to deploy their own small cell networks, leveraging recent acquisitions of CBRS spectrum and their existing Hybrid Fiber-Coax (HFC) infrastructure. Regardless of the reason, introducing small cells to the HFC network presents many challenges, from making a workable business case, to product design and development as well as operational practices.

Reliable power and quality backhaul are essential for small cells, and radios must be strategically located across a wide geographical footprint. You must also maintain a tightly coordinated schedule while working with a limited budget. The HFC network is a smart choice for distributed connectivity—it alleviates the cost of building a small cell network from the ground up, providing reliable, cost-effective infrastructure through most populated areas.

When HFC is not available to support small cell devices, alternative powering approaches may be more cost-effective. Remote Line Power (RLP) uses high-voltage DC power to distribute longer distances using copper with fiber, often in a hybrid fiber/copper composite cable. Local utility power can also be used, but often requires expensive construction, permitting and metering for new service to cell site installations. All three powering options have advantages and disadvantages.

This paper will evaluate HFC for small cell power and backhaul capabilities and explore different methods of deployment. We'll also look at local utility power as well as remote DC power solutions for small cell powering. Small cell deployment requirements and challenges will be explored with guidance on selecting connectivity solutions based on the situation and environment.

2. Small Cell Radio Deployment Challenges

In a perfect world, operators would be free to place small cell radios wherever they want, and every location would have a power outlet with reliable backup power and fiber for backhaul. The realities of small cell deployment are different, and it can be quite expensive and can take months to bring power and communications to the radio. Local siting restrictions and costly permits can add even more barriers.

2.1. Cost-Effective Infrastructure Availability

Unlike tower-based cellular radios which can provide several square miles of coverage, mid-band small cell radios output much less power with coverage areas of a few hundred feet maximum. This means radios must be close to the coverage target, and a large quantity is needed to cover a sizeable area. Small Cell Forum recommended best practice is to install small cells within 20-40m of heavy traffic locations.[1] In other words, a good deployment solution needs scalability and precise radio placement.

Getting permission to install a small cell can be a challenging process, with hurdles around zoning, securing siting, permitting and regulations. Jay Brown, Crown Castle CEO reported it can take up to 2

[1] SCF 2021 Market Forecast document 050.10.5; http://smallcellforum.org/scf-market-forecast; viewed 7/28/21

years to deploy a small cell on a wall or pole, due to wading through siting and construction issues.[2] That same deployment model can cost $25,000 or more.[3]

2.2. Reliable Power

More than ever, keeping the mobile network running at full capacity without interruption is essential. Networks must withstand daily power anomalies that plague the United States utility grids and cause damage to sensitive network equipment.

Extreme weather events are becoming more prevalent, resulting in more frequent, longer duration power outages. United States utility customers experienced 1.33 billion outage hours in 2020, up 73% from 2019's 770 million outage hours.[4]

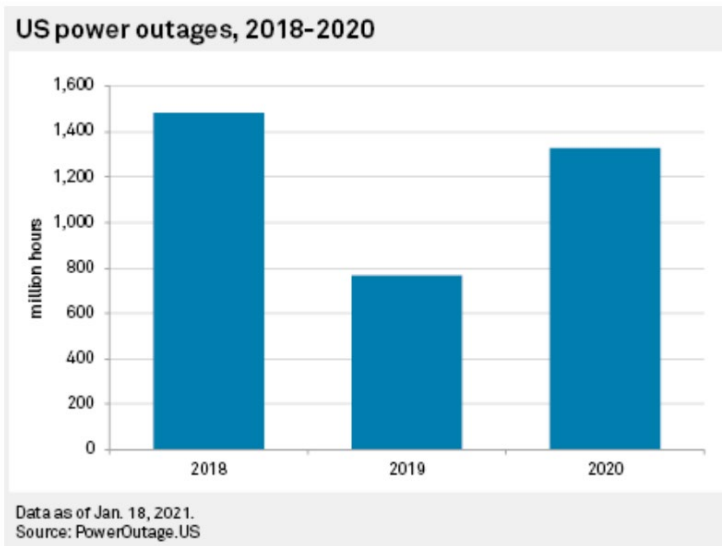

Figure 1 - US Utility Outages 2018 to 2020

A reliable small cell network requires clean conditioned power and, where econmically viable, energy reserves for backup during utility outages.

2.3. High Bandwidth, Low Latency, Reliable Backhaul Connectivity

Cellular networks have traditionally relied on fiber optic backhaul communications due to superior performance in bandwidth and latency. Next generation 5G design parameters specify delivery of up to 10Gbps throughput with less than 1ms latency[5]. These are essential factors for real-time use cases like gaming, video streaming and remote healthcare, where the experience requires seamless communications.

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[2] Small cells: Strand-mounted business opportunities; BTR; 9/5/2018; https://www.broadbandtechreport.com/docsis/hybrid-fiber-coax/article/16449380/small-cells-strandmounted-business-opportunities

[3] "Cable's wireless biz 'ready for its star turn' – analyst"; LightReading; J Baumgartner; 6/17/21; < https://www.lightreading.com/cable-tech/cables-wireless-biz-ready-for-its-star-turn---analyst-/d/d-id/770301 >

[4] US power outages jumped 73% in 2020 amid extreme weather events; G. Herring; 1/19/2021; https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/us-power-outages-jumped-73-in-2020-amid-extreme-weather-events-62181994

[5] 5G Low Latency Requirements, McLaughlin, 2019, https://broadbandlibrary.com/5g-low-latency-requirements/

While fiber may be preferred, it is not always cost-effective when construction is needed to bring the fiber to the location where the small cell is installed.

Meeting the goals of cable broadband small cell deployments will require operators to find financially viable ways to provide the fundamental elements for high quality small cell radio connectivity, while maintaining reliability of their existing network. Long term plans should consider product lifecycles and how to stay ahead of evolving radio technologies.

