Kuskokwim River Middle Mile Fiber Technical Feasibility Study
RD-RU-COOP-25-09

Telecommunications System Design

Prepared for:
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Rural Utility Services

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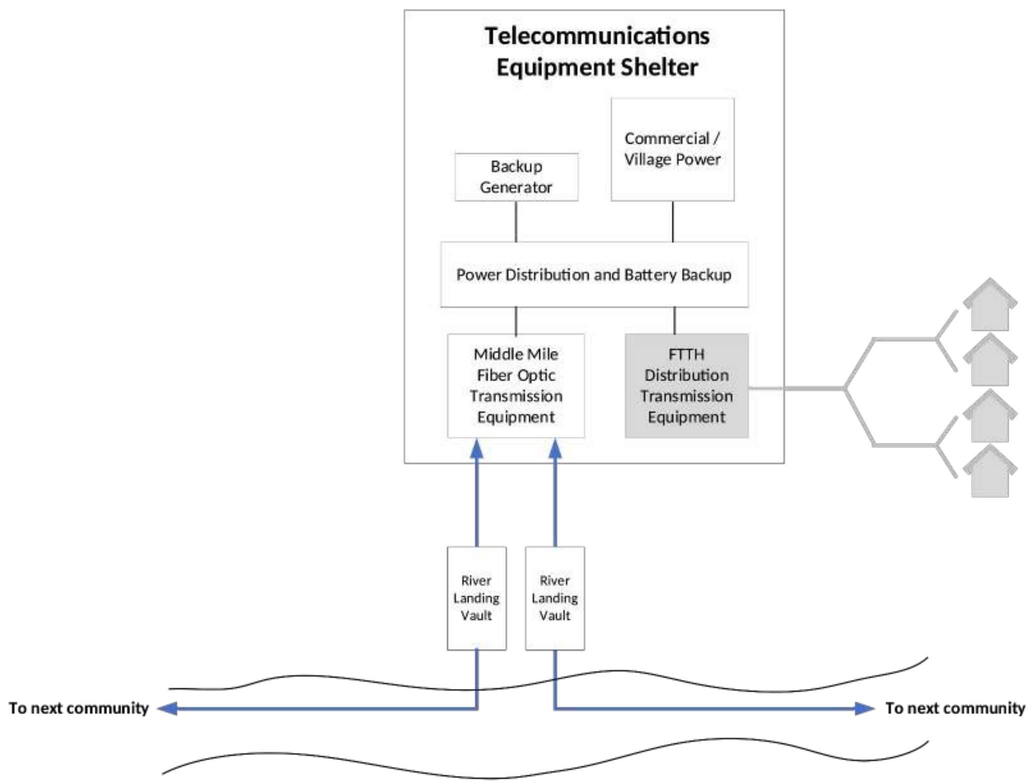
Introduction

The Kuskokwim River fiber installation feasibility study is fundamentally an engineering analysis to determine whether the placement of a fiber optic cable within the flowing waters of the Kuskokwim River can support the long-term operation of a carrier-grade telecommunications system. The telecommunications system used to deliver broadband connectivity to communities served consists of a basic set of components common to most telecommunications systems.

- Facilities
- Power systems and distribution
- Fiber optic cable(s)
- Transmission equipment

Each of these basic system blocks are discussed in this document and recommendations are provided to deliver middle-mile connectivity to the communities called out in the proposal. For the purposes of this study, last-mile connectivity is excluded from the discussion as it is not included in the scope of the grant funding. Last-mile connectivity within each community is a well understood topic and is most commonly achieved through the use of existing utility poles in rural communities. Fiber optic cables are attached to the utility poles within the communities to deliver fiber-to-the-home (FTTH) services. A diagram of a representative landing and interconnection station located within each community is provided in Figure 1.

Figure 1. Kuskokwim River telecommunications facility system block diagram



Components shown in grey in the diagram (Figure 1) are outside the scope of the study but will are included as placeholders. Exclusion of these components would neglect the primary purpose of a river-laid fiber, namely to provide high speed broadband services to community members.

System route landing point alternatives

The design of the fiber optic transmission system that utilizes the river-laid cable between communities relies on the optimization of transmission spans in order to minimize cost and achieve high performance. Optical transmission is dictated by attenuation, noise and required landing point locations. These requirements are compared with the available locations for cable landing and signal regeneration. Optimal landing locations are those for which village commercial power is available along with community resources such as heavy equipment, gravel and temporary housing.

