Town-Wide Wireless Broadband Access for Chesterfield: Budgetary Design and Cost Estimate

Prepared for the Town of Chesterfield by Fred Goldstein, Interisle Consulting Group, September 2016

The Town of Chesterfield has limited broadband service options today. Most of the population can get cable modem service from Argent, which covers the village area of Spofford, while parts of West Chesterfield near Brattleboro get service from Comcast. FairPoint's DSL covers some neighborhoods, largely but not completely overlapping cable coverage, but its speed is often limited to 3 Mbps or less and its quality is sporadic. Some parts of town have no broadband service at all.

The Town of Chesterfield thus retained the services of Interisle Consulting Group to prepare a study of a wireless option to reach the unserved homes. The goal of this design is to provide 25 Mbps service to a preponderance of homes, allowing a limited number of difficult locations to be served at speeds as low as 10 Mbps. This should prove the most cost-effective way to reach these locations, as the per-mile house density is generally too low to attract the existing cable companies, let alone sustain a fiber-based alternative.

Figure 1 Homes "served" with cable modems available (yellow) and "unserved" (red) in Chesterfield

A few homes are already able to receive signals from existing Wireless ISPs. Due to the terrain and tree cover, however, the cost of providing *universal* coverage to the town's unserved homes, vs. *opportunistic* coverage of those which it is easiest to reach, is likely to be too high to attract the needed outside investment without town involvement. However, the Town's ability to fund a network is limited, as the State of New Hampshire does not permit towns to issue long-term bonds for this purpose. While the network design proposed below is intended to specifically reach the unserved areas, it does also reach some areas that have service from existing providers, and it may become more attractive as a business proposition if some competitive sales in those areas are factored in.

A network design and budget is thus presented here which provides wireless coverage to over 95%of the still-unserved homes at the lowest possible cost. Most will be able to receive 25 Mbps download speeds. It is designed to be attractive for a public-private partnership, wherein the Town gives some assistance to a Wireless ISP that will own and operate the actual network.

The wireless network does not preclude the development of fiber optics as well, or in the future. Fiber may be justified in limited portions of the town, where the density of subscribers per linear mile is highest and thus the cost per subscriber is lowest. Fiber may well be a useful tool for reaching the business areas of town, especially along the Route 9 corridor, if the cable companies do not provide adequate service. Compared to fiber, wireless has the advantage of much faster time to market. A wireless network can be completed within a year, and started even sooner; a fiber network typically takes three years to construct, and often two years until "first light" is seen. This is a necessary consequence of dealing with the pole attachment and make-ready process, which constitutes the greatest share of the cost of a fiber network.

In some cases, where cable coverage approaches a neighborhood but does not reach it, the Town may wish to negotiate extension of the cable plant. This has been done in Massachusetts, where the state has offered subsidies to Comcast and Charter. The cost, however, is considerable higher than wireless would have been in most such cases. Many parts of Chesterfield would likewise be quite costly to reach via cable.

In this report we will address the actual design of the proposed wireless network, its costs, its key sites, and key operational issues for its construction and operation.

Radio spectrum issues

A wireless network design has to deal with issues of available radio spectrum. Broadband access networks need relatively wide swaths of spectrum in order to operate. Radio spectrum in the United States can be divided into three basic categories: licensed, unlicensed, and federal. The latter – spectrum controlled by the federal government – is not even regulated by the Federal Communications Commission, but by the Department of Commerce (NTIA), except to the extent that it is *shared* with civilian use. Recent acts of Congress have, however, forced the federal government to give up or share increasing amounts of its spectrum, which is largely used for radar.

Licensed spectrum is, for the most part, unavailable for this type of project. Major blocks of spectrum have been auctioned off to the Commercial Mobile Radio Service (CMRS) providers, such as AT&T, Verizon Wireless, and T-Mobile. And even where they are not making extensive use of it in or near Chesterfield, they are allowed to "bank" it and keep others from using it.[1] Thus we are focusing on unlicensed or, at most, "lightly licensed" or "licensed by right" spectrum, and one special case, TV White Space, wherein a licensed frequency band has vacant channels that can be used, with some restrictions, on an unlicensed basis.

[1] This is not the case, however, for two future bands. The 3550-3700 MHz Citizens Broadband Radio Service will auction off *priority* access, but unlicensed use will be allowed where priority licensees aren't using it. And the TV White Space rules will permit some unlicensed use of TV channels that are auctioned off (in late 2016) for other services, until the other service licensees put them into service.