3. HFC as an Advantage for Small Cell Deployment

3.1. Advantage: Ubiquitous Broadband and Power Grid

For many years, the core mission of the cable broadband network has been to deliver fast, reliable and high-quality wired connectivity. What started out as a scattering of coax cable networks intended to provide community access television in the late 1940s[6], has evolved into a vast network of fiber optic and copper coaxial cables delivering not only television, but Internet and phone service around the globe.

In the United States alone, cable broadband networks have over 1.7 million total miles of deployed fiber and coax to make up the HFC network. This vast expanse of physical infrastructure passes 96% of the homes in the U.S., providing service to 78 million customers[7].

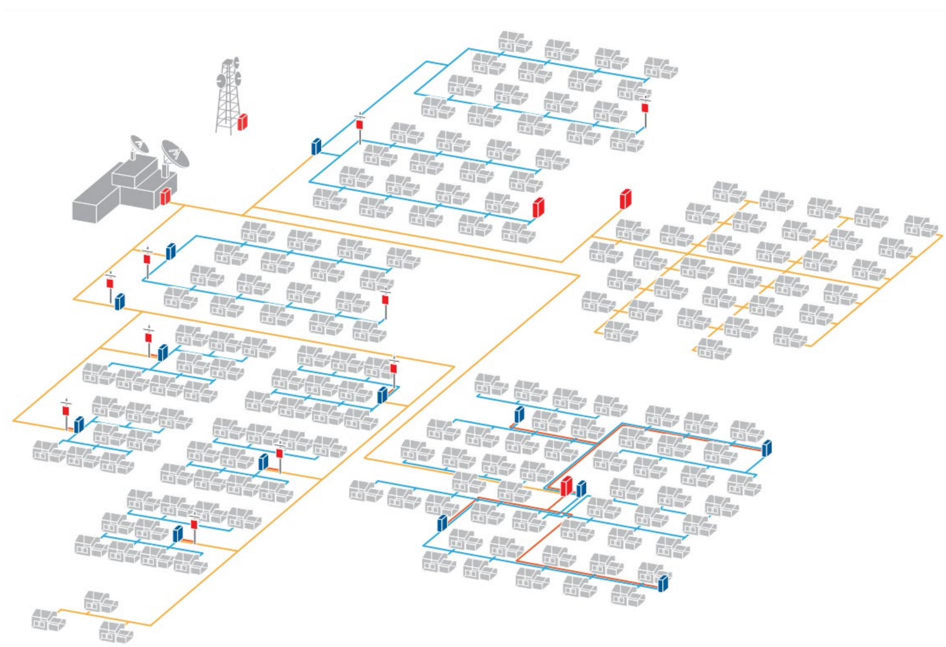

Figure 2 - HFC Network

In the HFC network, fiber optic cables are primarily used as an efficient delivery mechanism to bring long haul network traffic into neighborhood nodes; and in some new construction to end users directly using Fiber to the Home (FTTx). These nodes convert light signals to electrical signals for transmission over coax. The coaxial cable then delivers data for the “last mile” to each subscriber’s home through a cable

[6] The Cable History Timeline; Viewed 7/25/2021; https://www.cablecenter.org/images/files/pdf/CableHistory/CableTimelineFall2015.pdf

[7] NCTA Broadband Stats and Facts; Viewed 8/1/2021; https://www.ncta.com/broadband-facts

modem. Remote PHY (CCAP) nodes, traditional fiberoptic nodes, and amplifiers require power, so the practice of using the network coax to carry power is still widely used as illustrated in Figure 3.

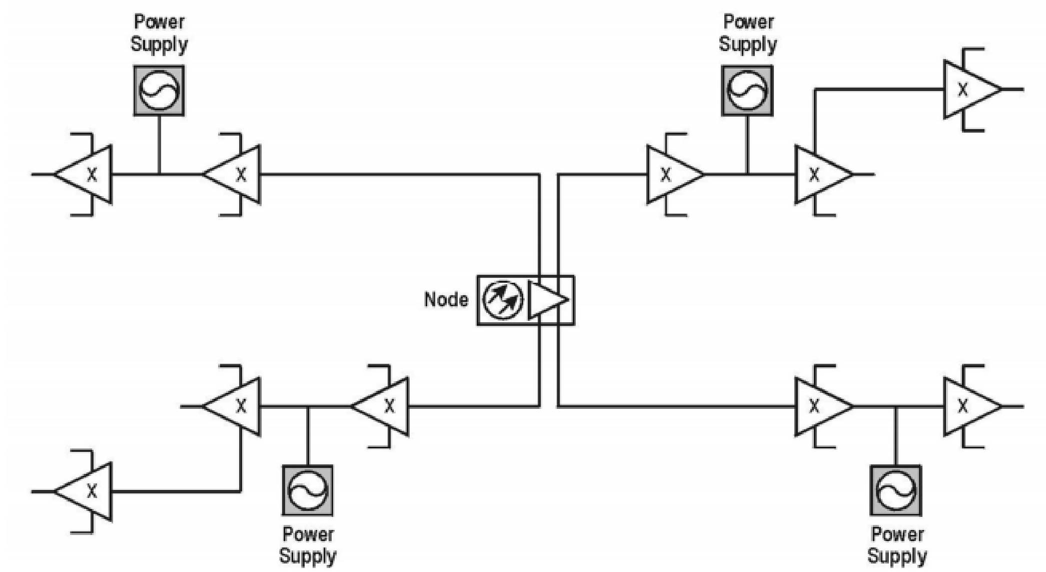

Figure 3 - Typical HFC Network Powering Diagram[8]

Coaxial cable accounts for 20% of the HFC network. This coaxial network can be looked at as 340 thousand miles of existing, accessible and available power lines running through most populated areas.[9] While utility power lines often span the same poles, there are other aspects of the HFC network that make it much more suitable for small cell deployments.

