Concept Paper: *Wireless Networks for Rural Distance Learning, Telemedicine, and Digital Inclusion*

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Executive Summary

Most U.S. states have ordered residents to shelter-in-place in response to the SARS-CoV-2 pandemic. This presents significant challenges for residents in areas with poor or no broadband service, preventing them from using the internet to access distance learning resources, contact health care providers while remaining sheltered, accessing online shopping, and other online activities that most people take for granted.

Residents need three things to overcome digital inclusion gaps: a suitable computing device, high-speed internet, and digital literacy. People with Access & Functional Needs (AFNs) cannot easily overcome the digital inclusion challenge without assistance from local governments, telecommunication providers, and corporate partners.

Some AFN communities are attempting to creatively solve the connectivity challenge by retrofitting school buses and "Bookmobiles" with Wi-Fi equipment and then parking them in neighborhoods with AFN residents. In some cases, schools and public libraries are petitioning the Federal Communications Commission (FCC) to waive some E-rate rules so they can open up their networks to the surrounding community. There are some significant downsides to this approach:

- Wi-Fi coverage is limited to coverage of about 200 feet.
- Wi-Fi signals are less likely to penetrate walls and windows.
- It encourages people to gather near the hotspot & ignore social distancing.

An alternative that can provide broadband service to AFN residents in areas that are unserved or underserved by existing telecommunication networks is to enhance the 4G LTE infrastructure to provide additional coverage – specifically indoor coverage – to a broader range of locations, by building temporary wireless sites near the areas of need. Once the sites are in place, government or community groups can provide AFN residents with a hotspot, or an inexpensive smartphone to be used as a Wi-Fi hotspot.

There are various configurations possible to provide broadband service to the largest number of AFN residents while keeping costs low, utilizing available equipment, and operating within legal and regulatory constraints:

- COWs, COLTs, RDSs, with local fiber backhaul
- Aerostat for coverage, with local fiber backhaul
- COWs/COLTs/RDSs, with Aerostat-based backhaul
- Aerostat for coverage, with wireless backhaul

This concept paper ***Wireless Networks for Distance Learning*** details each of these configurations, examines the pros and cons of each method, and explores funding options.

Scenario Presumptions

In developing this concept paper, we considered a pandemic response scenario that limits social contact and disrupts supply chains, using both the short-term scenario of residents asked to shelter-in-place for up to three months, and a long-term scenario of residents asked to shelter-in-place for up to 18 months. For the longer term scenarios, we considered both continuous and cyclical sheltering and social distancing models. The concepts we propose will work equally well for short-term and long-term scenarios.

Acknowledgement of Contributors/Reviewers:

- Jennifer Maddox
- Robin Doran, Joint Venture Silicon Valley
- Robert Tse, U.S. Department of Agriculture

Overview

The need for a rapid and aggressive response to the SARS-CoV-2 viral pandemic has led to regional and statewide shelter-in-place orders and school closures. A lack of broadband in underserved and unserved rural areas, but also in underserved and unserved urban areas, creates a significant challenge for sheltering residents. It prevents them from using the internet to access distance learning resources, contact health care providers while remaining sheltered, access online information and shopping/delivery services, and engage in other online activities that most people take for granted. (https://www.nytimes.com/2020/03/27/opinion/coronavirus-internet-schools-learning.html)

We propose to address this challenge using existing commercial wireless technologies applied in creative ways. Variations in terrain, available resources (sites, power, and connectivity to the network aka "backhaul"), and served-user density require that each solution be engineered for the location, but by using proven commercial technologies we can adjust as needed to balance for performance, cost, and user density.

In building our concept, we considered newer technologies — including 5G and Citizens Broadband Radio Service (CBRS) — but rejected them because user equipment (hotspots and phones) are either unavailable or too expensive.

Requirements for Successful Deployments

Broadband is defined by the Federal Communications Commission as a connection that reliably provides download speed of 25 megabits per second (Mbps), and upload speed of 3 Mbps, or what is often called in technical jargon "25/3 service". The California Public Utilities Commission defines broadband as 10 Mbps of download, and 1 Mbps of upload, or "10/1 service".

The connection between the wireless site and the internet must scale with the target number of users; if a network serves 10/1 Mbps broadband to 1,000 users, the backhaul connection must be able to sustain at least 10 gigabits per second (Gbps) of download and 1 Gbps of upload.