Wireless Internet Service Provider (WISP) operation has largely used three unlicensed bands, 902 MHz, 2.4 GHz, and 5 GHz. The 902 MHz band is narrow (26 MHz wide) and crowded in many areas by utility meter reading devices. It has seen little new usage in recent years, even though it has decent non-line-of-sight properties and foliage penetration, though it remains a viable option in some locations. The 2.4 GHz band is widely used for Wi-Fi and Bluetooth, as well as microwave ovens, baby monitors, and many other devices. As such it is usually too congested for widespread WISP use *except* in very rural areas, where the combination of low density and woods reduces the noise level. The unserved areas of Chesterfield may fall into that category. It has modest foliage penetration, and thus the 2.4 GHz band may play a role in subscriber access.

The 5 GHz band actually consists of multiple sub-bands with different regulations. The middle of the band is shared federal spectrum and requires radios to have radar detection, and to change frequency when radar is detected. The allowed power level there is relatively low. Two other sub-bands have higher power limits and do not require radar detection. This band has been the focus of most WISP development over the past decade. It has a wide selection of radio equipment, at low cost, and radios are now available that can carry about a gigabit per second on a point-to-point link. Even shared point-to-multipoint access channels can operate at 300 Mbps. However, it is easily blocked by hills and foliage, and thus cannot easily reach a significant share of Chesterfield's unserved homes, especially in the more wooded areas.

The best foliage penetration is available on the lowest-frequency available spectrum, TV White Space (TVWS). The access point must connect at least daily with a Spectrum Authorization System[2] in order to verify which channels are currently available at its location. As of this writing, between five and fifteen 6-MHz wide UHF TV channels are "white" in different parts of Chesterfield, more than sufficient to use wherever required. (No equipment is available to make use of vacant VHF TV channels, which are also technically available.) TVWS gear is relatively expensive, compared to other frequencies, and its narrower channels limit total capacity. Thus it is used as a last choice, but given parts of Chesterfield's dense foliage cover, especially in the unserved southern areas of the town, this nonetheless appears to be best choice for about 30% of potential customers.[3]

Another band, at 3650-3700 GHz, has been available on a "lightly licensed" basis. This behaves somewhat like 2.4 GHz, and some equipment is inexpensive. However, licensing was frozen as of April, 2015, and only existing licensees can use it at present. (WiValley, a Wireless ISP based in Keene, is one such licensee.) This is because it is being subsumed into a new 3550-3700 MHz Citizens Broadband Radio Service (CBRS). The new 3550-3650 range is shared federal spectrum, used mostly for naval radar, and the time at which it becomes available may depend on proximity to coastal base locations. (Chesterfieldf is, fortunately, outside of the coastal Exclusion Zone.) Under CBRS rules, a Spectrum Authorization System is required to assign frequencies to all access points and most fixed clients, based

[2] Contracts with the SAS are entered into by equipment vendors, not WISPs or users. Google, Spectrum Bridge, and Ericsson iConnectiv (f/k/a Telcordia) are among the operators.

[3] The TVWS equipment of choice is a new generation from Carlson Wireless that is expected to come on market late in 2016 (prototypes exist now), at a more reasonable price than earlier gear, and should be capable of 25 Mbps service to subscribers that receive a reasonably strong signal.

on a three-tier priority system, and that system is some months from being available. It is somewhat more complex than the SAS used for TVWS. It is possible that this band will open up in 2017.[4]

Existing licensees *may* install new equipment on the 3650-3700 MHz band, but it operates at a lower priority than equipment registered before April, 2015, and in any case most grandfathered licenses expire in 2020 (a few may continue until 2023). Thus investment in this band is only recommended when the equipment vendor has committed to upgrading to CBRS. For the most part, this is LTE equipment, still relatively expensive, and does not seem to offer advantages at this time to Chesterfield. However, a new generation of relatively low-cost *fixed* 3650 MHz LTE gear is now in trials, so it may become useful for future network upgrades, even if it is not available during the time of the initial build.

Higher frequency bands are available for point-to-point use, but do not appear to be needed in Chesterfield. Licensed microwave, on higher frequencies, may however be useful to provide the backbone (upstream) connection to an Internet Service Provider.

