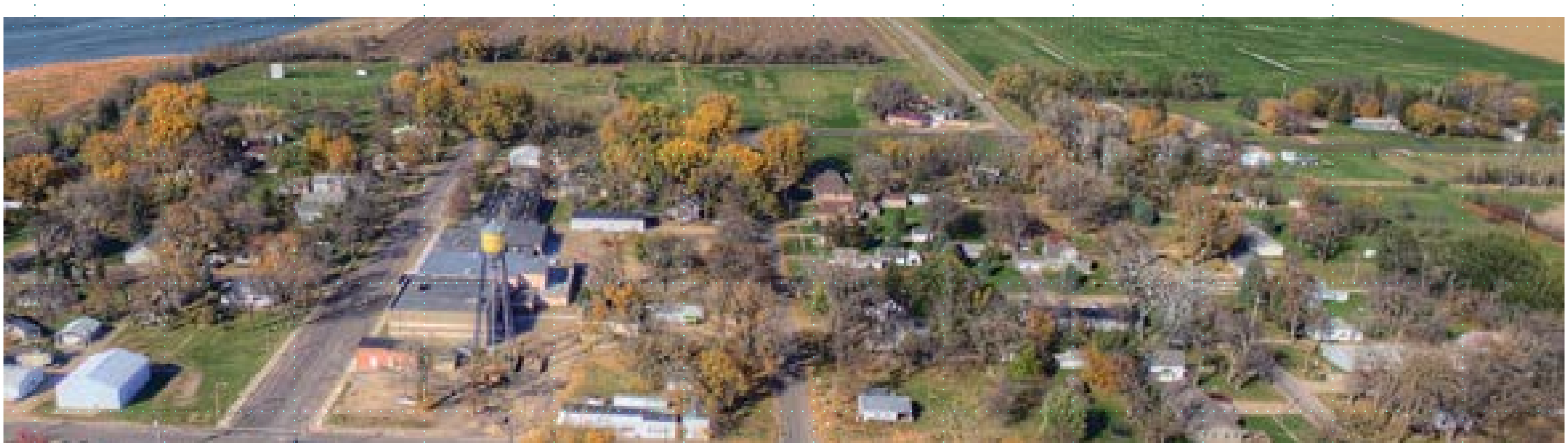
C Spire

Rural Broadband Consortium

Broadband Technology Options

A Paper by the C Spire Rural Broadband Consortium



EXECUTIVE SUMMARY

Technologies selected for rural broadband Internet services are a function of market and business needs. There are multiple technologies possible for each component in the network. As a result, technologies must be viewed as tools in the toolkit - no one size fits all. This paper focuses on the properties of the rural environment and known broadband technology options supporting access, core, backhaul, and operational support systems/business support systems (OSS/BSS) deployment in rural environments.

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2 INTRODUCTION

As bandwidth demand from services and multiple devices increases, the baseline definition of broadband has also increased. In 2015, the Federal Communications Commission (FCC) defined the minimum broadband Internet service level in the United States as 25 Mbps downlink and 3 Mbps uplink (25/3 Mbps). Internet service in many areas routinely exceed this basic level, even providing Gbps service. However, even the basic 25/3 Mbps service level is traditionally less obtainable in rural communities than in urban areas due to factors such as the technical challenges associated with delivering broadband to widely varying categories of rural areas. These technical challenges require a variety of solutions, which are discussed generally in this paper. The Appendices contain more specific technical details.

2.1 PROPERTIES OF THE RURAL ENVIRONMENT

The term rural can be difficult to define due to the numerous environmental locations it can be found in. One quickly finds that rural households are found globally in all sorts of regions and topographies, not just in one specific environment. The most commonly observed characteristic of a rural location is the population density in the area of interest. A rural environment can include various terrain types and clutter profiles, including isolated farmhouses on flat farmland, small clustered towns, and houses scattered across large, hilly multi-acre plots. This variety in rural environments creates a challenge to the standardization of a broadband design, whether wired or wireless. To serve these various rural environments, an entity must have multiple tools and approaches to serve rural consumers.

2.2 ESTABLISHING A BROADBAND NETWORK

The formation of any broadband service must include the following foundational components: Market Selection, Network Design, Network Deployment, Customer Acquisition and Setup, and finally Operations and Maintenance. When establishing a broadband service, rural or otherwise, these components must be thought through and formed to support the desired network. First, an entity must select a market to serve based on factors such as return on investment (ROI) and potential customer locations. The next component is network design, which is the design of the access network and backhaul that will cover the determined market with the desired use case scenarios and required service level agreements. Next, the network design must be constructed and turned up (i.e. deployed) for the market subscribers' access. Once the network deployment has begun, customers must be acquired and customer equipment installed, provisioned, and activated. Finally, operation and maintenance of the network must be prepared and supported through the lifetime of the broadband service.

2.3 SYSTEM COMPONENTS

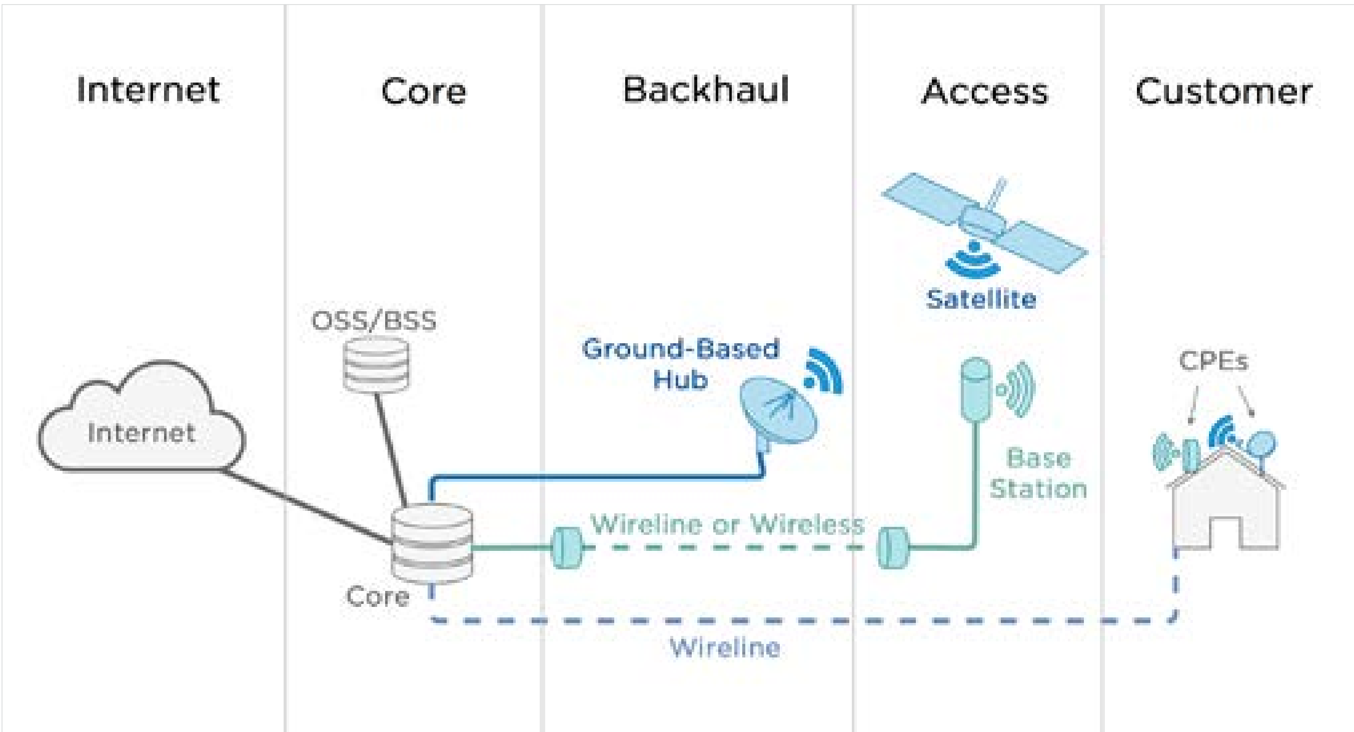

Figure 1: ISP architecture

Figure 1 illustrates the key components of how a customer obtains Internet access through wireless or wireline technologies. Via fixed wireless, Access is between a base station (or an access point (AP)[1]) equipped on a structure (tower, pole, or building) or a satellite and Customer Premise Equipment (CPE[2]) placed on the customer's home. The base station relays Internet through a backhaul link (either wireline or wireless) from the core of an Internet Service Provider (ISP), whereas with wireline access, there is a link directly from the customer's home to an ISP core. The Core manages the Internet traffic, supported by OSS/BSS functions that manage network resources and customer interactions (billing, service assurance, etc.).

[1] Base station and access point are used here to mean essentially the same thing. Base station is mostly used in the cellular, mobility world, while APs are often used to describe small low-powered base stations.

[2] The CPE could be a satellite dish, a wireless device, or even an ONT

3 TECHNOLOGY OPTIONS: ACCESS

There are many ways to provide Internet access, including wired and fixed and mobile wireless technologies. Access technologies capable of delivering broadband speeds to customer locations will be described in this section.

3.1 WIRELINE

3.1.1 Fiber

Fiber is a well-known broadband Internet technology capable of delivering Terabit-per-second speeds with the right electronics. Fiber works by sending binary data via light pulses through strands of glass. One pulse means one and no pulse means zero. Each strand of glass is about one-tenth the diameter of a human hair. The fiber cable is made up of an outer jacket, a strengthening member, coating, cladding and the core. A transmitter sends data via light pulses into the fiber while at the other end a receiver takes that light and translates it back into the data that was sent. Light can travel around 60 miles before it needs to be regenerated. Amplifiers are used to boost the light if the signal becomes degraded.