Success Factors for Wireless Broadband Networks

Any wireless network designed to provide broadband to multiple users simultaneously needs to successfully address several factors:

- High bandwidth connection to the internet. This is known as "backhaul".
- Electrical power for the networking and wireless equipment.
- A physical enclosure for the networking and wireless equipment.
- A method for mounting antennas, typically on a mast or tower.
- Physical security for the enclosure, electrical, and backhaul cabling.

Deployment Technologies

In development of this proposal, we looked at several technologies, and possible configuration of the technologies. Each technology has benefits and drawbacks that we examined in the context of the intended goal of creating rapid deployment networks to connect unserved and underserved residents sheltering-in-place during the pandemic response, and which would not require direct contact with users or entering dwellings – actions that would violate social distancing orders and potentially expose people to infection.

Wi-Fi (Fixed and Mobile)

Wi-Fi is effectively universal in existing user devices ranging from smartphones to tablets and PCs. For this reason, much has been written in recent weeks about using Wi-Fi to build creative solutions for access to serve residents across the country. Some municipalities have retrofitted school buses with Wi-Fi equipment, and parked them in neighborhoods for residents to access. (Bakersfield CA: https://fox6now.com/2020/04/01/california-school-district-uses-buses-as-wi-fi-hotspots-so-kids-can-connect-for-e-learning/)

There are also stories of Bookmobiles being converted into mobile Wi-Fi hotspots. (https://www.vice.com/en_us/article/z3b54j/libraries-want-to-turn-bookmobiles-into-free-wifi-trucks-during-coronavirus-lockdown)

In some areas, schools and libraries have petitioned the FCC for permission to open their networks to the surrounding community, or have simply ignored the FCC altogether and moved forward. (ibid. Vice.com)

Unfortunately, Wi-Fi has limited value as a wide area coverage technology. The ability of Wi-Fi to create coverage in public Wi-Fi networks is enabled by the use of high-end commercial network equipment controlling multiple access points. (http://bit.ly/gctcwifiblueprint)

Pros:

- Wi-Fi is nearly ubiquitous in user devices (phones, laptops, etc.).
- Client acquisition costs for Wi-Fi are effectively zero.
- Most users are familiar with set up and operation of Wi-Fi.
- Wi-Fi uses unlicensed spectrum, so coordination with commercial cellular carriers is not necessary.
- Federal Communications Commission has made additional spectrum available to Wireless Internet Service Providers (WISPs) for 60 days. (https://docs.fcc.gov/public/attachments/DOC-363358A1.pdf)

Cons:

- Wi-Fi coverage is limited by allowed power output of the user equipment to approximately 200 feet. (Modified Wi-Fi equipment, external antennas, or other engineered solutions can extend this distance, but these cannot be done easily on commercial equipment or without entering a user's residence.
- Wi-Fi signals are less likely to penetrate the walls and windows of homes located more than 100 feet away from the hotspot.
- Wi-Fi networks share spectrum with other Wi-Fi users, Bluetooth devices, cordless phones, and even microwave ovens. Interference will reduce performance, or can even shut down, Wi-Fi networks, especially if the signal is marginal to begin with.
- Creating a connectivity solution that tempts users to gather near a hotspot runs contrary to county health guidelines for social distancing. MIT research argues that sneezing can project the SARS-CoV-2 virus over 27 feet, which could expose residents gathered around a hotspot to infection beyond the current six-foot social distancing guideline.

4G LTE

4G Long-Term Evolution (LTE) is nearly ubiquitous in user equipment. All modern smartphones, all portable hotspots (sometimes called "MiFi" devices, although we note that this is a trademarked name of one company's product), and some tablets and PCs can access 4G LTE networks. When properly provisioned by the cellular carrier, modern smartphones can be used as Wi-Fi hotspots.

Pros

- 4G LTE uses licensed spectrum, which allows use of higher power equipment at the coverage site, and minimizes interference.
- 4G LTE operates in a variety of spectrum bands, including some lower frequency bands that are well-suited to penetrating walls.
- 4G LTE connections are managed by the carrier network controller; once the phone, portable hotspot, etc. has a valid SIM card installed there is very little need for user configuration of the device.