3.2. Advantage: Accessibility and Scalability

The HFC network architecture is built on a distributed access model that is extremely efficient and flexible, enabling Internet connectivity at any point in the network. According to a recent publication from iGR, it is estimated that the cable broadband aerial strand could support small cell installations for over 203 million people in the United States, about a quarter of the total addressable market.[10]

NCTA identifies the flexibility and continuous management as key value props of the HFC network:

> *"The beauty of HFC architecture is it marries the power of gigabit capable networks with an architecture that is extremely efficient and flexible…network engineers don't just plan for today, they build networks that accommodate future growth in consumer demand. That planning allows cable's networks to stay ready and robust in the face of events that may cause internet traffic surges."*[11]

[8] SCTE Standard 238 2017; https://www.scte.org/standards-development/library/standards-catalog/scte-238-2017

[9] NCTA Broadband Stats and Facts; Viewed 8/1/2021; https://www.ncta.com/broadband-facts

[10] iGR, 2020, A Strand of Hope: How strand-mounted small cells can address the demand for 4G and 5G mobile data, iGR Media Center, Viewed 3/15/2021 https://igr-inc.com/media-center/white-papers/strand-mounted-small-cells/strand-mounted-small-cells.asp

[11] *"Why Cable's Broadband Network Is Handling the Pandemic and Ready for the Future", NCTA; 4/29/2020;* https://www.ncta.com/whats-new/why-cables-broadband-network-is-handling-the-pandemic-and-ready-for-the-future

The coax portion of the network is used for broadband delivery, with physical 'taps' cut into the hardline coax to provide individual connections to the broadband network through smaller, more flexible and manageable premise coax. While most taps used for residential customer broadband connectivity prevent power from travelling to the home, a special style of 'power-passing tap' allows for both power and broadband to be extracted. These power-passing taps were initially introduced to support telephony systems and more recently re-introduced to provide power and backhaul communications for Multiple Service Operator (MSO) strand-mount, Wi-Fi access points. With hundreds of thousands of HFC-enabled Wi-Fi access points deployed worldwide, broadband operators have proven the effectivity HFC can play for scalable wireless access.

3.3. Advantage: Reliable Source of Power

HFC power supplies take power from a utility connection and energize the coax, enabling nodes and amplifiers to power directly from the coax, removing the need for utility connections to each device. Since the cable operator's communications channel radio signals (RF content) and alternating current both propagate using sinusoidal waves at different frequencies and can simultaneously travel over the same coaxial cable. This combination of power and communication is unique to cable broadband and a differentiator for small cells.

HFC power supplies utilize ferroresonant transformers to provide a very robust and quality powering platform, ideal for sensitive network equipment. Ferroresonant transformers by nature provide excellent line isolation; 1000:1 ratio for HFC power supplies. This means that any change to the input, small or large will have little effect on the output. A high voltage surge or spike from the utility will be minimized at the power supply before it can affect the HFC network.

Most broadband cable operators co-locate their HFC power supplies in cabinets with batteries to maximize network power availability when utility power fails. Today's HFC power supplies can switch to battery mode within a half duty power cycle, preventing the nodes, amplifiers and radios from dropping power and resetting during the power transfer.

3.4. Advantage: Physical Placement

Furthermore, most cable operators enter into franchise agreements with their local municipality which allows them to connect any network equipment to the HFC without requiring additional site approvals or permits.

New Street research analyst Spencer Kurn noted the value the broadband cable strand played in Sprint's recent 20,000+ small cell deployment in Long Island. "Cable companies already have the public right of way with poles and strands of aerial cables… Historically, cable companies have been reluctant to open their infrastructure to wireless carriers to deploy small cells… Altice is unique in that they did this for Sprint in return for a really attractive wireless Mobile Virtual Network Operator (MVNO)."[12]

Moffet Research estimates that an MSO can install a CBRS small cell for around $2,500 by avoiding the siting costs that are applied to pole and wall installations.[13]

[12] L Hardesty, 2019, Altice's 19,000 small cells in Long Island don't help Sprint's network much, say analysts, Fierce Wireless, Viewed 3/1/2021, https://www.fiercewireless.com/wireless/altice-s-19-000-small-cells-long-island-don-t-help-sprint-s-network-much-say-analysts

[13] "Cable's wireless biz 'ready for its star turn' – analyst"; LightReading; J Baumgartner; 6/17/21; https://www.lightreading.com/cable-tech/cables-wireless-biz-ready-for-its-star-turn---analyst-/d/d-id/770301

3.5. Advantage: High-Capacity Low-Latency Backhaul

MSOs are pushing fiber optics deeper into neighborhoods and moving much of their core network processing from regional headends out to the edge of their network. This "edge computing" application greatly improves processing time, enabling higher capacity with lower latency. A recent CableLabs® analysis showed >50% reduction in total cost of ownership (TCO) for an outdoor use case of backhauling small cells when served by DOCSIS® networks compared to a more traditional deployment served by fiber.[14]

DOCSIS® 3.1 is currently deployed globally in millions of homes and businesses. Today's DOCSIS® 3.1 introduces support for low-latency DOCSIS (LLD), and provides an option to increase upstream spectrum from the traditional 5 to 45MHz range to 5 to 205MHz. This adds significant upstream capacity improvements and sets the groundwork for future improvements coming with DOCSIS® 4.0.

Through DOCSIS® enhancements known as low latency X-Haul over DOCSIS®, 5G backhaul latency can be reduced to approximately 1ms, surpassing 5G vRan targets of 5ms.[15]

Extended frequency division duplex spectrum DOCSIS® 4.0 will take advantage of the extended 1.8GHz of spectrum as well as full duplex to maximize throughput. DOCSIS® technology leaders expect throughput target speeds of 10Gbps downlink and 5Gbps uplink.

3.6. Advantage: Existing Well-Maintained Resource

One major advantage of the broadband HFC network is it's the lifeblood of cable companies and warrants significant, continuous investments and routine maintenance. Cable operators in North America invested $17B in 2020 alone, on infrastructure and networks[16], with total investments of $290 Billion since the year 2020[17]. NCTA credits these cable broadband commitments to investing in their network as key factors leading to industry's ability to meet added demands from the COVID-19 pandemic work-from-home impact.