Fiber has around a 25-year life expectancy and can handle speeds far greater than the Gigabit per second services commonly provided today. The fiber in the ground today will be able to deliver the higher bandwidth speeds tomorrow with new electronics. Fiber uses light, not electricity, and is not hindered by electrical interference that can be present on copper cables traditionally used in Digital Subscriber Line (DSL) and on coaxial cable used in cable Internet services.

Residential fiber service delivery is called FTTX. For service providers the "X" is where the fiber ends.

- FTTH is fiber to the home - fiber is built all the way to the side of the house
- FTTP is fiber to the premise - fiber is built all the way to the side of the premise
- FTTC is fiber to the curb - fiber is built to a junction box at the curb and then service is delivered over copper from the curb to the home or business
- FTTN is fiber to the neighborhood - fiber is built to a junction box in the neighborhood and then delivered to homes via copper cable

Fiber tends to be scarce in rural environments, as telcos typically concentrate on connecting large cities and building long-haul routes to connect those cities and cellular towers along those routes. One way to bring broadband to underserved rural areas is to find a way to patch into some of the unused fiber on nearby long-haul routes and use more fiber or another appropriate access scheme to serve an area.

3.1.2 Copper

Twisted pair copper wiring is widely installed throughout the United States to almost every building and is used for plain old telephone service (POTS) as well as Internet access. Although copper is mostly an aging system which affects its ability to offer broadband speeds, it is still useful in a variety of circumstances. DSL is one of the most common Internet Service offering in rural environments, however, peak achievable data rates rapidly fall as the twisted pair length increases, with line lengths of 1 -2 km being the maximum viable distance to achieve required peak rates of 10-25 Mbps or more downstream. As a result, a very high number of DSL distribution points are needed to serve lower density areas, as is building fiber deep into the network in order to feed these distribution points. Copper can be used for very high speed broadband Internet with technologies like G.fast over relatively short distances, which could work with Multi-Tenant or Multi Dwelling Units where the premise may already be wired with modern Ethernet cable. Copper can be used in some areas to lower deployment construction costs by utilizing FTTN, however the farther from the junction box (or provider's central office) the home is, the weaker the signal becomes (and the slower the Internet speed). The ideal use of copper for rural broadband is in a small-town environment with clustered buildings.

Coaxial cable is often used by cable companies to achieve higher data rates than twisted pair copper offerings by using techniques such as DOCSIS 3.0, which can achieve 1.2 Gbps downlink. However, like twisted pair, coax plants are also aging, and while better techniques increase capacity on those systems, the industry is generally moving towards fiber as the preferred wireline access technology.

3.2 Wireless

Wireless communications are sent using various communications/signals protocols on different frequency bands with specific properties related to both the spectrum/frequency used as well as the capacity of the band used. As a result, the wireless technology used must be tied to the properties of the rural environment described in Section 2.1. While frequency is the primary driver in matching wireless systems to environment, deployment architecture, capacity/service needs, and advanced technology options likewise play a part. As with any shared-access resource, providers must plan for growth in terms of number of users, total traffic, and potential interference (e.g. for unlicensed bands).

3.2.1 Spectrum Properties

As frequencies get higher, obstruction penetration reduces as does range. For example, frequencies below 1 GHz have excellent inbuilding penetration and can serve non line of sight (NLOS) operations beyond 5 miles fairly easily. Millimeter waves[3] behave more like light beams—meaning that higher-frequency transmissions travel in a narrow, straight line and require direct LOS, with few or no physical obstructions. Many devices can use high frequency spectrum in close proximity without interfering with each other due to the narrow beams. While microwave links using millimeter waves can have a range of miles in environments with no obstructions, when used for broadband access, millimeter wave frequencies have a relatively short range (typically a few hundred meters, particularly for mobility). At these short distances, millimeter wave bands are less susceptible to atmospheric changes (e.g. rain fade at 28 GHz).

Capacity depends primarily on the size of the band and the channel bandwidths allocated within the band, but generally, sub-1 GHz bands have smaller allocations, while newer, higher frequency bands are either being re-farmed for or are being allocated with larger channel sizes, enabling higher throughput and more capacity overall. Millimeter wave bands have much higher capacity than any sub-6 GHz bands as their allocations run towards GHz rather than MHz. More capacity means networks can grow and scale more effectively. Because rural environments tend to need more coverage than capacity, lower frequency bands can be just as useful for rural broadband under certain conditions. Figure 2 gives a rough comparison of range, LOS, and capacity of various frequency bands from less than 1 GHz to millimeter wave. More details on more bands are found in Appendix 1.

[3] Strictly speaking, millimeter waves are frequencies from 30 GHz to 300 GHz, but 24 and 28 GHz are often called millimeter wave bands because their spectral properties and uses are similar to 30 GHz

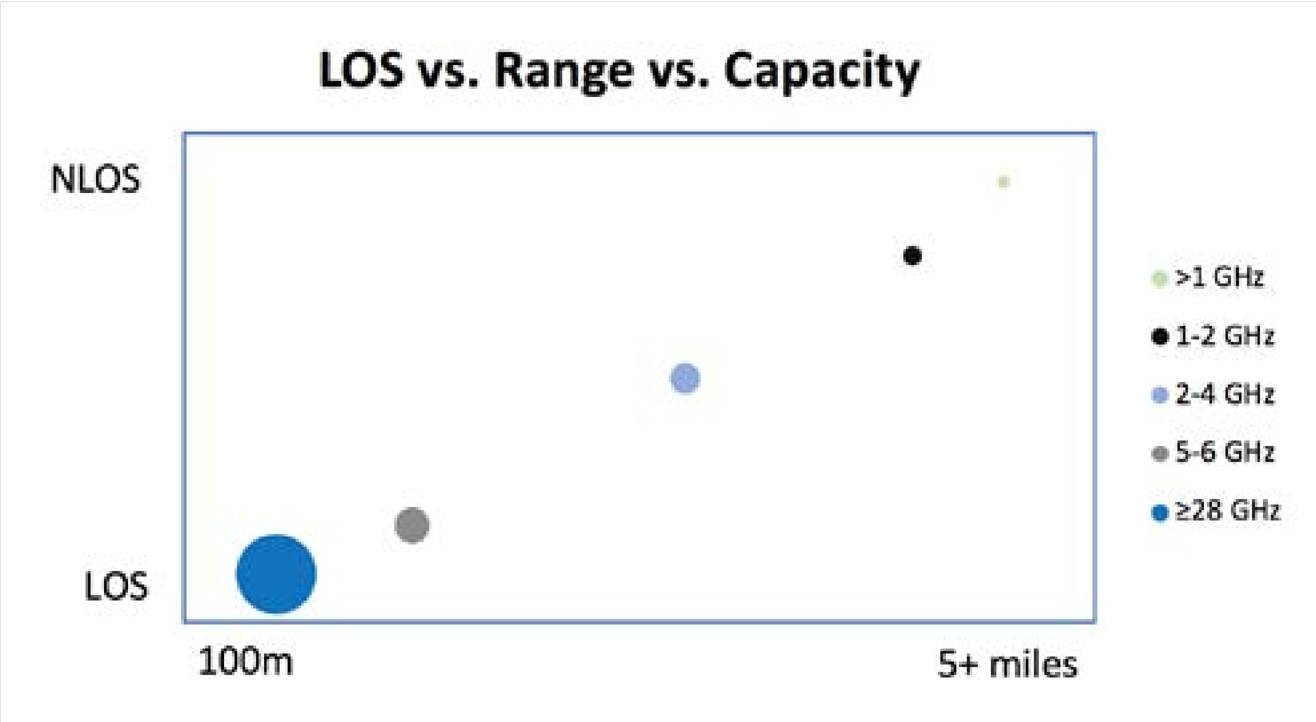

Figure 2: Spectrum Properties

Spectrum properties tend to drive deployment options, with LOS, short-range spectrum appropriate for micro-cellular deployments and sub 6 GHz spectrum practical for macro-site deployments depending on morphology (trees, hills, etc.). While low-frequency (sub 1 GHz) signals such as television white spaces (TVWS) and low-band cellular frequencies have the best ability to penetrate foliage and terrain, they cannot (on their own) deliver data rates comparable to millimeter wave. However, millimeter wave requires close proximity and/or a direct line of sight. Mid-band frequencies, such as the higher-frequency cellular bands between 1.7 and 2.7 GHz, the unlicensed 2.4 and 5 GHz bands, and the future 3.5 GHz CBRS band complement both low-band and high-band spectrum. Using multiple frequency bands simultaneously could allow an ISP to leverage the same tower assets to deliver higher throughputs in higher density areas while extending coverage to lower population density areas where the ability to penetrate foliage and terrain is more important.

While cellular (mobility) has focused primarily on licensed spectrum, the fixed market has focused primarily on unlicensed spectrum. Base stations operating in unlicensed spectrum are required to transmit at lower power than typical licensed-band equipment, thus reducing the range of the service. In addition, unlicensed bands operate in an uncoordinated manner, which can result in interference as a band gets more crowded, reducing overall capacity and user experience. This is much more of an issue in the 2.4 and 5GHz bands where spectrum is relatively scarce, unlike in millimeter wave bands. In rural areas, however, where Internet and wireless use is relatively scarce, sub-6 GHz unlicensed bands are a viable option and are regularly used for fixed wireless access.

3.2.2 Terrestrial Spectrum Options

There is often a dependency between the choice of spectrum band and the technologies available to deploy in that band, due to the impacts of standards bodies, regulation, and vendor implementations. A brief overview of the main options is summarized in this section with more details found in Appendix 1. For fixed wireless access, the possible bands of interest are divided into two categories, sub-6 GHz and millimeter wave. Each of these frequency ranges have licensed bands, unlicensed bands, and lightly licensed bands.