Cons

- There are three major wireless carriers in Northern California. Most temporary wireless sites can support equipment and antennas for only one or possibly two carriers at most. If existing deployment sites are not available, it may not be possible to deploy temporary sites for all three carriers in one location.
- Each carrier is being asked for support during the pandemic response. As a result, getting attention for this project may be challenging. Joint Venture has relationships with the major carriers that will help.
- 4G LTE radios have inherent capacity limitations. A given 4G LTE radio can only service about 200 simultaneous connections. Use of sector antennas and what's called "spatial diversity" allows a given physical site to serve larger numbers of connections but this adds to site complexity.
- At the beginning of the pandemic shelter-in-place order, nearly all portable hotspots were purchased by companies to support their work-from-home employees. Because effectively all portable hotspots are manufactured in China, the backlog of pending orders presents a logistic challenge. However, inexpensive Android smartphones (which cost approximately equal to a portable hotspot) can be used as substitutes.

5G NR

The fifth generation of wireless cellular, known as 5G, offers several advantages over 4G. Just as LTE is a 4G technology, New Radio (NR) is a 5G technology.

However, the newness of 5G NR in the market makes it less attractive for this project.

Pros

- Improved performance relative to 4G LTE, in terms of the amount of data that 5G NR can carry a given amount of spectrum.
- Improved simultaneous connection capacity, ability to service millions of concurrent sessions.
- T-Mobile has deployed a wide area 5G network in many rural areas of California in lower frequency bands that will allow signals to penetrate walls and windows.

Cons

- 5G NR is a relatively new technology, so availability of equipment to do immediate deployment is limited.
- Availability of 5G NR-capable portable hotspots is somewhat limited. However, T-Mobile has said that they are reserving their portable hotspot demonstration inventory for use by education users during the SARS-CoV-2 pandemic response.

JVSV Recommendation:

- If 5G NR hotspots can be sourced from T-Mobile, this would be a viable solution, but we should consider this option additive and opportunistic.

Deployment Platforms

Physical objects (houses, trees, walls, terrain, etc.) reduce radio frequency (RF) signal levels, which can reduce connection performance, or even prevent connections. For this reason wireless broadband antennas must be installed at elevations above ground to maximize coverage and overcome avoid obstacles.

Cells-on-Wheels and Cells-on-Light-Trucks

The commercial wireless carriers use vehicle-mounted cellular radio and switching equipment known as COWS (Cells-on-Wheels) and COLTS (Cells-on-Light-Trucks) to provide supplemental or replacement coverage. These are typically used in disaster response when existing infrastructure is damaged, but they are also used to provide supplemental coverage for sports events, large gatherings, music festivals, and to add capacity for humanitarian efforts such as refugee encampments. As with any communications technology, COWS/COLTS require electrical power, and connectivity to the network aka "backhaul". In rural deployments without electrical power and fiber optic backhaul, COWS/COLTS may serve voice and short-message service (SMS or "text messaging") only, and are powered by petroleum-fueled generators. If electrical power and fiber optic backhaul are available, COWS/COLTS can service voice, SMS, and broadband data typically using 4G LTE technologies.

Figure 1 - COLT in NYC near Freedom Tower

Portable Towers / Rapid Deploy Sites

COWs and COLTs are designed for mobility – they move between locations as needed based on carrier needs and mission objectives. About half the cost of a COW or COLT is the vehicle itself: heavy duty trucks capable of carrying a vehicle-mounted mast, cellular equipment, and power equipment. If a supplemental site is going to remain active for months, avoiding the cost of a vehicle allows us to deploy twice as many sites for the same cost.

Rapid deploy sites (RDSs) provide temporary or semi-permanent custom towers using a non-penetrating ground-mount system, secured against toppling with crane-lifted ballast weights.