Table 1 shows the approximate distance between river communities where power and facilities are generally available. Aniak and McGrath are considered system endpoints while Chuathbaluk is included in the scope of the proposal. Other named communities are not part of the project scope but are candidates for consideration in transmission system regenerator design[1]. Note the particularly long span between Stony River and McGrath.

Table 1. Kuskokwim River route span distance alternatives for transmission equipment design

Community Name A	Community Name Z	Distance (kilometers)
Aniak	Chuathbaluk	18.1
Chuathbaluk	Napaimute	35.0
Napaimute	Crooked Creek	59.0
Crooked Creek	Red Devil	55.2
Red Devil	Sleetmute	15.5
Sleetmute	Stony River	48.9
Stony River	McGrath	214.7

In the case of the three communities included in the funded project (Aniak, Chuathbaluk and McGrath) the distance between Chuathbaluk and McGrath is too large to span without an intermediate repeater location or wet-plant amplification[2]. Wet-plant amplification is not recommended for any segment of river laid fiber. The placement of wet-plant amplifiers in the system introduces active elements in the bottom-laid fiber, complicates installation and makes repairs costly and difficult. For that reason, any limitation in signal reach is addressed through the placement of onshore intermediate repeater or line termination equipment. It is prudent whenever signal regeneration is required to enable a community to take advantage of the middle-mile fiber by providing baseband distribution capabilities, even if the requisite FTTH distribution infrastructure has not yet been established in the community in question.

Transmission System Requirements

Modern fiber optic middle-mile transmission equipment has many options available to satisfy requirements in capacity and span reach. The transmission system was designed in

[1] Although this study includes only Aniak, Chuathbaluk and McGrath as named communities it is highly recommended that all communities passed have a vault where the cable enters and exits for future connectivity. This vault provides intermediate breakout access for repair (should they be necessary) and also allows individual communities not in the scope of this project to add transmission equipment gain access to the middle-mile broadband capabilities.

[2] We-plant amplifiers are powered from the shore and are placed in-line with the fiber optic cable at periodic intervals to boost signal strength across long cable spans.

collaboration with Ciena, an industry leader in long-haul fiber optic transmission. The selection of intermediate community landing points along the Kuskokwim River is dependent on defining a set of underlying design requirements and assumptions. Table 2 provides a basic outline of the design assumptions used in determining signal reach.

Table 2. Kuskokwim River fiber system specifications and performance targets

Specification	Value[3]
Fiber attenuation	0.17 dB / km[4]
PMD (mean)	< 0.04 ps / sqrt(km)
Channel capacity	800 Gbps
Optical power budget	55 dB[5]
Maximum span distance	~300 km
Channels per strand	42
Strand capacity	33.6 Tbps
Fiber strands	12
Terminal system capacity	400 Tbps

The fiber system performance specifications in Table 2 are used to identify candidate locations for signal repeater functions. It is assumed that Aniak, Chuathbaluk and McGrath will have terminal equipment due to their inclusion in the funded project. Using the span distances in Table 1 and the assumption that the maximum span length for 800 Gbps / channel operation is approximately 300 kilometers, it is apparent that at least one intermediate location is required between Chuathbaluk and McGrath. With this constraint in mind, the options for repeater function location (when viewed from McGrath) are shown in Table 3.

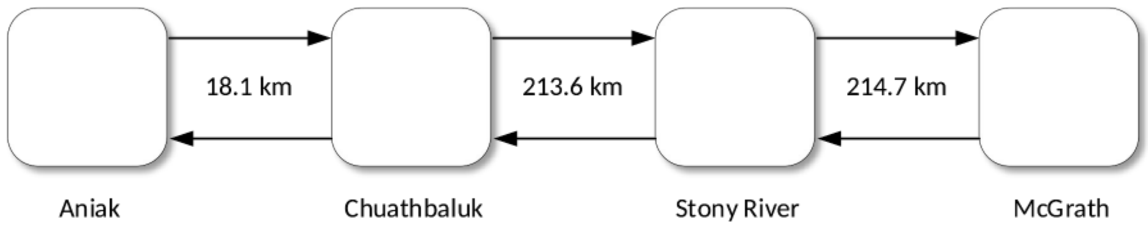
Table 3. Kuskokwim River repeater location options

Location	Span Distance
McGrath	0.0 km
Stony River	214.7 km
Sleetmute	263.6 km
Red Devil	279.1 km

Although any of the three options shown in Table 3 will result in acceptable performance, Stony River was selected as the intermediate repeater location as its distance from Chuathbaluk and the distance from Stony River to McGrath are nearly identical (213.6 km and 214.7 km respectively). That fact, in conjunction with the finding that McGrath is not recommended for construction, makes Stony River the logical choice for the repeater location.