3.2.2.1 Sub 6 GHz

Many bands are available for licensed mobility use in the United States; today, broadband access is often provided in these bands via LTE technology. These bands can be referred to by either the FCC or 3GPP designations and range from below 1 GHz to nearly 3 GHz today, with frequencies in the 3-4 GHz range under consideration by the FCC for licensed mobility in the future, including the C-Band which is currently used by satellite. Some of the more common broadband mobility bands include PCS (1900 MHz), AWS (1700/2100 MHz), and BRS (2500 MHz).

Unlicensed bands such as the 2.4 and 5 GHz bands, are used for Wi-Fi and point-to-multipoint wireless networks deployed by unlicensed wireless Internet service providers (WISP) and others. Unlicensed spectrum can offer broadband connection speeds without the complexity of acquiring exclusive-use licenses and operating carrier-grade 4G or 5G mobile technologies.

TVWS is another unlicensed spectrum band that offers better foliage and terrain penetration characteristics than other unlicensed bands. TV white spaces technologies use channels in the VHF and UHF spectrum bands that have not been assigned to television broadcasters. TV white spaces radios must access a database sanctioned by the FCC (Federal Communications Commission) to ensure that no access point interferes with TV broadcast reception. In urban areas, less TV white space spectrum is available because of the higher number of television broadcast station assignments. In rural areas, TV white space spectrum is more plentiful.

The lightly licensed sub-6 GHz band, 3.65-3.7 GHz, is being reallocated by the FCC. Many Wireless ISPs currently operate in this segment of the 3.5 GHz band under legacy FCC Part 90 rules. However, the FCC is revising the rules governing this band and allocating additional spectrum, operating under the new Citizen Broadband Radio System (CBRS) rules (Part 96), which will have both licensed and unlicensed operations. Both vendor-proprietary implementations, as well as LTE systems, are expected to be available for operation in the CBRS band.

3.2.2.2 Millimeter wave

Millimeter wave bands can be unlicensed (60 GHz), lightly licensed (70/80, and 90 GHz E band), or licensed (24 GHz, 28 GHz, and 39 GHz). Until recently, these bands focused on point-to-point or point-to-multipoint service, particularly backhaul links, but new high-frequency millimeter wave technologies are poised to expand the usability of this spectrum for mobility out to 100 GHz.

3.2.3 Air interface technologies

There are a variety of air interface technologies that are or can be used for broadband access, including standards-based technologies 4G/LTE, 5G/NR, and 802.11, as well as vendor-proprietary technologies. Technical details for standards-based technologies are found in Appendix 2.

Long Term Evolution (LTE) technology is standardized by the 3rd Generation Partnership Project (3GPP) standards body [d] and is supported by a worldwide eco-system of chipsets and vendors. While LTE is targeted for mobile system operation, it can be deployed as a fixed wireless access technology as well.

5G/New Radio (NR) radio technology is also standardized by 3GPP and is also intended for mobility. NR focuses on three use cases: enhanced mobile broadband (eMBB), ultra-reliable low latency communications (URLLC), and massive machine type communications (mMTC). While the addition of millimeter wave into the NR bands gets the most industry attention, NR can also be used in sub-6 GHz bands.

The Institute of Electrical and Electronics Engineers' (IEEE) 802.11 family of standards makes up the well-known Wi-Fi technologies, which commonly work in the 2.4 and 5 GHz unlicensed bands (e.g. 802.11a/b/g/n/ac) along with revisions that make use of TVWS and 60 GHz (e.g. Wi-Gig) bands (802.11af and 802.11ad respectively). Another IEEE standard, 802.16, has also been used for fixed and mobile access.

Proprietary air interface technologies can either be techniques wholly developed by a particular company or can be based on a standard such as 802.11 with additional proprietary techniques that improve performance in some way.

3.2.4 Satellite

Satellite, like DSL, is one of the most ubiquitously available rural internet options, but all too often does not provide true broadband service. Fixed satellite services typically operate in the C-Band, the Ku-band, or the Ka-band (3.7-4.2/5.925-6.425 MHz, 12-18 GHz and 26.5-40 GHz respectively). Operation in the higher bands limits service to LOS operation where reliability can be a problem as those bands are susceptible to rain fade. Latency is problematic for real-time services and capacity could also become a limiting factor for large-scale rural broadband adoption even with modern high-capacity satellites. There have been several proposals to add large constellations of low-earth orbit (LEO) satellites to provide greater capacity, higher throughput, and lower latency services. It remains to be seen if this can be done cost effectively.

3.3 Deployment Considerations

Certain wireline technologies such as FTTH have extremely high capacity and future scalability. The physical plant must be built all the way to each individual customer, while scale (capacity) is achieved by improved electronics at a central point. In contrast, scale for fixed wireless access is primarily driven by the coverage and capacity achieved at each tower or structure (and the backhaul available to the structure). Wireless technologies typically do not scale to 100% customer penetration rates in dense environments, though new ways of implementing millimeter wave technologies may change that in the future. In isolated rural environments, however, wireless technologies can have an advantage over wireline technologies by enabling broadband speeds over longer distances with less equipment. Eventually, the maximum range of the radio link becomes a limiting factor, and there will be insufficient households to consume all the capacity of the base station. As higher frequency bands tend to have high capacity (because more bandwidth is available) but lower range (poorer propagation characteristics) the choice of spectrum can be tuned to the target deployments/demographics. Very generally, lower frequency bands will suit lower household densities with possible compromises on capacity/throughput, and higher bands will suit higher densities and higher throughputs.

4 TECHNOLOGY OPTIONS: CORE

Technology core choices are based on many factors that should be defined prior to selecting a core option. One reason for defining the features and outcomes of potential core options is to understand the inherent advantages and disadvantages of each core technology flavor. For example, deployments may be small or large scale, utilize a third-party core as a service solution, or take advantage of a full-service ISP owned product. As a result, the desired deployment outcome will drive technology core selection.

Several functions are typically implemented by the core network to support the radio access network (RAN). These include the following:

- Authentication, authorization and accounting (AAA) type functions to authenticate and authorize the customer, enable and track usage of the network, and control network policies such as QoS
- Routing and gateway functions to enforce AAA requirements

Some additional features are embedded, even if not required for fixed access, for technologies that are based on mobile network architectures such as providing a mobility anchor point/gateway for data streams and managing power saving features for customer equipment. Additionally, in alignment with the overall evolution of telecoms networks, there are generic requirements such as control and user plane separation for supporting virtualization/cloud network functions and disaggregation of functionality to increase flexibility, agility, and scalability. This section outlines basic core configurations and discusses service options. More details on core configurations are found in Appendix 2.

4.1 MOBILITY

4.1.1 LTE Core

For LTE access, the core network is termed "evolved packet core" (EPC) and is illustrated in Figure 3. The RAN is connected to the EPC via the S1-U and S1-MME interfaces.

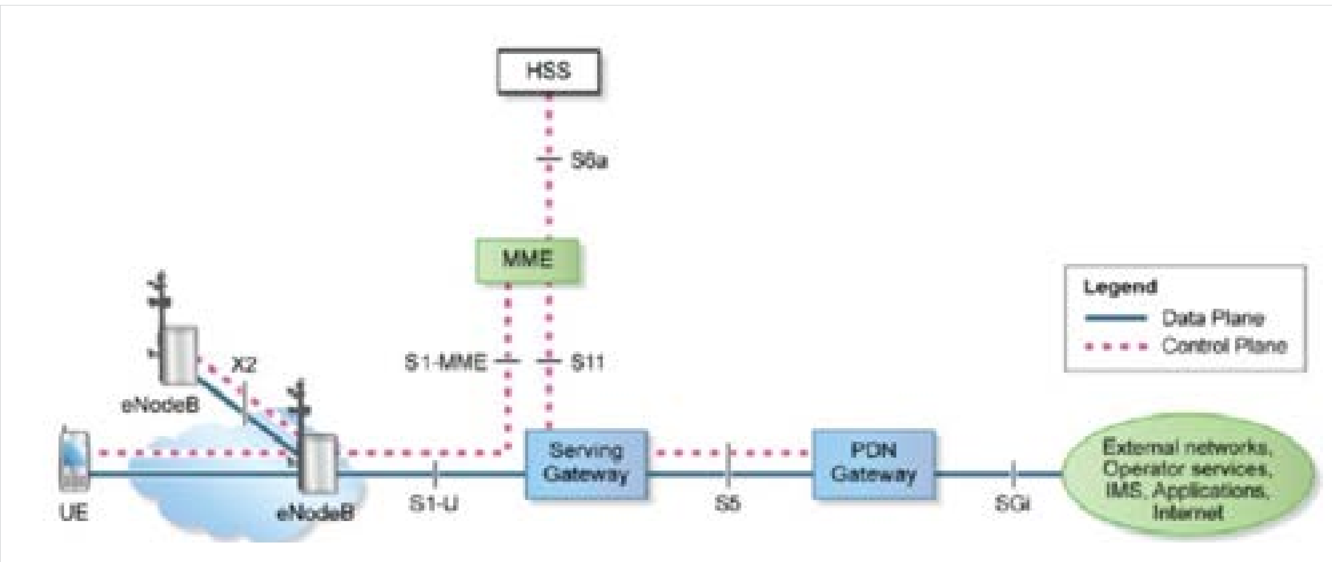

Figure 3: LTE EPC

The key functions implemented in the EPC are

- Mobility and session control management
- CPE session connectivity to packet data networks
- Policy enforcement and charging
- Routing and forwarding of user packets

Some common EPC functions, namely mobility and roaming, are not typically required for fixed access purposes. However, other EPC functions map to needed AAA control and enforcement functions.