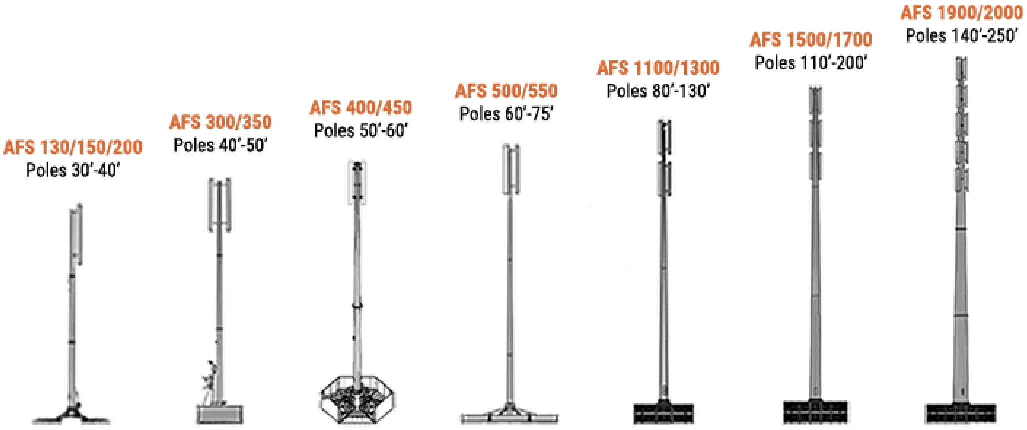

Figure 2 - Rapid Deploy Site Towers

Aerostats

Aerostats are unmanned lighter-than-air vehicles, tethered to the ground, carrying cellular equipment. Power is provided via heavy-gauge conductors in parallel with the tether. They are typically raised to heights of 1,000 – 2,000 feet above ground, which allows a wide coverage footprint. Backhaul can be either (a) fiber optic cabling in parallel with the tether, or (b) high-bandwidth wireless point-to-point links. In the case of wireless point-to-point links, the ground site for the wireless link must have fiber optic service.

Refer to our Aerostat Overview *document for more information.*

Backhaul Technologies

Any wireless broadband site must connect to the internet via a high-speed data link capable of carrying large amounts of data. Wireless broadband equipment serving 4G or 5G must link to the carrier's core network for authentication, connection and resource management, data transfer, and a host of other functions.

Typically backhaul connections are fiber optic lines, but can also be high-speed digital lines (Gigabit Ethernet, T-Carrier lines, etc.) or wireless broadband using microwave or millimeter wave links.

In extreme cases where the carrier must provide voice, SMS, and limited data services, the backhaul can be via satellite links, but this is very expensive and cannot provide broadband to large numbers of users.

Choosing a site suitable for deployment of wireless broadband equipment thus requires locating and securing permission to use existing and available fiber optic or high-speed digital lines or building a wireless backhaul network between the deployment site and a location where fiber optic or digital lines are available.

Aerostats can be used for backhaul. High-bandwidth wireless equipment is installed at a suitable location with fiber optics and power (such as a school) and a link is established between the fiber site and the Aerostat. The temporary deployment site (COW, COLT, or RDS) is also wirelessly linked to the Aerostat. One Aerostat can provide backhaul for several temporary deployment sites.

Free Space Optical Communications (FSOC) is an optical data linking technology developed by Google for Project Loon. It uses a self-aiming near-infrared laser that would allow links between the ground and aerostats or other non-stationary platforms.

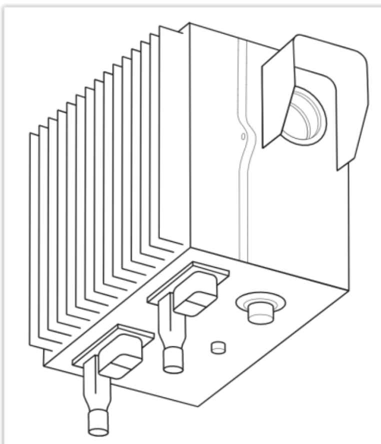

Figure 3 - Free Space Optical Node (Google X)

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Served User Equipment

Served users may use 4G-enabled smartphones, tablets, laptops, and other devices to access the provided 4G LTE signal. For users without these devices, it is necessary to convert the 4G LTE signal into a Wi-Fi signal via a hotspot; the user can then link Wi-Fi enabled devices to the hotspot. Some hotspots also allow wired networking over USB cabling. During the early days of the pandemic, many hotspots were purchased by companies for their work-from-home employees.

However, most 4G LTE smartphones are capable of operating as Wi-Fi hotspots, and we believe it's possible to source large numbers of 4G LTE smartphones for reasonable cost; the Motorola G6 can be purchased online for under $100. We should look for "big box" vendors such as Best Buy and Costco that can donate and/or sell phones at reduced prices.