Figure 2. Kuskokwim River fiber optic transmission repeater location

[3] Note: dB (decibel), Gbps (gigabits per second), km (kilometers), Tbps (terabits per second), PMD (polarization mode dispersion), ps (picoseconds)
[4] Assumes the use of ITU-T G.654.E pure silica core fiber strands.
[5] This is a conservative value assuming a hybrid Raman line amplification system. Actual optical power budgets are vendor and system specific and require modeling and collaboration with manufacturer engineering staff.



System Topology

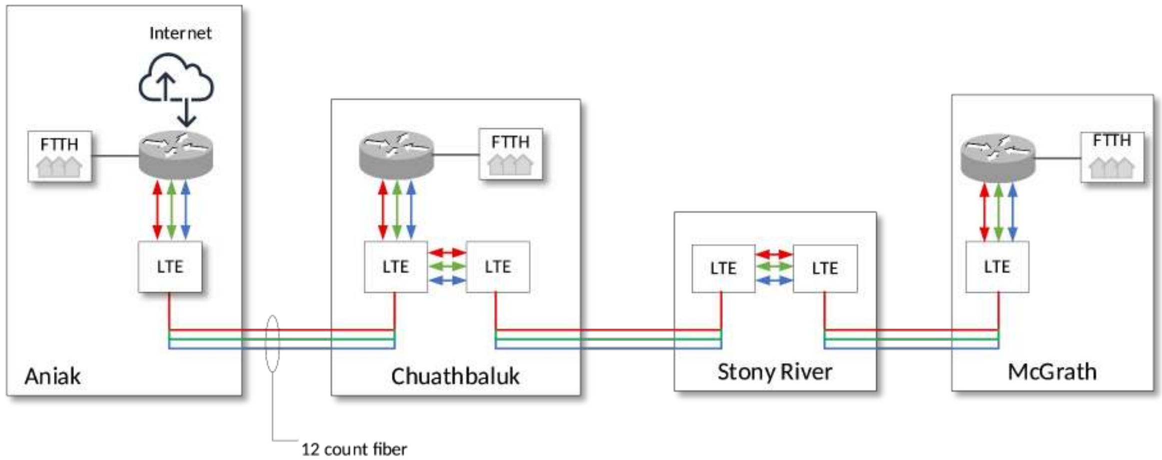
In order to ensure adequate capacity is available in the communities served it is recommended that the deployed fiber contain at least 48 individual strands. This provides for spare fibers and sufficient capacity to provide one or more fiber optic strands to each community served. The price differential between low count (approximately 12 fiber strands) and 48 count fiber is negligible. Expanding beyond 48 strand fiber begins to increase cost and deployment complexity. It is expected that this level of capacity will be adequate for at least a 25-year system life.

Two primary topology options exist for the delivery of service using the transmission equipment. For the purposes of the discussion here it is assumed that Aniak will be the location where the fiber is connected to the public internet[6]. Two options for transmission system configuration are listed below. It is recommended that the system use the “daisy chain” system design. This system architecture requires less equipment and is less complex while providing sufficient capacity.

1. Provide a serial “daisy chain” of packet switches that connect the locations together on a shared backbone of capacity dropping and adding services at each location. This alternative has the benefit of enabling direct point-to-point wide area network (WAN) connectivity between locations. Figure 3 shows a block diagram of a daisy chain transmission system where each location terminates and re-uses capacity between locations. This topology provides transparent WAN connectivity between each community but can reduce the available bandwidth to McGrath if intermediate locations use significant capacity.