> *"…hundreds of billions of dollars in investment in infrastructure and technology, smart and responsive network engineering, and a flexible network foundation that is being constantly upgraded with hardware, software and other technical modifications* (NCTA, 2020)[18]. "

And in addition to capital investments, cable broadband's smart architecture and commitment to localized management provides a very resilient and reliable infrastructure. *"By having eyes on every aspect of network performance, engineers are able to diagnose localized issues and often troubleshoot them quickly."*[19]

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[14] DOCSIS® Network vs. Fiber Backhaul for Outdoor Small Cells: How Larger Footprint of DOCSIS Networks Lowers TCO in the Outdoor Use Case, https://www.cablelabs.com/docsis-vs-fiber-backhaul-outdoor-small-cells

[15] CableLabs Low Latency DOCSIS® Technology Launches 10G Broadband into a New Era of Rapid Communication; https://www.cablelabs.com/cablelabs-low-latency-docsis-technology-launches-10g-broadband-into-a-new-era-of-rapid-communication

[16] "Internet Facts and Stats; NCTA; viewed 7/20/2021; <https://www.ncta.com/broadband-facts>

[17] *"Why Cable's Broadband Network Is Handling the Pandemic and Ready for the Future", NCTA; 4/29/2020; < https://www.ncta.com/whats-new/why-cables-broadband-network-is-handling-the-pandemic-and-ready-for-the-future >*

[18] Ibid

[19] Ibid

4. Connecting Small Cells to HFC

4.1. Design and Integration Considerations

The cable broadband HFC network brings a unique set of connectivity considerations for small cell radios. Creating HFC-compatible small cell radios require integration of HFC components and elements into radio design allowing them to mount and receive power from HFC coax, backhaul via DOCSIS® and enable remote system management and reporting.

4.1.1. Housing Size Limitations

Cable broadband operators typically enter into franchise agreements with local municipalities that include rights-of-way. These agreements provide cable operators with the freedom to hang outside network equipment from the steel messenger cable, or "strand" that spans between utility poles and lashes the coaxial network cables. The terms of the agreements typically allow the operator to deploy their networks in this fashion without requiring new permits for each piece of equipment deployed. The equipment deployed on the strand, however, must meet size, weight and power restrictions.

Starting with form-factor, any device designed needs to fit into what the National Electric Safety Code (NESC) defines as the Communications Space. NESC specifies a minimum 12" clearance between cable TV and telephone lines as shown in Figure 4, but some jurisdictions lower that to 11in or even 9in in some cases.

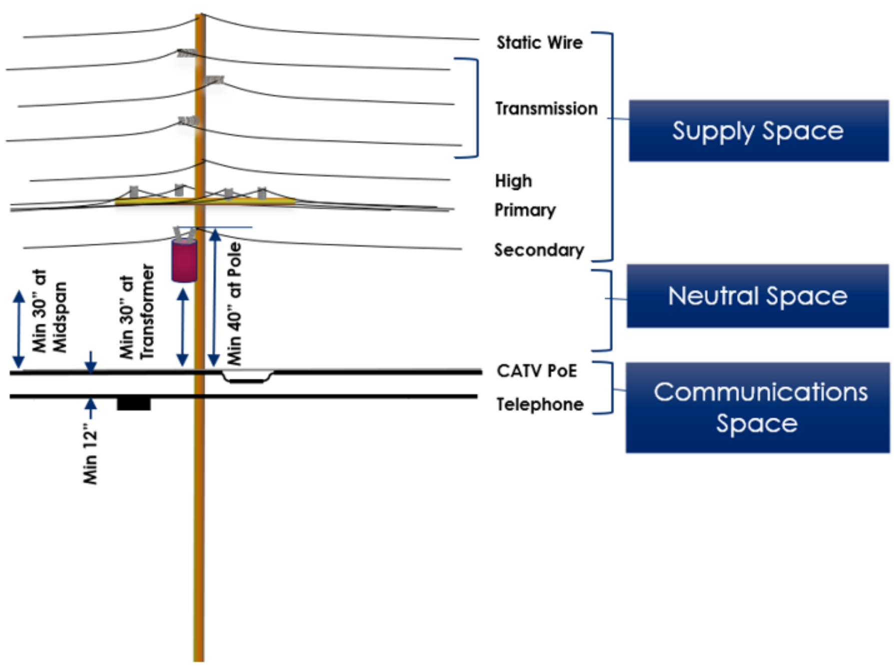

Figure 4 - Communications Space

The coax itself must be accounted for in this space as well which can reduce this space by 2 to 3in, and some broadband operators have individualized stringent space requirements. This means small cell radios should be no taller than 9in (including integrated antennas).

Figure 5 - Small Cell Radio within Communications Space[20]

4.1.2. Physical (Outside) Connections

The main connection points for the HFC small cell are the mounting connections to the strand, the grounding connection, and most importantly the connection to the HFC coax.

There is no industry specification for strand-mount brackets but there are basic guidelines to consider. Messenger strands are typically 0.25in or 0.375in in diameter, so useful designs would include flexibility to support either size. A potentially large cable bundle, up to a 3in diameter may be tethered to the strand, creating an obstacle between the strand and radio. Most strand brackets are designed with a "C" shape to accommodate the coax bundle. Another important consideration for the strand bracket is to check that materials are galvanically compatible with radio housing and the galvanized steel strand. Metals with dissimilar galvanic properties can lead to unwanted corrosion.

Figure 6 - Strand Bracket

The strand messenger, in addition to mounting, also provides the electrical grounding for strand-mounted equipment. While many radio designs use the mounting bracket as the ground connection, a ground lug on the radio housing can facilitate a dedicated cable to secure a ground connection between the radio and strand.