Deployment Configurations

Using the above technologies, there are various configurations possible. For the purpose of this overview, we will ignore configurations that do not provide broadband service. We considered several technology configurations with the goal of creating a successful deployment strategy that serves the largest number of residents, maximizing coverage while keeping costs low, and utilizing available equipment in a time of crisis and supply chain constraints, and operating within legal and regulatory constraints.

COWs/COLTs/RDSs, with local backhaul

This is a well-proven configuration used innumerable times for over a decade. Power and fiber are connected to the COW/COLT/RDS equipment. The antenna mast is extended to a height of approximately 50 feet above ground level. Coverage from this configuration is an area of approximately 25 square miles, or 2.8 miles radius from the site.

Aerostat for coverage, with local backhaul

The Aerostat carrier vehicle is parked in a location near electrical power and fiber optic service, with sufficient clearance to allow for wind-driven movement of the lifting body. Power and fiber are connected to the ground vehicle's equipment. The Aerostat is inflated with helium and the tether is extended to place the Aerostat at a height of approximately 1,500 feet above ground level. The carrier vehicle acts as the ground anchor. Coverage for this configuration is an area of 5,000 square miles, or 39.8 miles radius from the site.

COWs/COLTs/RDSs, with Aerostat or FSOC backhaul

The Aerostat carrier vehicle is parked in a location near electrical power and fiber optic service, with sufficient clearance to allow for wind-driven movement of the lifting body. Power and fiber optic service are connected to the ground vehicle's equipment. The Aerostat is inflated with helium and the tether is extended to place the Aerostat at a height of approximately 1,500 feet above ground level. The carrier vehicle acts as the Aerostat ground anchor.

A COW/COLT/RDS is sited in a location near electrical power. Backhaul is via the Aerostat. The antenna mast is extended to a height of approximately 50 feet above ground level. Coverage from this configuration is a radius of approximately 25 square miles.

Aerostat for coverage, with wireless backhaul

The Aerostat carrier vehicle is parked in a location near electrical power. Electrical power is connected to the ground vehicle's equipment. The Aerostat is inflated with helium and the tether is extended to place the Aerostat at a height of approximately 1,500 feet above ground level. The carrier vehicle acts as the ground anchor. Coverage for this configuration is a radius of 5,000 square miles.

Wireless link site equipment is located near electrical power and fiber optic service. A directional antenna or FSOC node is attached to the link site equipment and pointed towards the Aerostat. Electrical power and fiber optics are connected to the link site equipment. The link site equipment connects the Aerostat to the fiber optic network via a managed wireless link or free space optical connection.

Considerations for Deployments

COW/COLT/RDS, with local fiber backhaul

- Obtain permission to park the COW/COLT or build the RDS.
- Obtain permission to run electrical cabling and fiber optics between the COW/COLT/RDS and the service building.
- Physical security of the COW/COLT/RDS.
- Municipal permitting/planning.
- Contracting, insurance, etc.
- Limited coverage area.

Aerostat for coverage, with local fiber backhaul

- Obtain permission to park the ground vehicle.
- Secure a location with sufficient clearance to allow for wind-driven movement of the lifting body and tether.
- Obtain FAA permission for use of airspace, issuing safety notices to aviation.
- Obtain permission to run electrical cabling and fiber optics between the ground vehicle and the service building.
- Physical security of the ground vehicle.
- Municipal permitting/planning.
- Contracting, insurance, etc.

COW/COLT/RDS for coverage, with Aerostat or FSOC backhaul

- Aerostat requirements, and COW/COLT/RDS requirements.
- FSOC has a distance limitation of 10 kilometers, less in heavy rain or fog.