The backhaul links between sites will primarily use 5 GHz point-to-point systems, but 2 GHz point-to-point links may be used at some locations if tree density makes 5 GHz unworkable.

Path prediction methodology

The radio network design was prepared with the help of Radio Mobile, a widely-used mature program for predicting coverage. It predicts point-to-point paths between two sites in a network using a model that takes into account both terrain and ground cover. The terrain data comes from SRTM, the Shuttle Radio Topography Mission, a worldwide digital topography model based on radar taken by the Space Shuttle Endeavor in 2000. Its precision is between 1/3 and 1 arc-second. Ground cover data is taken from the US Geological Survey. For this study, deciduous and mixed forests were assumed to have a tree height of 22 meters; evergreen needleleaf forest 23 meters. These dominate in New England. Old-growth trees do get taller, and recently-logged forests are shorter, so coverage predictions may vary from actual performance based on the imprecision of these estimates. Sites thus need to be evaluated during final base station siting.

Paths between each base station site (pole or tower) and each subscriber were computed on all four bands of interest using Radio Mobile. Because the cost and performance of higher frequency bands is superior *when* the path is usable, the budgetary network design uses a “waterfall” method (in Excel) to assign homes to bands: If a 5 GHz signal is predicted to be strong, use it, if not use 2.4 GHz, if not use TVWS, if not use 900 MHz, and if none are strong signals, repeat, comparing the bands in the same order with lower signal strength thresholds, which are likely to either provide slower service or require larger antennas. The final determination of which band to use at a given location will be verified at time of installation. It should be noted that the path quality prediction software is configured with a 70-75% probability factor: The signal is that likely to be *at least* as strong as predicted. Thus in most cases it will be stronger than that.

[4] The FCC has essentially delegated the creation of standards for the CBRS SAS and its users to the Wireless Innovation Forum (WinnForum), a membership trade association. The author participates at WinnForum as a representative of the Wireless ISP Association.

Geographic Network Design

The design was based upon a list including all of Chesterfield's homes. They were divided into "served" and "unserved", based on whether or not cable modem service was available. Some of the "unserved" locations can get DSL, but that does not reach 10 Mbps, and DSL service in non-cable areas tends to be especially spotty, due to distance.

The original list included 1791 locations. Each of these was assigned a street address for the purpose of this study; however, these did *not* necessarily have the *correct* street numbers, so the generated "band selector" spreadsheets show these addresses but may not be labeling them correctly. This set of addresses was further narrowed down to 717 for the study: All of the "unserved" addresses were kept, but only a sampling of "served" addresses was retained, mostly for comparison and path-sampling purposes. A few percent of homes also did not have actual latitude/longitude coordinates, so they could not be evaluated for coverage, but it is highly likely that they will receive service if their neighbors do. The final study thus involved 337 unserved homes with known coordinates, and also computed coverage data to about as many served homes.

The working network design provides coverage to over 95% of Chesterfield's currently-unserved homes. It makes use of 15 "base station" locations, which are a mix of new and existing towers and new wood utility poles (dedicated to the purpose, not attachments on existing poles). A network hub location still needs to be identified, based upon connectivity to the upstream provider. A site near Town Hall or the nearby municipal office building is a possibility.

Site name	Latitude	Longitude	Height	Type
Streeter Hill	42.92222	-72.49917	80-90'	New tower
Spaulding Hill	42.88167	-72.53778	65'	Pole
Wellington Dr	42.90944	-72.40472	47'	Pole
Town Hall E lawn	42.88778	-72.46972	42'	Pole
River@Stoneleigh	42.93	-72.52389	57'	Pole
BST Brattleboro	42.88778	-72.5525	80'	Commercial tower
Atherton Hill Rd	42.90556	-72.39361	57'	Pole
Herrick	42.88222	-72.51194	57'	Pole
Pinn Spgs.&Split Oak	42.91083	-72.46	47'	Pole
Rt. 63S	42.86083	-72.47833	65'	Pole
S end OSR	42.86889	-72.38194	42'	Pole
Mid-OSR	42.88278	-72.40556	42'	Pole
Zinn near 43	42.89194	-72.41028	65'	Pole
Merrifield East	42.86194	-72.50417	42'	Pole
Gulf west hollow	42.87528	-72.52722	42'	Pole

Base Station Site locations.