Perhaps the most important physical connector is the HFC coax connection. The coax cable delivers power to the radio, provides the network backhaul and is a potential source of water intrusion and radio noise ingress. There are two standard connection types used for HFC equipment, typically selected based on the size of coax cable connecting the equipment, which is determined by the cable operator based on

[20] Image taken from Airspan website; 8/1/2021; https://www.airspan.com/cbrs/

the amount of power that the equipment draws from the HFC coax. Most strand-mount HFC equipment like nodes and amplifiers connect directly to distribution "hardline" coax, which is much heavier and less flexible than the smaller coax "drop" cable that run from the HFC to a residence. Smaller drop coax, which is more flexible and less expensive than hardline can be used to connect smaller loads like Wi-Fi access points. While the decision is made by each cable operator, general guidelines limit the smaller drop coax for loads under 90W, with hardline coax is suitable for any loads. Smaller coax cables use F-style connectors, the same as home modems and set top boxes specified by ANSI_SCTE_124_2021[21]. Hardline coax uses a standard 0.625in x 24 threaded connector as specified by ANSI_SCTE_91_2015[22]. It is important to follow SCTE 91 specifications closely as there are essential elements like shrink sleeve ridge and galvanic considerations.

Figure 7 - Hardline 'KS' connectors

Designing small cell radios around SCTE 91 specifications (hardline connection) provides the cable operator with flexibility to connect using either hardline distribution cable or drop cable by installing a 'KS male to F', or "pin-to-F" adapter. The pin-to-F has the standard 0.625in x 24 threads to connect into the radio, with the other end having F-type threads for drop cable.

Figure 8 - Pin-to-F connector

4.1.3. Power

An HFC small cell radio must be able to power from the HFC coax, which delivers an alternating current (AC), quasi-square wave in the range of 45-90VAC, depending on resistive losses created by distance from the local HFC utility power supply. Cable networks work similarly to wireless networks, sending digital data over radio frequency (RF) waves, only the waves are sent within coaxial cables and fiber optical cables instead of openly through the air. A unique and important feature of the HFC network is the

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[21] https://www.scte.org/standards-development/library/standards-catalog/ansiscte-124-2011/

[22] https://www.scte.org/standards-development/library/standards-catalog/ansiscte-91-2015/

use of Alternating Current (AC) for power, both power and data can travel through the same coaxial cable at the same time.

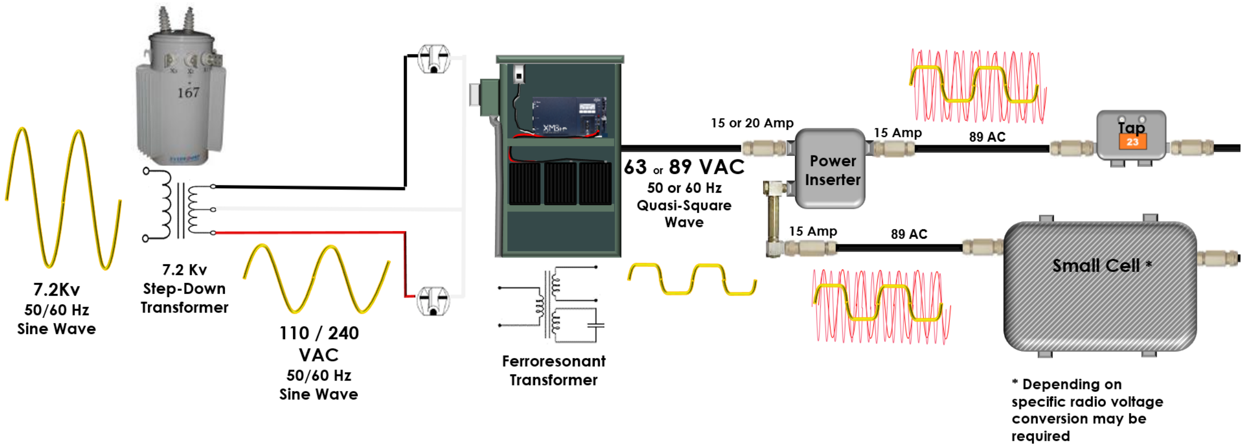


Figure 9 - HFC Power System

The device being powered by the coaxial network, be it a node, amplifier or in this case a small cell radio, will use RF filters to separate the power and DOCSIS® RF. At this point, the device can convert the voltage from AC to DC to power the device, and RF can be used for DOCSIS® backhaul with the integration of a cable modem.

Voltage levels drop over distances per Joule's I2R law, meaning voltage at the small cell will be lower than at the cable power supply. Most cable operators dictate that devices powered by HFC automatically shut down at lower voltages in the 35 to 45VAC range protecting the device from drawing too much current [Current (I) = Power (P)/Voltage(V), therefore a 100W radio will typically draw twice the current at 45VAC compared to 90VAC]. Many cable operators also require the powered-device (small cell radio in this case) sustain operation over a full duty-cycle of sustained power loss, requiring additional capacity in the power circuit.

Another consideration around small cell power is the advantage of using watchdogs and remote power control to reduce outages and costly truck rolls. Most end users have had experiences with home networking equipment locking up, requiring a power cycle to bring the device back online. This is simple when the device is in a home, office, or headend, but problems on the HFC strand require expensive truck rolls to perform the most basic tasks, like pushing a reset button. A good watchdog system should catch any problems with routine operation of the device and will auto-reset or trigger a power cycle to the system without human intervention. It's also valuable to provide remote power control of the radio element independently of the overall radio system. This can be very useful if the radio element gets stuck or if the operator wants to shut down the radio transmitter for a local service call. This value-added feature however requires communications and power control between the DOCSIS® modem and onboard AC/DC power supply.

4.1.4. Backhaul

One of the primary benefits of deploying small cell radios over HFC is the ability to use DOCSIS® for data backhaul. DOCSIS® 3.1 has incorporated features useful for small cells including: low-latency DOCSIS®, mid-split and high-split spectrum options to increase throughput, and additional tools like business services over DOCSIS® for added management and security. Cable operators deploy millions of DOCSIS® modems to their home and business subscribers. Managing a cable modem inside of a small cell radio should not be much different.