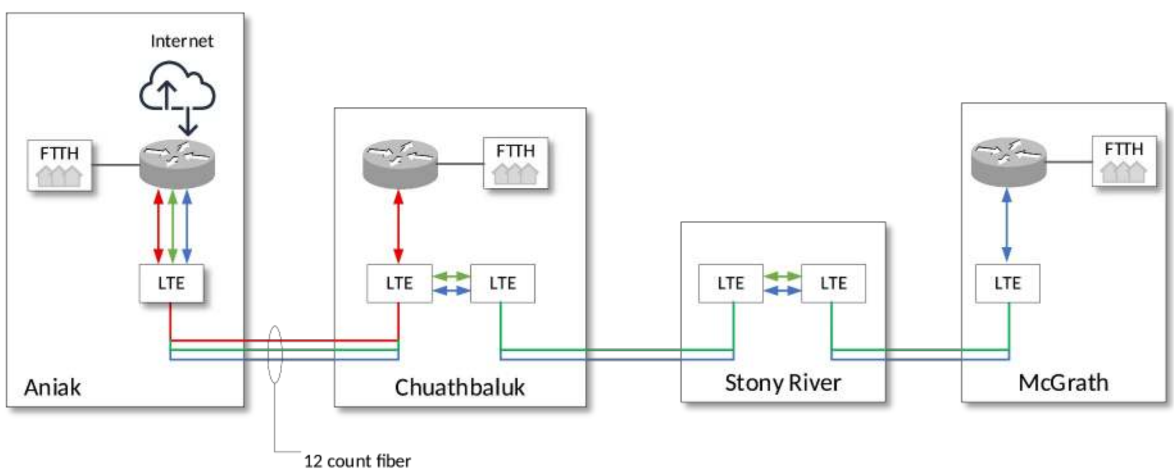
[6] Aniak does not currently have fiber middle-mile connectivity. Access to fiber-based broadband interconnection in Aniak is a pre-requisite for Phase 2 of the proposed construction plan.

Figure 3. Daisy chain transmission system design



2. Provision a single fiber or fiber pair allocated to each community served. This option provides direct “express-route” connectivity between Aniak and each community. This option does not provide direct WAN connectivity. In lieu of inter-village direct WAN connectivity and routing this option directly connects each location to the internet point of presence in Aniak. Figure 4 provides a block diagram of this configuration.

Figure 4. Dedicated fiber transmission system design



Facilities

Telecommunications transmission equipment requires facility infrastructure to deliver service. The shelter facilities associated with the Kuskokwim River project are referred to as “Cable Landing Stations” or CLSs in this report. These facilities provide environmentally conditioned space with access to uninterrupted power and fiber-optic cable terminations. These terminations allow the transmission equipment to be interconnected with the outside plant cabling, establishing link between geographically distant locations.

Primary Commercial Power

Each location housing transmission equipment requires commercial power to provide high availability, low-cost operations. Commercial power within rural communities is notoriously sporadic in its reliability and availability. Commercial power is delivered by the community power utilities which are listed in Table 4.

Table 4. Kuskokwim River village power utilities

Location	Utility
Aniak	Aniak Light & Power
Chuathbaluk	Middle Kuskokwim Electric Cooperative
Stony River	Middle Kuskokwim Electric Cooperative
McGrath	McGrath Light & Power

Selection of the landing station facility location is an important consideration as the facility will require approximately 12.0 kilovolt-Amperes (kVA) of commercial power to support the initial demand. Projected demand with 25% growth increases the required power to 15.0 kVA. A summary of the equipment and its associated power consumption is provided in Table 5.

Table 5. Kuskokwim River cable landing station facility power requirements

Building space	140.0 sq. ft. (10 ft. x 14 ft.)				
	Stated Power Consumption	**Unit Count**	**Power Factor**	**AC Power (real + reactive)**	**DC Power Consumption**
Long Haul Transmission	2.0 kW	1	1.00	N/A	2.0 kW
FTTH OLT	0.8 kW	1	1.00	N/A	0.8 kW
Packet Switching	2.0 kW	2	1.00	N/A	4.0 kW
DC Rectifier	9.0 kW	1	0.98	9.2 kVA	
Monitor and Control	0.3 kW	1	1.00	N/A	0.3 kW
Instrumentation	0.3 kW	1	1.00	N/A	0.3 kW
3 ton CRAC unit	1.2 kW	2	0.90	2.7 kVA	
Lighting[7]	0.1 kW	1	0.95	0.1 kVA	
		Minimum Feed		12.0 kVA	7.3 kW
			Growth	25%	
			Total Feed	**15.0 kVA**	

Relay Racks / Cabinets

Telecommunications equipment within facilities is typically housed in an equipment cabinet or relay rack. The Kuskokwim River system is a traditional telecommunications network and as such is being designed to use standard 23 inch, 42 rack unit (1.75 inches per RU) relay racks. The system deployed provides three (3) 42 RU relay racks to ensure that sufficient space is available for both initial installation requirements and future growth.