It should be noted that an LTE/EPC network uses Layer 3 Internet Protocol (IP) addressing and protocols for access and core and is a routed network. Wireline networks typically are based on layer 2/Ethernet protocols in the access layer, and then transition to IP at the gateway (e.g. Broadband Network Gateway) where AAA/service enforcement functions are implemented.

4.1.2 5G Core

The 5G core is an evolution of the EPC, with enhancements to allow improved scalability and flexibility, support of network slicing, and API exposure to third party networks.

The 5G core uses a Service Based Architecture (SBA), which is based on loosely coupled and autonomous Network Functions (NF) that interconnect using a single API calling interface and provide the authorized services. The Network Repository Function (NRF) allows every NF to register itself and to discover the services offered by other NFs. These interfaces are standardized and open.

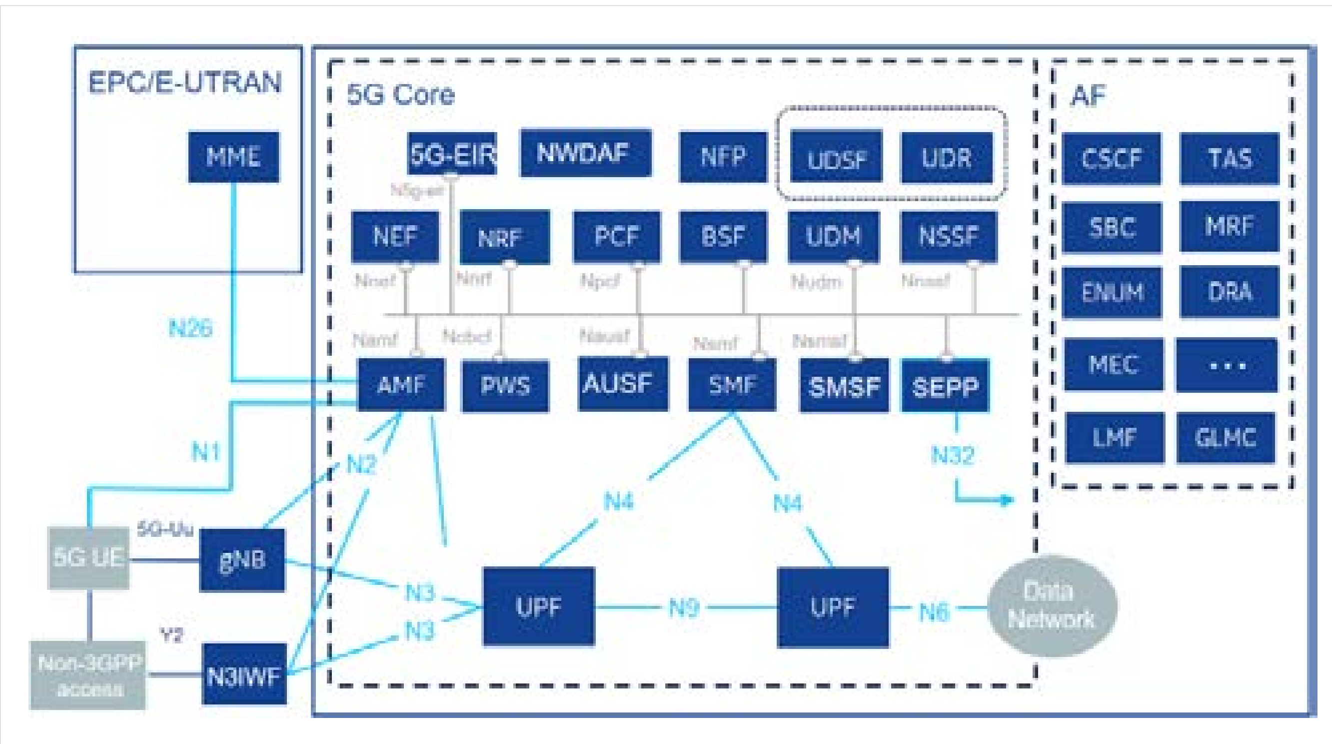

Figure 4: 5GC architecture including interfaces

While a detailed description of the 5G core (see Figure 4) is beyond the scope of this paper, some of the key functions are the following:

- UPF – User plane function, analogous to the user plane functions of the SGW and PGW in EPC
- SMF – Session management function, analogous to the control plane functions of the SGW and PGW in EPC
- AMF – Access and Mobility function – analogous to the MME in EPC
- UDM – User Data Management function – analogous to HSS
- PCF – Policy and Charging Function – analogous to Policy and Charging Rules Function (PCRF)

4.2 Wireline and Fixed Wireless Core

Wireline and fixed wireless core (see Figure 5) architectures typically align with Broadband Network Forum [c] architectures, and often connect to the customer home gateway via a layer 2 aggregation network and wireline access technology such as Passive Optical Network, DSL network, or similar technology. A Broadband Network Gateway then implements broadband services and routes user packets, with AAA and PCRF providing subscriber management capabilities and policy control. Network access and subscriber authentication often leverage protocols such as 802.1x and Dynamic Host Configuration Protocol (DHCP) option 82 along with digital certificates.
In comparison to a mobility core, the AAA is analogous to Home Subscriber Service (HSS) functions, and the Broadband Network Gateway (BNG) is analogous to the S/PGW functions.

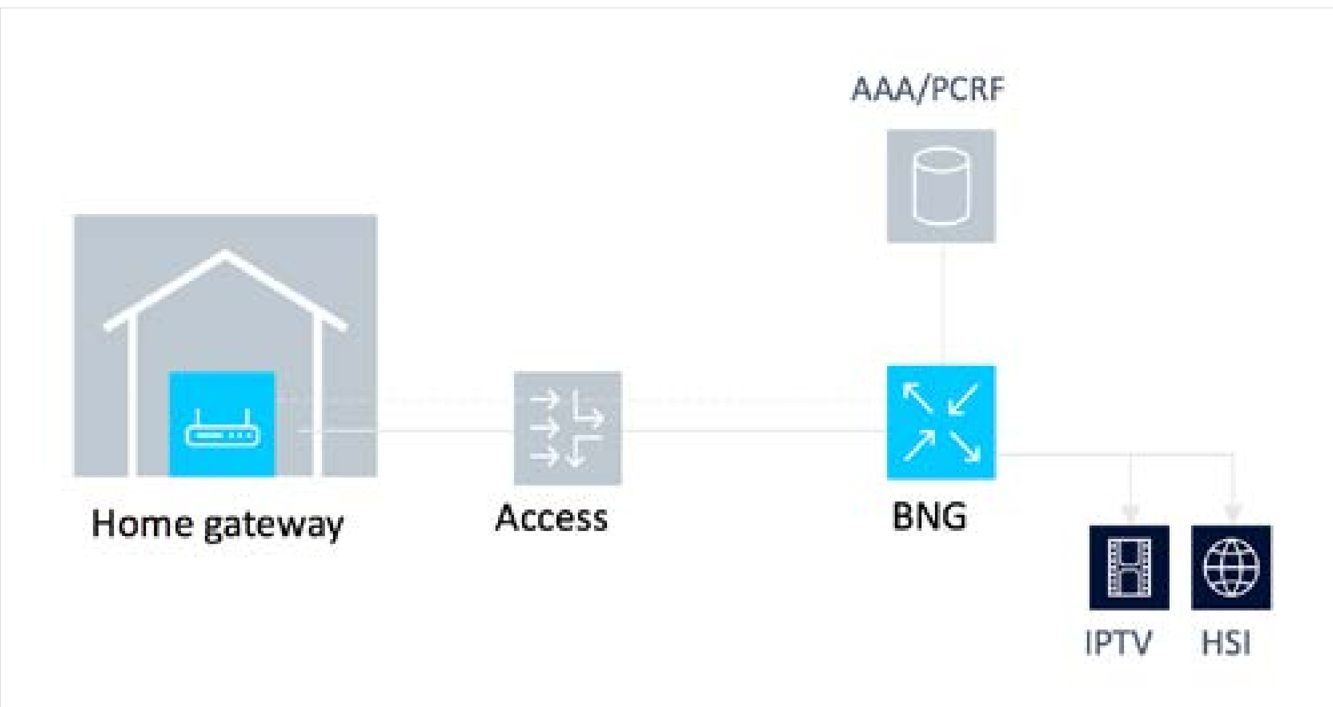

Figure 5: Basic Wireline Core

4.3 Core service options (EPC in a Box and Cloud Solutions)

One example of a flexible core technology is Evolved Packet Core (EPC) in a box solutions that enable the deployment of networks for a variety of use cases including LTE networks for rural customer populations, private LTE for small and medium businesses, Internet of Things (IoT), and fixed wireless broadband services. With flexible core technology options, ISPs gain the ability to increase access to broadband services in rural regions with low latency EPC solutions ranging from cloud-based standalone networks to customer centered network edge solutions. In other words, EPC-in-a-box solutions allow customers to choose to deploy core technology as a full-service or self-service option. Benefits of cloud-based standalone networks include enabling automated network monitoring, management, and optimization resulting in the ability to deploy networks quickly in a plug-and-play self-service atmosphere.

The inherent scalability of EPC-in-a-box solutions will also help future proof for prospective growth. In comparison, a full-service EPC-in-a-box solution will incorporate LTE network elements such as MME, SGW, PGW, ePDG, HSS, and PCRF in addition to functions such as roaming, load balancing, Wi-Fi or WLAN offload, and online charging system (OCS). Therefore, configuration options must be evaluated and defined for any flavor of EPC-in-a-box solution selected for each deployment since design possibilities range from a full-service solution with all LTE network elements supported (the easiest solution for customers) to hybrid configurations that combine a select number of network elements in a boxed solution with existing ISP network elements. It is reasonable to expect that EPC-in-a-box or cloud-based solutions will move core network elements from dedicated hardware in the network topology to cloud-based environments using general purpose or off-the-shelf servers.