However, there is a significant difference between a home or office modem and an outdoor hardened modem, especially when it resides inside an enclosed housing with an RF transmitter. Outdoor small cell radios are designed to operate in outdoor climates and be exposed to extreme hot and cold temperatures where modems must be built with more expensive, rugged components. In addition to harsh environmental conditions, outdoor HFC modems carry more stringent requirements to withstand power disturbances like surges, line cross and electrical static shock. They are expected to self-recover from network and power outages and can require operator-specific firmware for remote system management.

4.1.5. Safety

Electrical shock hazards and RF radiation are the top safety concerns for strand-mount small cells. The NESC limits products residing within communications spaces to 90VAC which is considered 'low voltage' and safe for technicians to work around without requiring electrician licensing. This however does not mean that HFC power is not dangerous. While it is important for technicians to use safety procedures when working on or near HFC, the products using HFC for power must meet rigorous standards for electrical shock and be proven through agency testing.

Small cell radios fall under the category of 'Information Technology Equipment' for Underwriter Laboratories[23] (UL) and CSA Group[24] (CSA – formerly Canada Safety Agency), the two primary safety certification agencies in North America for cable broadband equipment. Both UL and CSA are Nationally Recognized Testing Laboratories (NRTL) that test to the same harmonized Canadian Electrical Code (CEC) and National Electrical Code (NEC) standards, making their certifications virtually interchangeable.

4.1.6. Environmental

Outdoor small cell radios are subjected to harsh weather conditions, including extreme temperatures, ice, rain and wind. Installations in coastal areas add the element of salt, an enemy to steel and electrical circuitry. Aluminum housings coated with salt-resistant paint, along with designing around dissimilar metals, will go a long way to preserve equipment integrity.

4.1.7. Network Integrity

A challenging but important element of the small cell radio, especially when connected to the cable broadband network, is the mitigation or prevention of electromagnetic interference (EMI) between the cable and wireless networks. Both wired and wireless networks use radio signals for communications, often in the same frequency range. It is essential these networks are isolated from each other and radio signals from one medium do not bleed into the other.

Damaged or improperly installed coaxial cable can act like an antenna and is more susceptible to conducted interference, where RF noise or signals are propagated through the coax. This interference can impact the RF signals from the cable headend, resulting in poor or lost communications for customers

[23] https://www.ul.com/
[24] https://www.csagroup.org/

across the network. Conducted noise can also come from crystal oscillators in tuner circuits, or from AC/DC power supplies within the small cell.

Wireless networks are more susceptible to radiated interference, where RF signals leaking from the cable network via an enclosure or poor connector affect the wireless signal of the radio. The effects are similar to those on a wired network, impacting overall performance and integrity of the wireless network.

A sealed, aluminum small cell housing acts as a Farady cage and provides most of the protection needed to mitigate interference between networks. However, RF inside the sealed housing, especially when housing a cable modem and wireless radio can be exceedingly difficult to overcome. Shielding, grounding, internal wiring, EMI filters and a lot of testing are required to truly protect the cable network.

4.2. HFC Connectivity Methods: Integration and Demarcation

This section will discuss two methods of deploying small cells over the HFC network and provide advantages and disadvantages to both.

4.2.1. Small Cell with Integrated HFC Elements

A DOCSIS® small cell radio is one that has been designed specifically for strand-mount and connecting directly to HFC coax for power and backhaul. The radio manufacturer will design a housing to meet the industry requirements, including but not limited to:

- Strand mounting connections
- Coax connection including seizure screw
- Status indicators (modem, radio)
- Water intrusion
- UV
- Wind loading
- Antennas
- EMI
- Communications space limitations
- Electrical grounding
- RF Protection from external impairments
- Corrosion (water, salt water, dissimilar metals)
- Vibration
- Labelling
- Internal circuitry including RF protection
- Electrical surge

HFC-specific internal components must be designed or purchased to include:

- Coax interface
- RF/Power Filter
- Outdoor hardened DOCSIS® modem including all firmware for management, MSO-specific features

A single box system minimizes the number of cables, connectors and external components. This reduces the number of potential failure points and makes for simple system installation, troubleshooting and management verses a solution with multiple elements for power and backhaul.

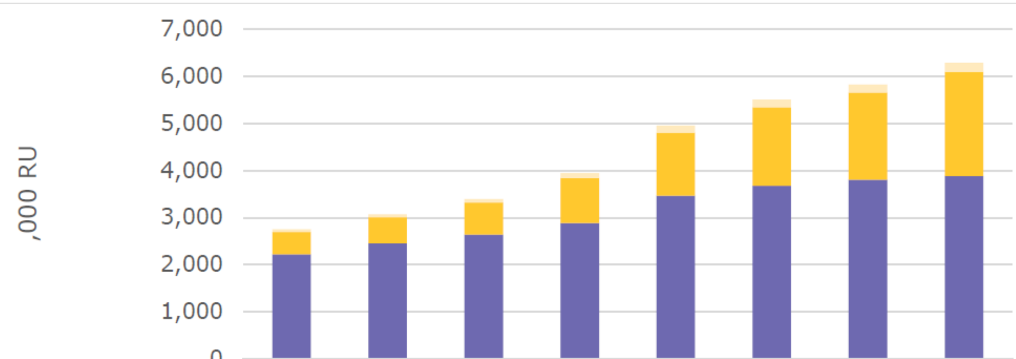
The procurement process is also simplified by having a single manufacturer to coordinate with for purchasing if any problems arise. Instead of spending time to understand which part of the system is causing problems, the radio can be replaced, returning the defective unit to a single vendor.

However, creating a small cell radio specifically for HFC has its own drawbacks. The biggest challenge is with small cell radio manufacturers and their need for a business case to justify the investment needed to bring an HFC-specific radio to market.

Like any manufactured product, one goal is to create products serving multiple markets without additional SKUs, allowing manufacturers to leverage economies of scale to lower their overall component and operational costs.