The allocated relay rack space for each piece of telecommunication equipment and floor space required for battery and Computer Room Air Conditioner (CRAC) units is provided in Table 6.

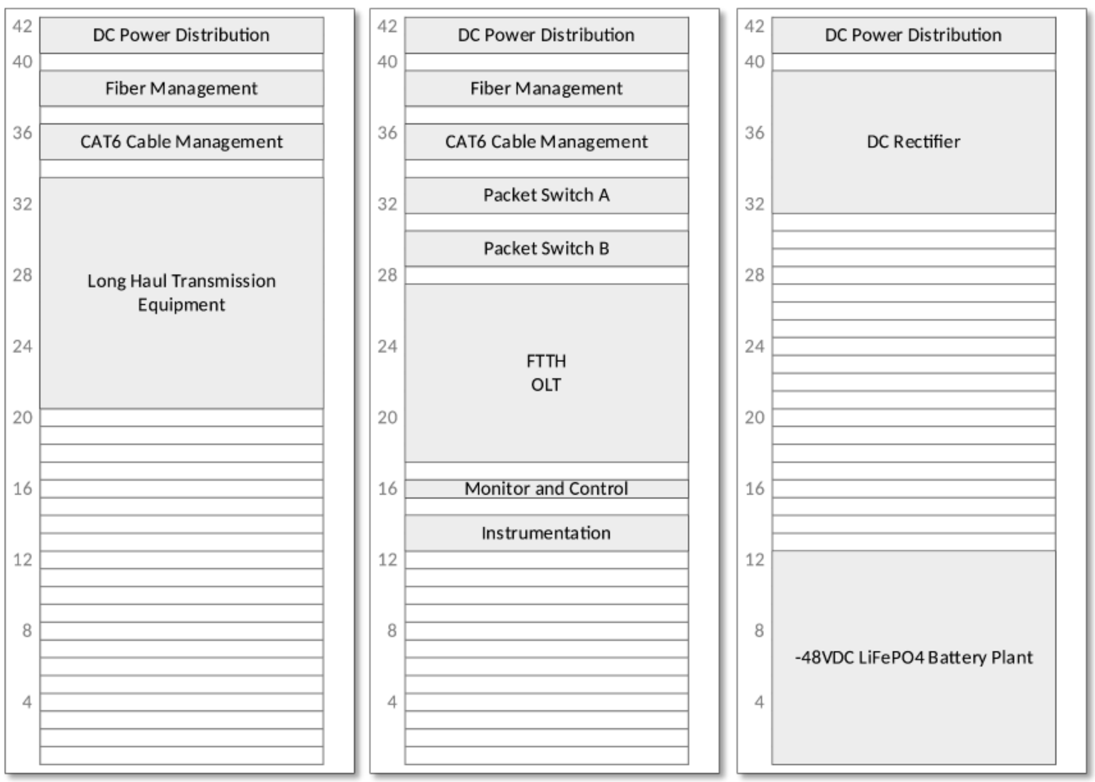
[7] Lighting is modeled at 0.8W / sq. ft. of floor space.

Table 6. Rack space requirements for system components within the landing station facility

Equipment	Rack Space
Long Haul Transmission	13 RU
FTTH OLT	9 RU
Packet Switching	4 RU (redundant)
DC Rectifier	8 RU
Monitor and Control	1 RU
Instrumentation	2 RU
-48VDC $LiFePO_4$ Battery Plant	12 RU

Figure 5 provides a graphical depiction of the relay racks inside of the facility with the associated equipment shown in each rack.