The preciseness of these locations varies from place to place. In many cases the pole can be moved tens of feet, or across a street, in order to find a more suitable or easier to build location; in some spots where hill tops or trees may block critical links, the specific site may need to be very carefully selected. These sites are selected based on a model that takes into account terrain and ground cover, but only approximates tree height, and only has 25-meter accuracy for ground cover. Thus actual visual sighting should precede installation siting. A weather balloon on a calibrated tether may be useful for determining actual height tree and tower visibility.

A 42’ height is the top of a 50’ standard wood utility pole (which is set 8’ into the ground). A 65’ height is achieved from an 80’ pole. While larger poles exist, even an 80’ pole runs the risk of being too large to transport to some locations, due to the turning radius required of the transport vehicle. It should also be noted that antennas can be installed above the top of a pole, so if a few extra feet of height is needed, a mast can extend it higher. Poles up to the 47’ level can be accessed via a standard-sized bucket truck, or by climbing. Taller poles are likely to require the services of a tower climber. A small equipment box mounts on the side of the pole for locations with a small number of radios (sectors plus backhaul) on it; a larger pole or tower will have its electronics in a pedestal.

Gaps in coverage

A handful of unserved homes were predicted as not reachable with adequate signals using the provided design. They are identified on the attached spreadsheet. Suggested means of potentially reaching them are also noted. This may involve putting a “mini-POP” at or near a nearby served home, or using a taller-than-normal antenna mount. A “mini-POP” differs from a base station in that it does not have a dedicated backhaul microwave radio, but instead shares a subscriber access radio with its own access point.

It must be stressed that predictions of coverage are based on probabilistic estimates. Coverage may be better or worse than predicted to any given home. While a relatively conservative model was used, actual performance will be impacted by factors such as tree height and density and neighboring house locations.

Sector antennas

For each location, one or more sector antennas, with associated radio, is mounted with specific beam headings. It is quite rare for “360 degree” coverage to be necessary, as a mountain is usually in the way in one or more directions. Often a site serves users in only one direction, at least on a given band. But some sites may require several sectors, on multiple bands. The majority of sites use two 90° sectors; some use three, some only one, on a given band at that site. This is in addition to the backhaul network of dedicated microwave radios.

Sector *capacity* is rarely if ever expected to be a problem. A single 5 GHz or 2.4 GHz access sector should be able to support 20-30 users, and few in this design see that many end users. The main exception appears to be the commercial tower in Brattleboro that can be rented from Blue Sky Towers. It reaches over 50 unserved homes, almost all from south to east, with a sufficiently clear path to use 5 GHz. But that load can still be divided between two overlapping 5 GHz sectors on that tower, using different channels. As a commercial matter, the site on Pinnacle Spring Road overlooks Spofford Village across the lake. Those are not unserved homes and are not counted in the inventory. But if the network operator chooses to compete for their business, an additional sector would be useful there too. A few other base station sites also have similar opportunities. TV White Space and 900 MHz channels are narrower, but still no planned sectors appear to have capacity issues.

Backhaul links

The point-to-point links between the base station sites are designed to provide redundancy in most cases, so that failure of one radio or link will not impact sectors at a redundantly-served site, and will allow traffic to route around a failed link in the backhaul network. (Not all sites are able to get redundant links, as they do not see two other sites.)

It should be emphasize that the links between the sites use separate radios on separate frequencies from the subscriber access networks. These are highly-directive point-to-point microwave radios with a typical beam width of 6 to 10 degrees, vs. the 90 degrees typical of sectors.