HFC deployment historically has been a small niche sub-market for outdoor small cells, and outdoor small cell deployments are a fraction of indoor enterprise. For example, according to Small Cell forum around 468,000 outdoor small cells were deployed in 2019, approximately 20% of the total deployments.[25] In that same year Sprint deployed ~20,000 strand mount small cells over Altice's HFC, which would have accounted for ~4% of the total outdoor small cell deployments.

The outdoor small cell market share is expected to increase to 35% by 2026 to over 2 million radios installed, but it is too early to say how many of those radios will be targeted for HFC deployments.



	2019	2020	2021	2022	2023	2024	2025	2026
Rural and remote	55	62	76	110	145	156	170	185
Urban	468	556	680	950	1,345	1,670	1,850	2,210
Enterprise	2,228	2,455	2,643	2,890	3,465	3,680	3,810	3,890

Enterprise Urban Rural and remote

Figure 10 - Small Cell Deployments by Segment 2020 - 2026[26]

Other large MSOs are planning their small cell programs with help from recent allocations of licensed and unlicensed CBRS spectrum by the FCC, and their deployment numbers will likely reach over 100,000, but this is not a proven market and any forecasted numbers must be met with caution. Without solid commitments, radio manufacturers are faced with high-risk investments which pull resources away from other revenue-generating opportunities.

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[25] SCF 2021 Market Forecast document 050.10.5; http://smallcellforum.org/scf-market-forecast; viewed 7/28/21

[26] Ibid

Another challenge for the integrated small cell radio is each vendor must go through steep learning curves with regards to cable networks and nuances involved with HFC power, RF mitigation and industry practices. This can add significant delays in development schedules and require radio vendors to become experts in technologies outside of their core competencies. Vendors must invest in costly CMTS and HFC power equipment and may need to build their own cable networks for development and testing.

Certification is another pain point for radio manufacturers. Small cell radios must be FCC certified for each radio band they serve and may require additional certifications for each country where the radio will be deployed. The addition of a cable modem to the radio requires CableLabs DOCSIS® certification at costs intended for high-volume amortization seen in the residential modem market.

Each MSO will further qualify and verify the hardware for operation in their networks. These tests include functional, RF emissions and operational test as well as environmental tests. Test and certification cycles are lengthy and expensive, requiring heavy investments in specialized equipment and expertise. In a best-case scenario, the radio passes all tests on the first attempt but this is rarely seen if ever. Multiply this by several vendors and it can have a significant impact on complexity and schedule.

4.2.2. HFC Demarcations for Small Cell Radios

Another approach to bringing small cell radios to HFC is to create demarcations allowing radio vendors to use off-shelf products with minimal changes. Cable broadband already uses demarcations in the form of taps used to deliver DOCSIS® to residential customers. It is widespread practice within the industry for MSOs to establish standardized RF levels at their taps so technicians can deploy a set length of drop cable knowing it can provide the optimal signal at the user's cable modem.

An HFC demarcation device for small cells would perform the power and media conversions and provide the radio the power and network connections.

Figure 11 - Small Cell with Demarcation Gateway (Author's Photo)

Demarcations allow small cell radio manufacturers to use radios for multiple purposes, eliminating the need for them to design low-volume niche products for HFC. Radio certifications and SKUs are reduced, proving additional economies of scale for the radio vendor. The MSO can then leverage competition between radio vendors which can result in additional cost reductions.

Demarcation gateways are not radio vendor -specific, so operators can source from one or two manufacturers directly, leveraging volume pricing.

Demarcation also provides additional reliability to the HFC network by acting as an isolator between the wired and wireless networks, protecting both from RF ingress. It gives the MSO better control of the cable modem which interfaces directly with the core network. Demarcation gateway manufacturers have expertise in outside HFC plant and DOCSIS® modems, providing additional quality assurance to the operators.

Finally, the overall TCO of the radio network will continue to stay low as next-generation radio products come to market. Wireless products tend to evolve faster than DOCSIS®, and demarcations provide the ability to upgrade your forward-facing technologies without sacrificing the entire system. MSO lab qualification and testing time is also greatly reduced for even better financial results.

A downside of using demarcations is the burden of extra inter-connecting cables between the demarcation device and radio. Extra cables and connectors do add some cost, but more importantly add points of failure to the system. It adds complexity to installations and potential problems when troubleshooting in the field.

When an unexpected problem occurs in a 2-box system (demarcation + radio), a technician must isolate the problem and work with the vendor to troubleshoot. Having two vendors to coordinate with can drag out repairs, adding cost and potential network downtime to resolve. However, that ability to troubleshoot from the demarcation point can provide additional information to speed the troubleshooting process.

Another disadvantage to the demarcation concept is aesthetics. More cities and municipalities are requiring outdoor equipment to be more aesthetically pleasing. Fewer devices hanging from the strand looks better than a multiple boxes with cables in between.

One concept addressing the problem of multiple connected products is a direct connection where the radio and demarcation are physically attached to each other with virtually unseen power and network connections. This model still isolates the radio from the demarcation, providing the benefits stated previously, but provides the benefits of a single-box solution.

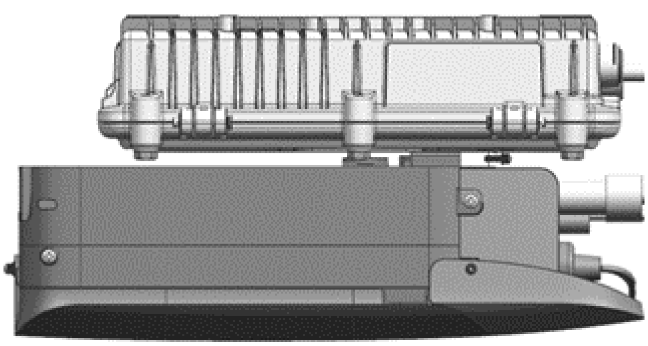

Figure 12 - Demarcation with Radio Attached

5. Local AC Utility Power for Small Cells

While this paper focuses primarily on HFC for small cell power, there are other options broadband operators can leverage.