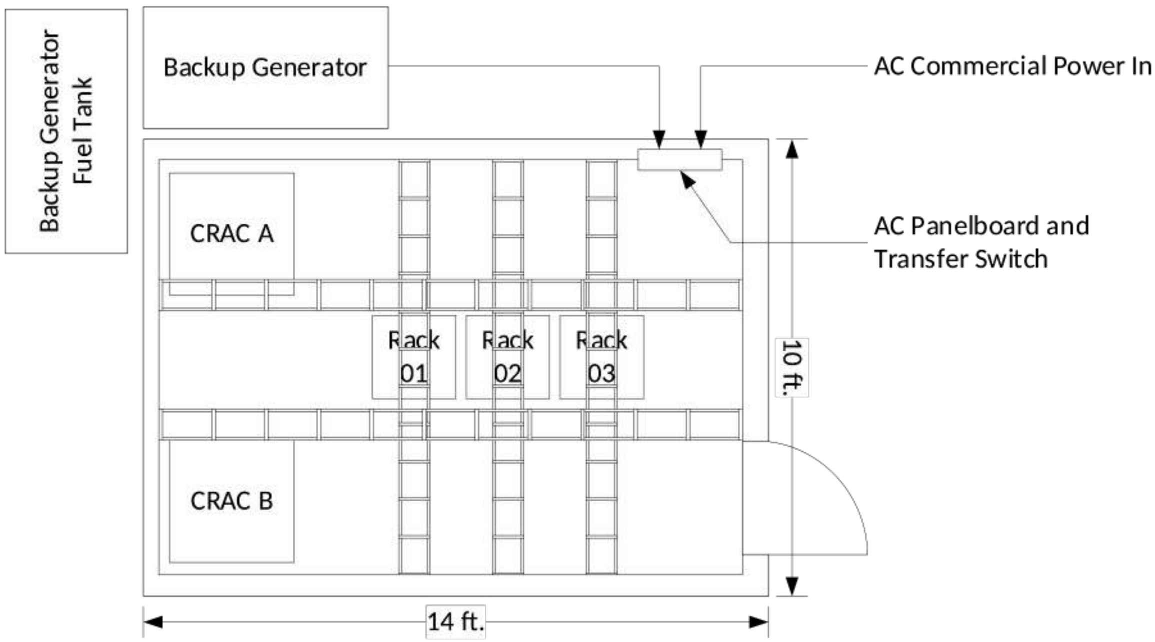
Figure 5. Kuskokwim River landing station relay rack elevation with associated equipment shown



Structure Size and Floor Space

The CLS terminates the incoming fiber from the river route and provides space and power for the transmission and communications equipment. The design for the facility structure assumes a simple shelter with the dimensions shown below which are adequate to support the three (3) relay racks, wall-mounted AC switchboard and floor mounted CRAC units. Ladder racks are assumed for routing of signal cabling. Figure 6. shows a sample sketch of the CLS floor plan design.

Figure 6. Kuskokwim River landing station building floor plan sketch



Batteries

Battery back-up is a critical component of telecommunications systems. Typically, large scale facilities rely upon valve-regulated lead acid (VRLA) or flooded cell battery technology due to their relative insensitivity to maintenance neglect and high performance. These battery systems are environmentally challenging to manage and are extremely heavy which complicates logistics in rural Alaska.

The Kuskokwim River CLSs are specified to use lithium iron phosphate ($LiFePO_4$) battery technology which has a much higher energy density, lower weight and are well-matched to this application. In the case of the CLSs the battery plant's purpose is to support the continued operation of the system while the backup generator comes on-line during a commercial power failure. The small building air-space envelope and high heat load cause the loss of commercial power (and thus active air cooling from the CRAC units which are not backed up by battery systems) to result in an overheat condition in well under 30 minutes. With this in mind, it is imperative that the backup generator start and come online or the systems will shut down due to overheating (>140 degrees) and sensitive electronic telecommunications equipment will be damaged.

A brief comparison of the battery technologies is shown in Table 7. This table demonstrates the superior energy efficiency of $LiFePO_4$ when compared to traditional lead acid battery plants. The reduced cost of shipment, lowering of environmental capture methods, and implementation ease of the $LiFePO_4$ batteries shows their superiority to VRLA and flooded cell systems. The VRLA and flooded cell systems typically require building floor reinforcement to support the high mass per unit area.