It is important to understand that effective scalable EPC-in-a-box solutions are standards compliant and have the elasticity to support easy, friction-free, small- and large-scale network deployments. The question of how to access and deploy core technologies becomes one of choosing scalability and ease of deployment for customer and ISP to meet customer needs for specific broadband service types and levels of service.

5 TECHNOLOGY OPTIONS: BACKHAUL

Traditionally, the term backhaul is used to refer to the transport technology between the access network and the core network. With technology evolutions driven by 3GPP standards such as baseband processing centralization, split of real time and non-real time processing, and edge clouds, the concepts of mid-haul and fronthaul transport may also be part of the access transport architecture. More information on these mid-haul and fronthau technologies is found in Appendix 2.

A typical/classical transport network view is shown in Figure 6. Point-to-point connections at the radio sites and core elements use Ethernet interfaces, often with Gigabit Ethernet (GigE) at the base station site. The two main challenges are physical cell site access and several stages of aggregation as traffic is backhauled between the radio site and core. Fiber is the preferred media but microwave transmission and satellite backhaul can be used. Passive optical networking (PON) is also an option in denser neighborhoods clusters where fixed broadband infrastructure is affordable. While satellite backhaul can be much easier to obtain and use in a rural area than wired backhaul, as with using satellite for access, the base station services must be latency tolerant with relatively low capacity needs.

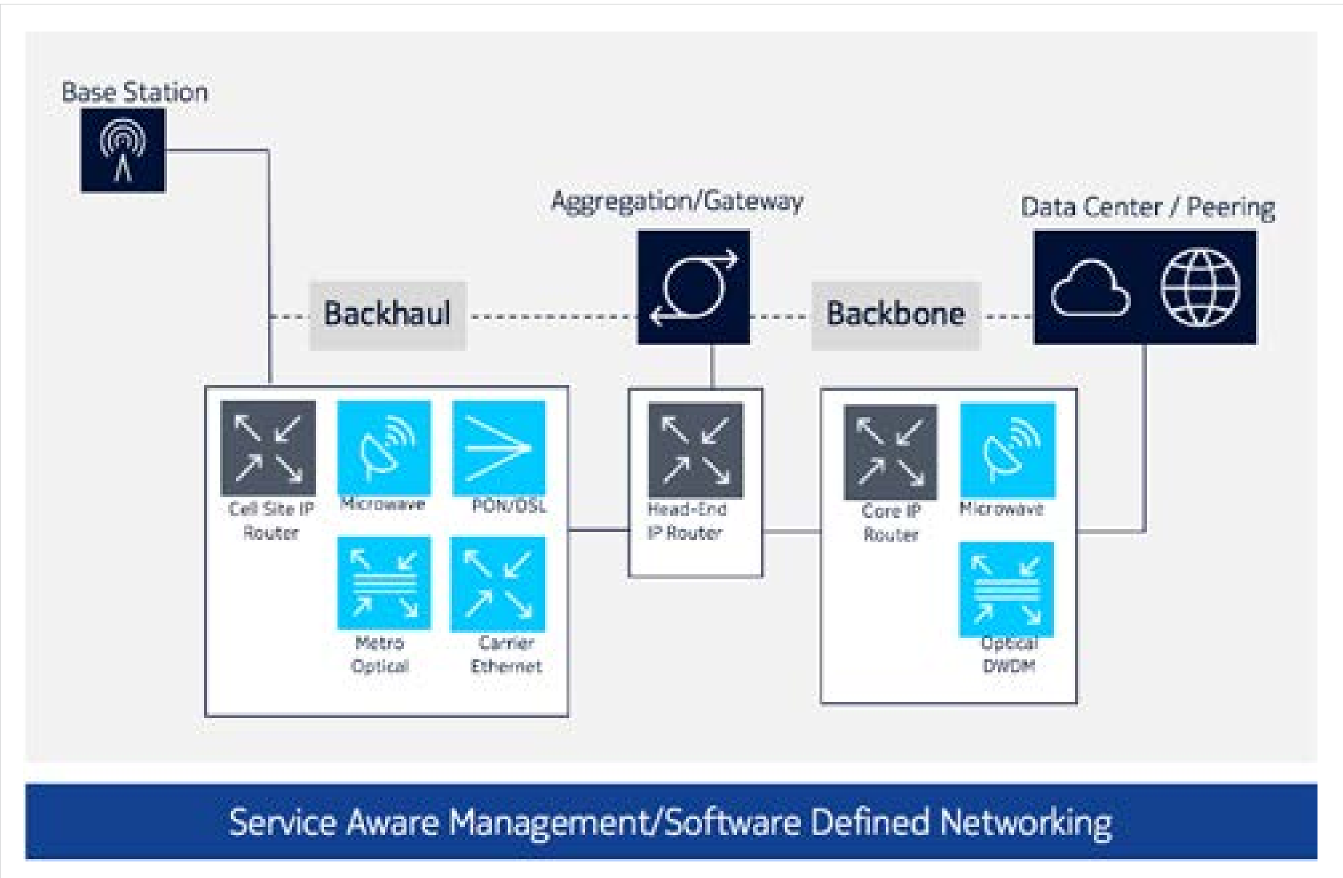

Figure 6: Transport network view

Note that the "cloudification" of networks with Software defined wide area network (Carrier SDN) will enhance the network over time, enabling more agility, scalability, and flexibility in provisioning connectivity, and defining service level agreements (SLAs).

6 TECHNOLOGY OPTIONS: OSS/BSS

Traditionally, the term backhaul is used to refer to the transport technology between the access network and the core network. With technology evolutions driven by 3GPP standards such as baseband processing centralization, split of real time and non-real time processing, and edge clouds, the concepts of mid-haul and fronthaul transport may also be part of the access transport architecture. More information on these mid-haul and fronthaul is found in Appendix 2.

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6.1 Overview

Operational support systems (OSS) enable management of the various network elements involved in supporting fixed wireless access service. This includes configuration of network elements, monitoring of status and faults, maintenance tasks such as software updates, and network performance monitoring/auditing. Standardized protocols are defined for some of these functions, but element management systems are usually configured with customized parameters or are vendor specific for more complex functions and parameters.

In many cases a layered architecture is used to create an aggregated view across the many network elements sourced from multiple vendors. A layered architecture considers the lower layers to be vendor aware, adapting to vendor specific (possibly proprietary) interfaces, and providing services to upper layers in a vendor agnostic way. The upper layers process and abstract the network management and topology in a vendor agnostic way, simplifying the task of the network administrator.

The expectation is that the OSS will go beyond managing network resources and also intelligently capture and process relevant network insights. For example, a consolidated view of the entire network would be available. The availability of real time performance and fault management, automated configuration and access to tools needed to improve network performance and subscriber experience comprise the essential functionality expected for network management.

Tools in an OSS solution should include:

- Monitoring - centralized network monitoring for all network technologies from element management to operational management. Monitoring should support user-specific workflows. Granular filtering and correlation of alarms for fast root cause identification must also be available.
- Performance Management - helps improve service quality and optimize network performance through real-time performance management and monitoring. Solution should be scalable to meet the needs of any size network from small local networks to large global networks.
- Configuration Tools - offer comprehensive functionality for configuration management with common processes and data storage in multi-technology radio and core networks. Automated network planning and network consistency checking actions are carried out with easy-to-use tools. Configuration management enables flexible and automatic workflows for fast network roll-out and expansion.
- Administrator tools - manage network element hardware and software from one central location. Offer backup and restore functionality across network domains.
- Network Overview - provides a single, simplified, and integrated view of all operational data from network elements. By cutting through the complexity, Network Overview helps operations personnel quickly see the network status or ‘big picture’ at a given point in time.

6.2 OSS/BSS Technology Agnostic Elements

Regardless of the technology selected, OSS/BSS must also be addressed in order to create a commercial solution. For example, customer facing Business Support Systems (BSS) activities including order management, customer relationship management (CRM), billing, and product offerings must be defined. Additionally, OSS (operational support systems) activities include support for service/security assurance, inventory, design, and provisioning/activation of customer services. Ideally, OSS/BSS should be approached as an integrated system to support customer needs proactively and position 3rd parties to provide various technology options as a service.

An OSS/BSS solution must support various forms of customer self-service orders. Self-service orders may range from allowing a customer to select a premium full-service solution that includes field support for network design and technology solution component deployment with self-care for ongoing support and service needs to presenting customers with specific cloud-based or EPC-in-a-box self-care solutions that are presented based on service location, technology availability, and other factors determined in advance by the service provider. Regardless of the technology involved, decision points will occur throughout the customer journey to address technology requirements and OSS/BSS needs for each customer.

Decisions must also be made about how authentication, authorization, and accounting (AAA) for subscribers on the network will be handled. For example, will AAA functions be handled as part of the technology service in the cloud-based or EPC-in-a-box solution? Or, will AAA functions be addressed by a full-service provider? Is it possible to automate AAA functionality to identify each subscriber, to authorize subscriber access to different service levels or restrict usage to specific locations, times of day, or other factors? Is real-time analysis of subscriber usage available regardless of service selected or is real-time analysis restricted dependent upon technology and/or service plan selected?

New ways of performing services must be considered such as having a pool of "as a service" workers. In this scenario, the entity providing the technology as a service might utilize an automated field service application to identify workers in close proximity to a self-service technology location and assign jobs. Ideally, OSS/BSS will be fully automated from self-provisioning/activation to self-care/service support to billing.