COW/COLT/RDS for coverage, with direct wireless or FSOC backhaul

- Same as COW/COLT/RDS with local backhaul, plus:
- Obtain permission to locate the wireless site link equipment.
- FSOC has a distance limitation of 10 kilometers, less in heavy rain or fog.
- Engineer the link to ensure signal performance – managing distance losses, foliage obstructions, etc.
- Obtain permission to run electrical cabling and fiber optics between the wireless site link equipment and the service building.
- Physical security of the wireless link site equipment.
- Contracting, insurance, etc.
- *Recent FCC waiver of the E-Rate rules as part of pandemic response provide an opportunity to use of schools and libraries as wireless link sites.*

Aerostat for coverage, with wireless or FSOC backhaul

- Same as Aerostats, plus:
- Obtain permission to locate the wireless site link equipment.
- Engineer the link to ensure signal performance – managing distance losses, foliage obstructions, etc.
- FSOC has a distance limitation of 10 kilometers, less in heavy rain or fog.
- Obtain permission to run electrical cabling and fiber optics between the wireless site link equipment and the service building.
- Physical security of the wireless link site equipment.
- Contracting, insurance, etc.
- *Recent FCC waiver of the E-Rate rules as part of pandemic response provide an opportunity to use of schools and libraries as wireless link sites.*

Appendix: Funding Sources

Note: Potential resources and requirements are in flux. Applicability of programs depend upon specifics of the project. This list is correct as of 08-April-2020 but may be subject to change.

Federal Coronavirus Economic Response

- FCC:
  - Request telecommunication providers to accommodate customer needs.
  - Regulatory Waivers
    - E-Rate Gift rule waivers.
    - Schools and Libraries outside venue access.
  - Congressional Waivers Needed:
    - Statutory language changes needed to allow E-rate funded broadband connections to schools and libraries to be repurposed as backhaul connections.
- CARES Telehealth Funding:
  - $200 Million for broadband connectivity and devices.
  - Benefit: Residents and families remain at home, it's safer for them and medical workers if they don't go to a doctor or hospital.
- DHS:
  - FEMA, via existing disaster response structure.
  - *Note: Existing EOC structure and mission does not cover broadband.*
- Economic Development Administration:
  - CARES provides $1.5 Billion for grants.
- Treasury:
  - https://home.treasury.gov/cares
- US Department of Education:
  - $30.75 billion allocated under CARES.
  - Hardware, software, connectivity are eligible expenses.
  - Distance Learning projects are likely fundable under this allocation.
  - New waiver request process allows states to request permission to repurpose existing funds to pay for remote learning technology. (https://bit.ly/2JP5omT)

Appendix: Equipment Costs

The following cost estimations are provided for budgetary purposes. Actual costs will vary based on project implementation and market realities. We can and should expect that these costs will vary from budgetary estimations.

COWs/COLTs

Based on conversations with cellular carriers, the cost to construct a COW or COLT is roughly $250,000, of which $125,000 is the vehicle itself, and the vehicle-mounted hydraulic antenna mast. Presuming the vehicle and all equipment\and parts are available, time to construct a COW or COLT is 45 days. The purpose of having a COW or COLT is transportability; the ability to pull down the mast and drive to another location makes them ideal for temporary deployments in chaotic situations such as natural disaster response. For the purposes of this project and our duration estimates we don't need a vehicle, so a COW or COLT is contraindicated.

RDSs

Rapid Deployment Sites (RDSs) are essentially COWs/COLTs without a vehicle, and without a hydraulic antenna mast. A simple RDS platform can be created from a repurposed shipping container, a "crank up" antenna mast, and ballast weight to keep the container/mast secured during wind storms, seismic events, or other unintended movement. The cost of an RDS including the container and antenna mast is $125,000 and possibly less.

Free Space Optical Connections

FSOC technology is still early to market; cost for a pair of link nodes is about $48,000.

Aerostats

Aerostat costs are based on their weight-carrying capacity, and range from $600,000 to $900,000 each. Aerostats are helium-filled, and the cost of filling and recharging will be about $10,000 to $15,000 per year – less for shorter-term deployments.

Hotspots/Phones

Costs for hotspots are highly variable. Normally costing about $100 MSRP, they are difficult to find. We have seen offers of refurbished units on the secondary market for $50 each. The pricing will change based on availability.

Inexpensive smartphones such as the Motorola G6, the Samsung Galaxy J3, or the Nokia 5 can be found for about $100 via online retailers. It may be possible to source them at cost via a large chain store such as Best Buy or Walmart, via a charity agreement. These phones are not very powerful, but since they are only being used as hotspots, their performance as phones does not matter. In fact, it may be a benefit because the users will be less inclined to use them for non-hotspot purposes.