Table 7. Relative size and energy density of LiFePO4, VRLA and flooded cell lead acid battery systems

Battery Type	Approx. Weight for 400 Ah	Volumetric Energy Density (Wh/L)	Space required for 400 Ah
$LiFePO_4$	~440 – 640 lb	200–350	12 RU
VRLA (AGM / Gel)	~1,600 – 2,200 lb	90–140	1 – 2 relay racks
Flooded Lead Acid	~2,400 – 3200 lb	60–110	10-16 sq. ft. with spill containment

Backup Generator

On-site backup power generation capability with automatic transfer switching is a fundamental component of high-availability telecommunications systems in rural Alaska. The relatively low availability of commercial power in rural communities means that the on-site generator must be well maintained and function with very few faults. The generator is sized to support continuous operation of the entire building load including the telecommunications equipment, cooling systems, and any other critical system elements. It is recommended that the on-site fuel be maintained for up to 3 days of uninterrupted operation before re-fueling is required.

The generator selection is based on both the required power delivery of 12.5 kilowatt (kW) and the available packaging. A 20 kW generator is selected for this application since smaller units, although adequate, are not well suited to the cold temperature environment and aren't designed for industrial / telecommunications applications. The standby generator is equipped with enough fuel on-site to provide 3 days of uninterrupted operation. This amount of backup provides adequate time for field crews to assemble required repair materials, dispatch to the community and repair the community power generation capabilities before the station would go off-line. Longer operation can be supported by refilling the fuel tank(s) during backup generator operation. Table 8 provides a fuel-tank sizing calculation. The CLS fuel tanks are sized at 100 gallons as these tanks are a readily available size. A larger tank could prove economically beneficial due to the cost of fuel transport if the generators are used on a regular basis. Alternative tank sizes of 250 or 500 gallons might be considered in those cases.

Table 8. Kuskokwim River CLS backup generator fuel tank sizing calculation

Generator System Requirement	Value
Manufacturer	Cummins / Onan
Model	C20D6
Load Capability	20 kilowatts
Assumed Restoration Load	10 kilowatts
50% Load Fuel Consumption	1.0 gallon per hour
Run-time	72.0 hours
Fuel Required	72.0 gallons
Fuel Margin	25%
Fuel Tank Size	87.3 gallons

Power Distribution

All telecommunications equipment within the facility is specified for -48VDC operation and is therefore supported by the battery plant. Power is distributed within each relay rack using a top-of-rack direct current (DC) fuse panel. Primary DC power is derived using a DC rectifier placed in the power and battery plant relay rack.

Long-haul transmission equipment

The long-haul transmission equipment connects to outside plant fiber and transmits optical signals through the fiber optic cable. These modulated signals propagate along the individual strands of fiber until they reach a receiver on the far end of the path. At the far end the signals are demodulated and converted back to baseband Ethernet signals for connection to a packet switch where forwarding decisions are made. The long-haul equipment used in this system design connects to the outside plant fiber optic cable on the upstream side and provides 100 gigabit Ethernet (GbE) or 400 GbE customer traffic interfaces. The transmission equipment's power consumption is typically 2.5 kW or less.

Packet switching equipment

Packet switching equipment makes forwarding decisions based on available routers and provides a low-speed customer interface to the long-haul transmission equipment. In the case of the Kuskokwim River design, redundant packet switches are assumed at each location where traffic ingresses and egresses. Packet switch redundancy is implemented using dual switches with port-level protection. Each carrier-class packet switch is assumed to occupy 2RU each with a maximum power consumption of 2.5 kW or less. The combined, redundant system with cable management in place is assumed to occupy 10-12 RU.

Broadband Access Network

The broadband access network is assumed to be FTTH XGS-PON[8] technology. The specification of this equipment is beyond the scope of this project but its inclusion in the power budget and rack space requirements is implied. For the purposes of this project, it is assumed that half of a 19-inch full-height relay rack is sufficient that the equipment will consume less than 750 Watts of power when fully loaded.

Monitor and Control System

Monitor and control equipment is used to gather facility and network element alarms, aggregate the data and forward it to the operations center. Typical monitor and control systems collect dry contact relay states, simple network management protocol (SNMP) alarm traps and provide a consolidated interface to operators.

[8] XGS-PON is a 10 Gbps-capable passive optical networking technology that provides symmetric broadband access that scales from hundreds to thousands of subscriber terminals.