6.3 Deployment models

There are multiple deployment models possible for fixed wireless networks and each can have implications for the OSS architecture. For example, it is possible to partner with local community resources to scale and accelerate deployments of fixed wireless access. Local partners will not always be highly skilled in the tasks required to configure and manage fixed wireless network deployment. Therefore, a model where configuration and management functions can be hosted by a wholesale service provider and made available to local partners is of high interest. Such a model envisages a plug-and-play style concept for radio equipment installation and power-up with a simple portal, or other mechanism, that enables a local partner to monitor the health and performance of assets and receive alerts to perform simple maintenance tasks. These concepts are illustrated in Figures 7 and 8.

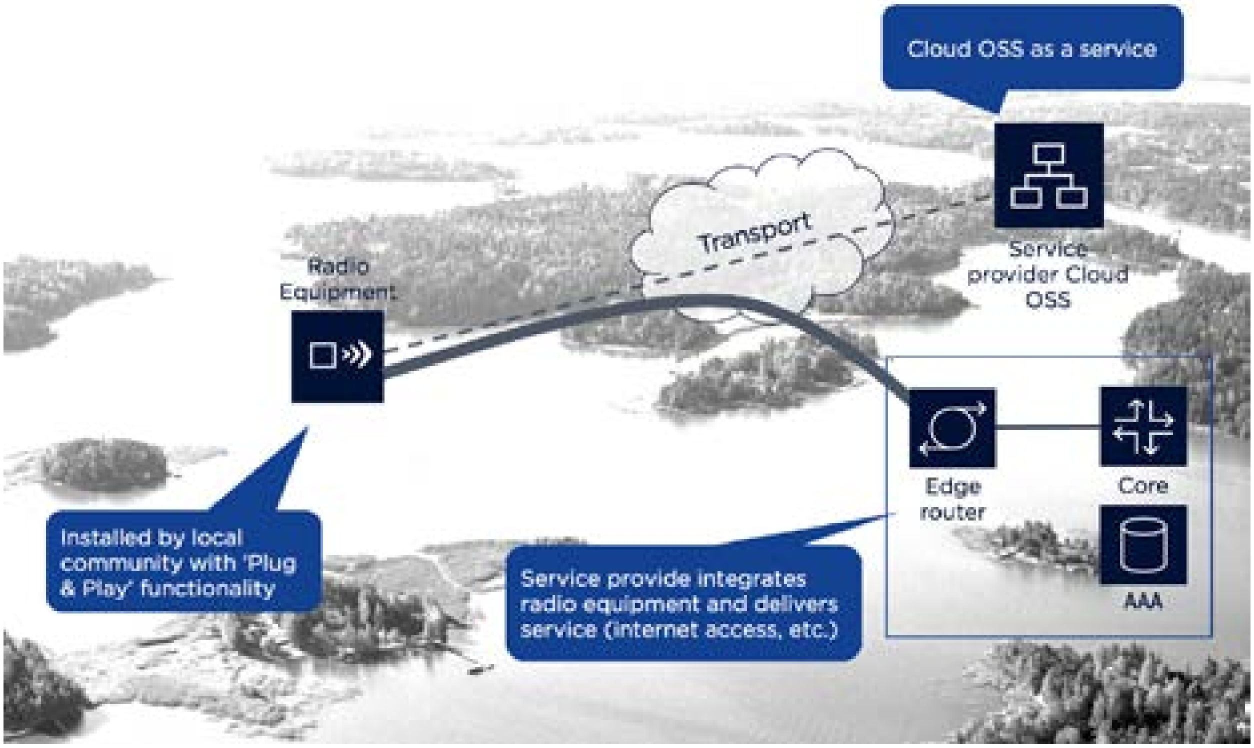

Figure 7: Service provider hosting core network and OSS capabilities to local partner

Figure 8: Self-service capability for local partner

7 RECAP & FUTURE STUDY

As discussed in this paper, there are a wide variety of technologies that can be used to bring broadband to rural communities in each part of the system (access, backhaul, core, and OSS/BSS). Each technology has unique properties, which can guide its use for a certain type of rural environment or deployment. The access network especially has many options to choose from; narrowing the options requires knowledge of the market being served. For example, a small cluster of buildings with few trees can be served by a millimeter wave deployment using 28 GHz NR with fiber backhauled to an 5G-core-in-a-box with OSS/BSS fully managed by a local WISP. Another option for the same environment could consist of using the same access and backhaul solutions with a cloud core managed by a third party, OSS managed by the local WISP, and BSS managed by another party.

The variation in rural environments requires the availability of multiple solutions and combinations of solutions to match both the environment and the business needs of each deployment. While business models are beyond the scope of this paper, technologies that enable various potential business models are discussed. It is important to keep many tools in the rural broadband toolkit and to continue exploring where more tools might be needed. Some tools to follow include LEO satellite deployments, future sub-1 GHz allocations, and 5G.

8 REFERENCES

[a] https://www.fcc.gov/general/types-broadband-connections

[b] "Understanding the Rural Broadband Problem," C Spire Rural Broadband Consortium white paper, July 2019, https://www.cspire.com/resources/docs/rural/ruralbroadband-whitepaper.pdf.

[c] Broadband Forum TR-178, "Multi-service Broadband Network Architecture and Nodal Requirements," Issue: 2, Sept. 2017. https://www.broadband-forum.org/download/TR-178_Issue-2.pdf

[d] https://www.3gpp.org/

[e] https://standards.ieee.org/

9 APPENDIX 1: COMMON US SPECTRUM BANDS

US Band Name	FCC Frequency Range DL/UL MHz)	3GPP Band (B=LTE, n=NR)	Duplexing	Primary Application	Typical channelization
TVWS	54 – 698[4]	N/A	TDD	Unlicensed, fixed (TV)	6 MHz
600 MHz	617-652/663-698	B71, n71	FDD	Licensed, mobility	6 MHz
700 MHz[5]	698-806	B12, B13, B14, B17, n12	FDD	Licensed, mobility	5/6 MHz
SMR[6]	817-824/862-869	B26	FDD	Licensed, mobility	5 MHz
Cellular	824-849/869-894	B5, n5	FDD	Licensed, mobility	5-10 MHz
AWS[7]	1710-1780/2110-2180	B4, B66, n66	FDD	Licensed, mobility	5-20 MHz
PCS	1850-1915/1930-1995	B2, B25, n2, n25	FDD	Licensed, mobility	5-20 MHz
ISM 2.4 GHz	2400-2483.5	N/A	TDD	Unlicensed, fixed	20 MHz
BRS	2496-2690	B41, n41	TDD	Licensed, mobility & fixed	20 MHz
CBRS	3550-3700	B48, B49	TDD	Licensed & Lightly licensed, fixed (other)	TBD
C-Band	3700-3880[8]	N/A	TBD	(satellite)	TBD
U-NII 5 GHz[9]	5150-5850	B46	TDD	Unlicensed, fixed	20-80 MHz
24 GHz	24250-25250	n258[10]	TDD	Licensed, fixed	100 MHz
28 GHz[11]	27500-28350	n261	TDD	Licensed, fixed & mobility	100 MHz
39 GHz	38600-40000	n260[12]	TDD	Licensed, fixed & mobility	100 MHz
60 GHz	57000-64000	N/A	TDD	Unlicensed, fixed	
70/80 GHz	71000-76000/81000-86000	N/A	FDD	Lightly, licensed, fixed	2GHz

[4] Excluding certain TV channels, and only if the remaining channels do not have a primary user
[5] LTE/NR bands are subsets of the FCC 700 MHz allocation
[6] SMR frequency range shown is only the non-BILT/Public Safety (not inclusive of exception areas – international borders and in the southeastern US); Band 26 includes both SMR and Cellular bands – 817-849/862-894 MHz
[7] Frequency range for AWS includes the contiguous AWS1 and AWS3 (paired) allocation; B4 only includes AWS1; B66/n66 includes AWS4 downlink (1710-1780/2110-2200 MHz)
[8] TBD how much C-Band spectrum will be released for mobile and fixed (land-based) operations
[9] U-NII band subdivided into different parts (U-NII-1, etc.), some of which are not allocated for unlicensed use
[10] Frequency range for n258 is 24200-27500 MHz
[11] 28 GHz A1 Block (27.5-28.35 GHz) is for flexible use (i.e. mobility). The LMDS 28 GHz band includes A2 and A3 Blocks at 29.1-29.25 GHz and 31.075 31.225 GHz respectively and B Blocks at 31-31.75 GHz and 31.225-31.3 GHz and is used for fixed links.
[12] Frequency range for n260 includes the US Upper 37 GHz band (37000-40000 MHz)[13] 28 GHz A1 block (27.5-28.35 GHz) is for (flexible use). The LMDS 28 GHz band includes A2 and A3 Blocks respectively at 29.1-29.25 GHz and 31.075-31.225 GHz and B Blocks at 31-31.75 GHz and 31.225-31.3 GHz and is used for fixed links.

10 APPENDIX 2: TECHNOLOGY DETAILS

10.1 TVWS

Current TV white spaces radios rely on proprietary access protocols; standardized 802.11af ASICs will be available in late 2019[13]. TVWS channels limit the maximum throughput to approximately 15 Mbps per 6 MHz carrier, at the transmission control protocol (TCP) layer, using single input single output (SISO) technology. Channel bonding up to a 24 MHz passband is currently possible, which allows greater than 100 Mbps, with Multiple Input Multiple Output (MIMO), under excellent radio conditions. As carrier aggregation (aggregating multiple passbands) becomes available, speeds will increase. As with any licensed or unlicensed wireless technology, individual user speeds may be lower, depending on link budget, number of simultaneous users and client radio capabilities.
Networking features such as full layer 2 support, 802.1p, 802.1q, DHCP Option 82, QinQ and centralized network management systems (NMS) are standard.

Even with access to the TVWS spectrum database, service providers typically conduct an RF survey at the access point site to select optimal available channels. Spectrum sensing capability built into the TV white spaces equipment is also able to detect whether a channel is being used by other access points. Because there is no formal coordination mechanism among service providers, network operators will need to leverage various coordination techniques as TV white space spectrum is used more intensively.