In rare situations where rooftop power is available from a building where power distribution is managed by an operator, local AC utility power may be the ideal powering solution for small cells if it is the only source available, and if the small cell radio is designed to operate from AC voltage. The benefits are apparent: No time constraints for permits or meter installations, and only incremental monthly power consumption costs. However, the limitations of direct utility power for small cells include limitations around power quality and reliability.

If the availability of the radio is a high priority, or if the radio is designed for DC power, a local power supply should be installed between the utility and radio. A local power supply can condition utility power to remove noise and voltage spikes, and if the radio requires it, convert utility AC voltage to useable DC power. Batteries can also be added to the local solution to facilitate radio availability during utility outages and power disturbance events.

Using local utility power can become a disadvantage if that power is not readily available at or near the radio location.

6. Remote DC Line Power for Small Cells

RLP uses a centralized power hub to deliver DC power long distances over copper pairs to remote locations. The basic design involves converting local utility power to DC, elevating the DC to high voltage for distribution, then lowering the voltage at the delivery point.

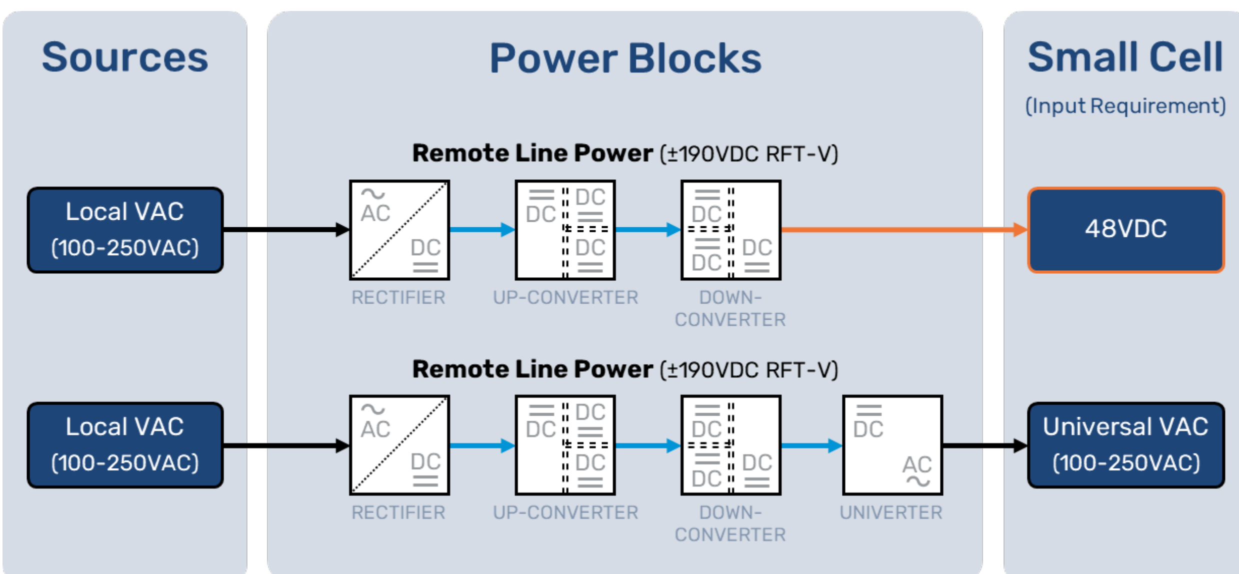

Figure 13 - Remote Line Power for AC or DC Delivery

RLP is a good solution for small cells, especially in green field or locations where other power sources are unavailable. RLP is popular with neutral host providers as it allows them to use existing telephony copper pairs to deliver power in high density areas, eliminating the need for costly construction or meter installations. Advances in this technology supports higher power using fiber and copper pairs, significantly more appealing in cost per node than local AC utility power. The time savings alone can more than justify the use of RLP.

While remote line power is an excellent solution for many use cases there are some limitations and drawbacks. Systems that use existing twisted copper pair may be limited to 100W per circuit. Multiple circuits can be used in parallel but must be aggregated at the small cell site. This aggregation can add more components on the strand for undesirable aesthetics as shown in the figure below.

Figure 14 - Remote Line-Powered Small Cell

7. Conclusion

It's time to bring awareness and identify different solutions to fulfill the objectives around network reliability, wireless connectivity, and corporate management. By highlighting the pain points in deploying small cells we explored three solutions to power small cells: utility power, HFC power and remote line power. We highlighted the benefits of using the HFC infrastructure for low-cost high value connectivity and discussed two methods of deploying small cells over HFC.

HFC certainly provides the cable broadband market with significant advantages in infrastructure availability, not only for small cells, but for any network-enabled product:

- Ubiquitous Broadband & Power Grid
- Accessibility and Scalability
- Reliable source of power
- Physical placement
- High-capacity low-latency backhaul
- Existing well-maintained resource

Hundreds of thousands of outdoor small cells will need to be deployed in the next 5 years to meet 5G demands. Upcoming smart cities, autonomous vehicles and drones will create even more demand for reliable network infrastructure for scaled deployments. Cable broadband operators are well situated to capitalize on these emerging markets.

Abbreviations

AC	alternating current
CBRS	Citizens Broadband Radio Service
CEC	Canadian Electrical Code
CEO	Chief Executive Officer
CSA	Canadian Standards Association
DC	direct current
EMI	electromagnetic interference
FCC	Federal Communications Commission
FTTx	fiber-to-the-home
HFC	hybrid fiber-coax
LLD	low-latency DOCSIS®
MSO	multiple system operator
MVNO	Mobile Virtual Network Operator
NCTA	The Internet & Television Association
NEC	National Electrical Code
NESC	National Electric Safety Code
NRTL	Nationally Recognized Testing Laboratories
RF	radio frequency
RLP	remote line power
SCTE	Society of Cable Telecommunications Engineers
SKU	stock keeping unit
TCO	total cost of ownership
UL	Underwriters Laboratories
UV	ultraviolet

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