[13] Announced at Digital Spectrum Alliance (DSA) Global Summit, May 3, 2018, London, England.

Figure A2.1 depicts a heatmap from the Nominet TVWS database of the available channels in the United States (https://usa.wavedb.com/channelsearch/tvws). Greater numbers of TV white space channels are available as one gets farther away from large metropolitan areas with large numbers of broadcasters and other licensees.

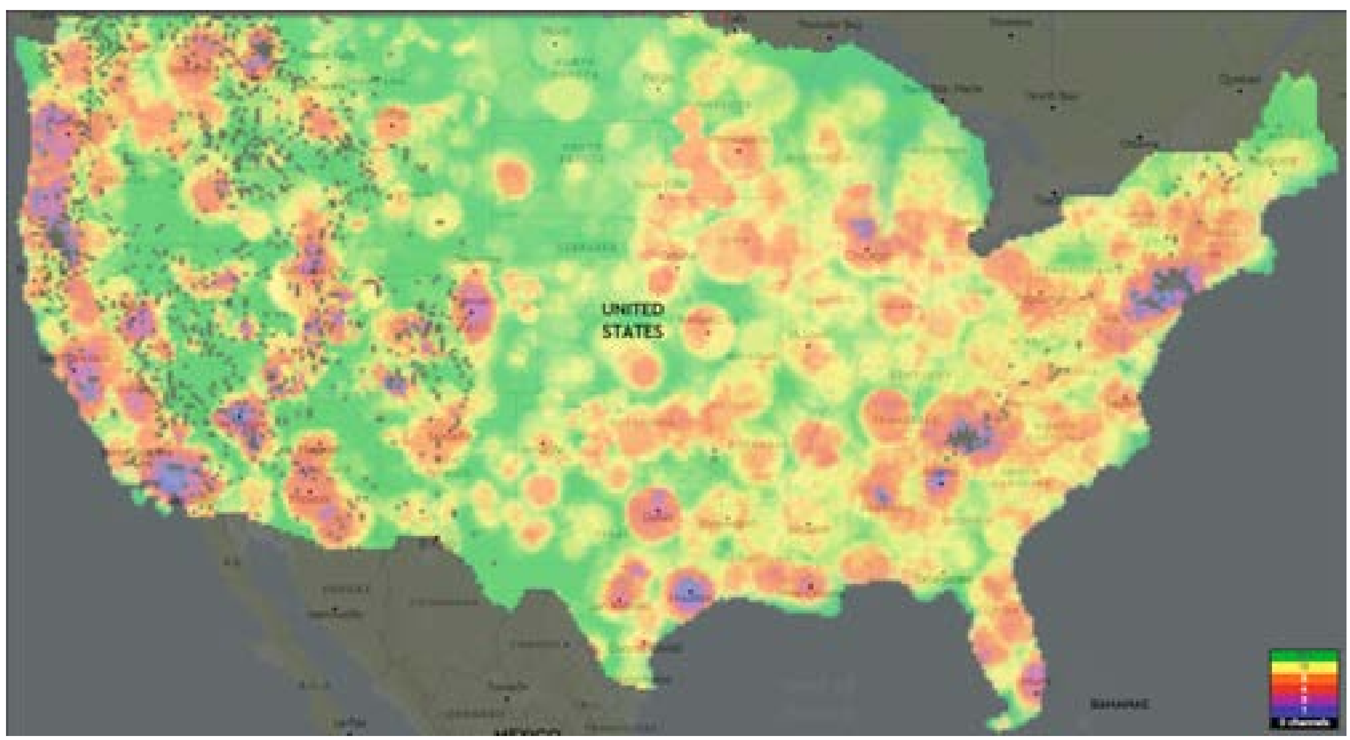

Figure A2.1: TV White Spaces Channels Availability

10.2

10.2.1 LTE RAN

As mentioned in Section 3.2.3, LTE is a 3GPP-based mobile technology, often used inter-changeably with the term 4G. Some key attributes of LTE include the following:

- Carrier bandwidths up to 20 MHz and aggregation of up to 5 carriers in the same, or different, bands
- Operation in FDD (paired) or TDD (unpaired) bands with a variety of frame formats (uplink/downlink) ratios supported for TDD
- Adaptive modulation and coding operation with support of up to 256 QAM downlink and 64 QAM uplink, with possible higher rates to be supported in future
- Comprehensive MIMO modes of operation including single user and multi-user MIMO (SU-MIMO, MU-MIMO) supporting up to 16-layer operation and massive MIMO antennas available including 8, 16, 32, and 64 element antennas depending on radio band
- Comprehensive end to end Quality of Service (QoS) framework
- Comprehensive security framework including SIM card used in the customer premises equipment, mutual authentication of CPE and network, and over the air encryption
- Multicast support using eMBMS operation
- Multiple Radio access architectures including all-in-one integrated radio and baseband and split radio and baseband processing connected via CPRI optical interface
- Comprehensive analytics capabilities
- Self-Organizing Network (SON) features such as 'zero-touch' CPE installation, coverage and capacity optimization, etc.

[7] TBD how much will be released for mobility vs. fixed
[8] Subdivided into different parts (U-NII-1, etc.), some of which are not allocated for unlicensed use
[9] 28 GHz A1 block (27.5-28.35 GHz) is for (flexible use). The LMDS 28 GHz band includes A2 and A3 Blocks respectively at 29.1-29.25 GHz and 31.075-31.225 GHz and B Blocks at 31-31.75 GHz and 31.225-31.3 GHz and is used for fixed links.
[10] Announced at Digital Spectrum Alliance (DSA) Global Summit, May 3, 2018, London, England.

10.2.2 LTE EPC

The EPC described in Figure 3 (Section 4.1.1) includes the following physical entities with capabilities as described below:

- The serving gateway provides a mobility anchor point, performs routing and forwarding of user packets, buffering of downlink packets for an idle CPE, and provides a lawful interception point. User data packets between the LTE base station (eNB) and core are carried in tunnels using GPRS Tunneling Protocol (GTP) which serves to support the mobility/handover requirements are the network, as well as a comprehensive mechanism for QoS support, and supporting multiple overlapping IP address spaces (Packet Data Networks, mapped to access point names/APNs).
- The PDN (packet data network) gateway is responsible for CPE IP address allocation, uplink and downlink service level gating control and rate enforcement, and lawful interception point.
- The gateway functions are split between SGW and PGW in order to support mobile roaming architectures but can also be used to support wholesale/retail architectures.
- The MME (Mobility Management Entity) keeps track of the CPE location and manages overall connectivity of the CPE to the core.
- The policy and charging rules function (PCRF) creates rules on how a data flow is to be treated and charged and sends the rules to the PGW for enforcement.
- The HSS (Home Subscriber Server) is the master database for customers and is responsible for authentication of the CPE (based on SIM card information), access and authorization support, and storage of the customers location and IP information.

10.3 5G/NR

Two main deployment options for 5G/NR are of initial focus in the industry. The first is non-standalone (NSA) operation (also known as Option 3), where 5G bands are deployed with an LTE anchor band. The second is stand-alone (SA) operation (also known as Option 2) where there is no dependence on LTE.

Some NR radio access characteristics that are evolutions beyond LTE include:

- TDD operation in millimeter wave bands (up to 52.6 GHz in Release 15)
- Support for wider carrier bandwidths, with up to 100 MHz in bands below 6 GHz, and up to 400 MHz in higher bands
- Lower latency options, especially with the upcoming URLLC mode
- Flow-based QoS framework (as opposed to LTEs bearer-based scheme)
- Additional flexibility in radio access architectures, with eCPRI Ethernet-based Fronthaul option between radio unit and baseband processing unit, as well mid-haul option.

10.4 802.11

IEEE 802.11 standards include the well-known basic Wi-Fi protocols, 802.11a/b/g/n, as well as the more advanced 802.11ac. Each iteration adds capabilities such as additional frequency bands or more advanced antenna techniques (e.g. MU-MIMO and beamforming) to enable faster data rates and lower latencies. There are amendments for TVWS (802.11af) and 60 GHz (802.11ad) that have been added more recently. 802.11ax is an enhancement to 802.11ac enabling OFDMA (vs. OFDM for earlier versions) as well as numerous MAC layer improvements, which will enable lower-latency and higher number of simultaneous users through more flexible physical layer resource scheduling.

(60 GHz) 802.11ad characteristics include the following:
• 2.16 GHz carrier bandwidth
• Small antennas with beamforming support
• Adaptive modulation and coding operation, with support of up to 64 QAM
• Support for relay nodes

802.11ay adds further enhancements including the following:
• Channel bonding and/or aggregation for up to 8 GHz of bandwidth
• Support of up to 4 MIMO streams
• Mesh topology support

10.5 Backhaul

One representation of the backhaul/mid-haul/fronthaul concepts is illustrated in Figure A2.2, with approximate indications of the required latency (noting that specific latency targets are dependent on target services and other network engineering considerations). The terms found in Figure A2.2 are defined as follows:

- RU – Radio Unit, including RF processing functions and digitization/compression
- DU – Distributed Unit, providing real time processing functions at layer 1 and layer 2 of the radio access technology
- CU – centralized unit, providing non-real time/signaling processing at layer 2 and 3+ of the radio access technology

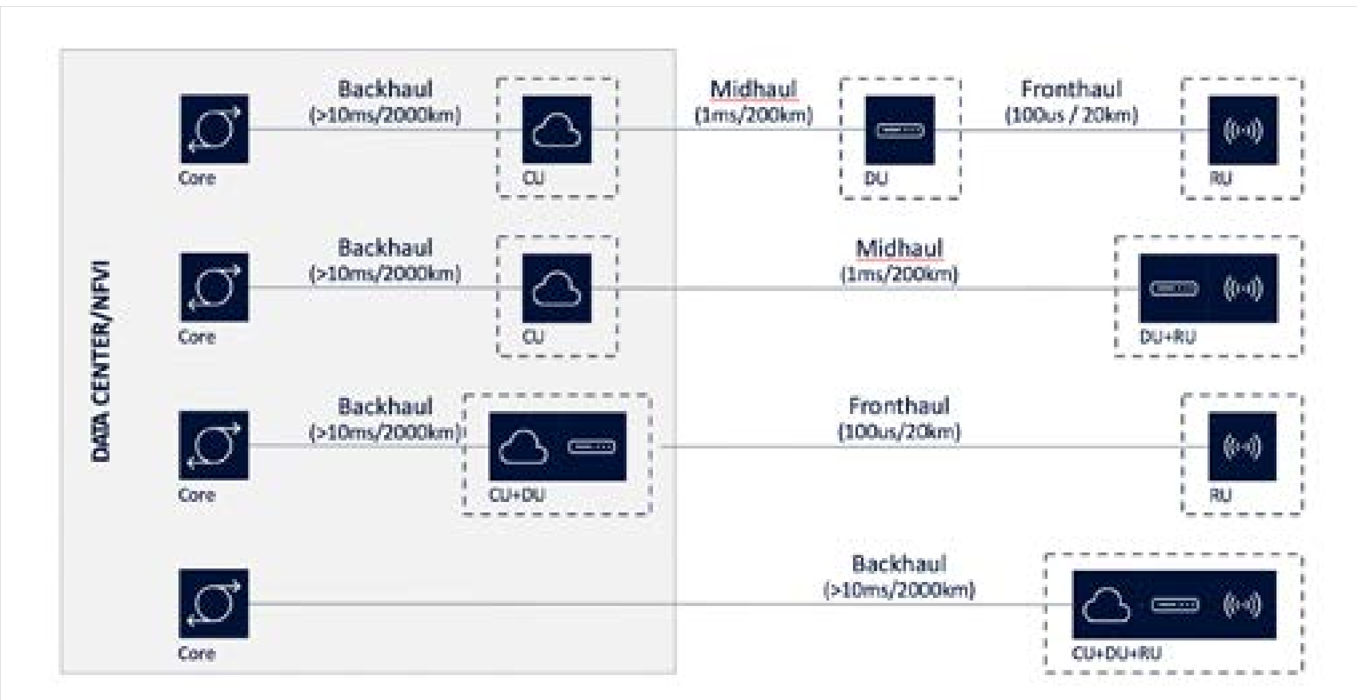

Figure A2.2: Variations of Backhaul, Mid-haul, and Fronthaul

The mid-haul and/or backhaul transport is usually based on Ethernet (Layer 2), IP, Multiprotocol Label Switching (MPLS) or MPLS-Transport Profile (MPLS-TP) (Layer 3) technologies. The required bandwidths are closely related to the aggregated amount of user traffic to be carried by the access network, and latency requirements are typically in the 1 – 20 ms range.

The classical transport network view shown in Figure A2.3 includes the fronthaul concept. Fronthaul transport is typically based on Common Public Radio Interface (CPRI) (most common for LTE today) or eCPRI (real time Ethernet based, relevant to 5G 3GPP standards). CPRI is serialized, sampled I/Q. Optical fiber is the de facto standard for CPRI given the high bandwidth and extremely low latency requirements. The reachable distance between a centralized baseband unit (BBU) hotel and the radio units is about 20km maximum. eCPRI uses Ethernet to transport the fronthaul packets, and bandwidth requirements are significantly less than CPRI by a factor of 10 or more due to additional digital processing in the radio unit. The ultra-low latency requirements are similar to CPRI but may be slightly relaxed in some models.

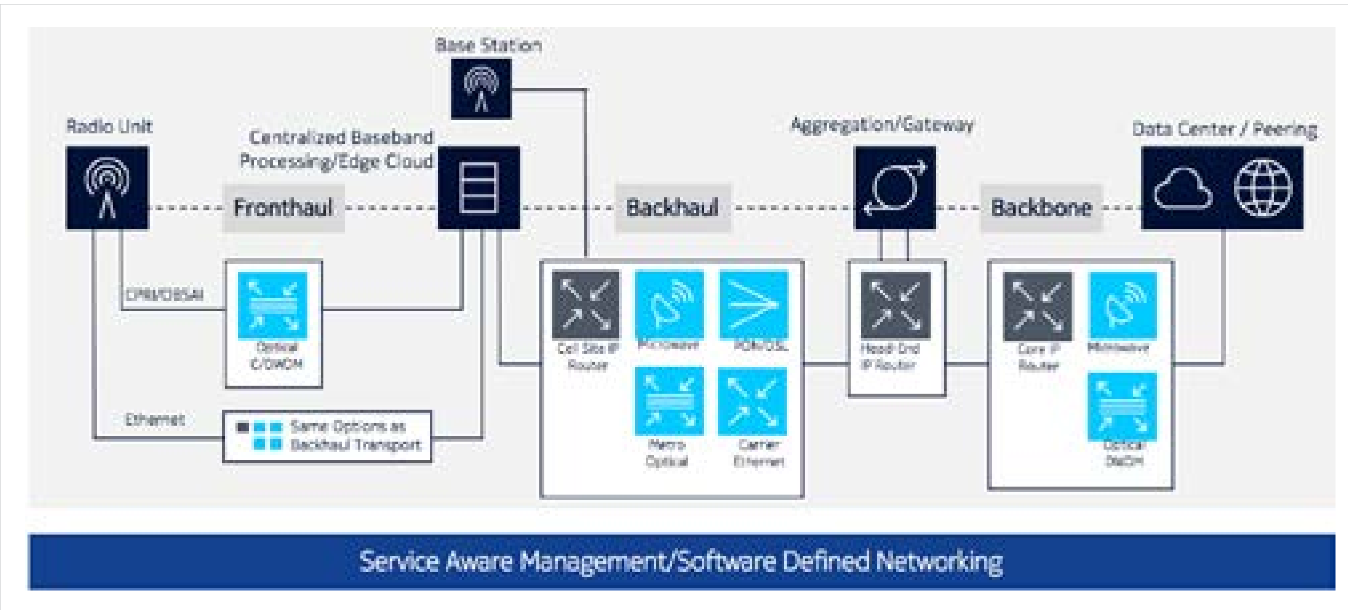

Figure A2.3: Transport network view including fronthaul

Figure A2.4 illustrates the unified vision of transport architecture which leverages a full solution sets in microwave, IP, optical, NG PON and mobile.

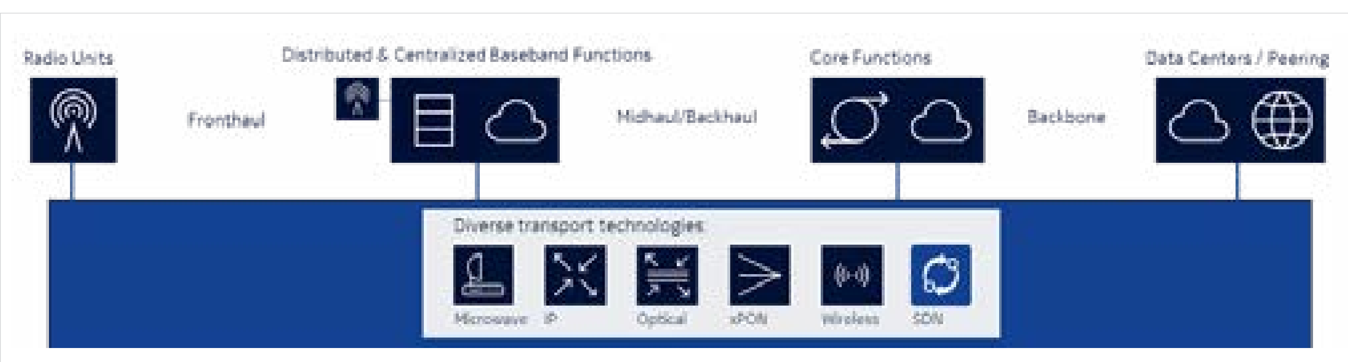

Figure A2.4 Unified Transport Architecture Vision

10.6 Technical Glossary

Abbreviation	Term	Definition
ASIC	Application-Specific Integrated Circuit	Microchip designed for a specific application
SISO	Single Input Single Output	Radio link where transmission is from one antenna to a receiver with one antenna
MIMO	Multiple Input Multiple Output	Radio link where information is transmitted from multiple antennas and is received by multiple antennas
SU-MIMO	Single User MIMO	Radio link where information is transmitted from multiple antennas to a receiver with multiple antennas
MU-MIMO	Multiple User MIMO	Radio link where information is transmitted from multiple antennas to multiple receivers that could have one or more antennas
eMBMS	Evolved Multimedia Broadcast Multicast Services	Broadcast transmission through an LTE network
TDD	Time Division Duplexing	Where downlink and uplink transmissions occur on the same frequency, separated in time
FDD	Frequency Division Duplexing	Where downlink and uplink transmissions occur at the same time, separated in frequency
CPRI	Common Public Radio Interface	Wireless communication specification that defines criteria for interfacing transport, connectivity, and control communications between baseband units and remote radio units of a base station
OFDMA	Orthogonal Frequency Division Multiple Access	Transmission technology in which data is divided over a large number of radio frequencies; data from multiple individual users can be transmitted simultaneously on different frequencies. OFDM transmits a single user's data at any one time, but across multiple frequencies.

The C Spire Rural Broadband Consortium is made up of various partner companies interested in finding new ways to bring broadband Internet to rural communities. To learn more, click **here**.