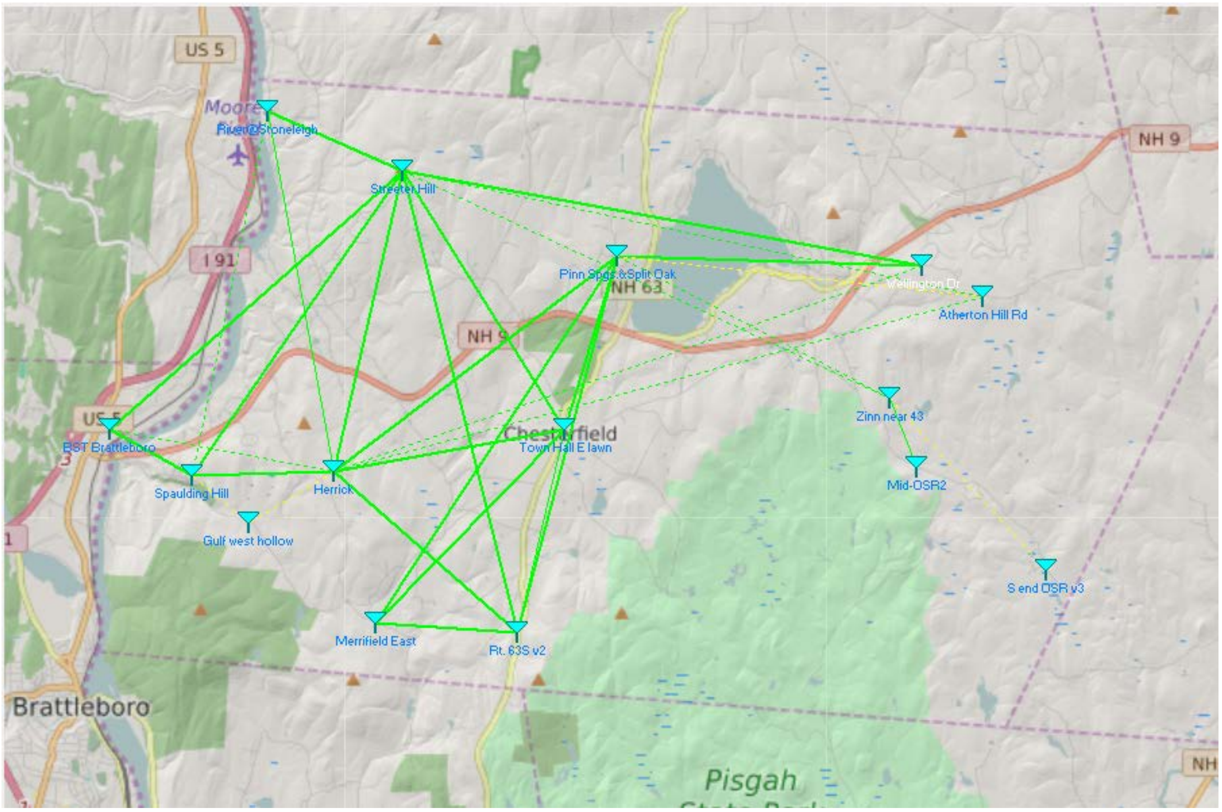

Figure 2 Base station sites showing potential backhaul paths. A subset will be selected for actual use.

Base station sites

A substantial number of candidate sites were examined before arriving at the pattern of 15 sites suggested here. The goal of site selection was to reach as many unserved homes as possible at the least cost. Since the most expensive cost is for building towers, use of roadside poles was preferred. Some site optimization was done after visits to potential locations.

One major hilltop new-tower site, Streeter Hill, is proposed. This site currently supports a large guyed tower owned by the State of Vermont. There is probably room for a second guyed tower, though placement of the guy wires will require extreme care and may be the primary factor in finding the exact location on the hill. By using a 90’ guyed tower, the antennas go above the treetops and will have line of sight coverage for some miles. This is useful for both backhaul and coverage to many unserved homes in the northwest portion of Chesterfield.

Use of one commercial tower is proposed, owned by Blue Sky Towers. This firm is smaller and appears to be far more cooperative than the bigger tower firms, such as American Tower and Crown Castle. The Blue Sky Towers site in Brattleboro is a 120’ tower with one cellular customer on top. It has line of sight to most of the homes on Mountain Road, an otherwise very hard to reach area overlooking the river from the western side of Wantastiquet Mountain, and other west-facing parts of West Chesterfield. Rent is negotiable and is based on both the total size (wind load) of antennas on the tower and their elevation. The 80’ level should be high enough; even 72’, at lower rent, might suffice.

A tower was originally proposed for the ridge west of Zinn Road, but a site could not be secured that did not require extensive road and/or electrical construction. Instead, coverage will be provided by a jumbo pole on Zinn Road itself, relaying from Pinnacle Springs Road to two poles south on Old Swanzey Road. This section of the plan is marginal due to tree cover and may require more extensive testing before determining that a tower, or an additional pole or two, is not necessary.

A site on a hill west of Merrifield Road was originally slated for a tall pole or tower, but it too would have significant cost. An alternative was created by using a standard-sized pole on Merrifield itself and a second pole well to its west on Gulf Road, to fill in that hollow.

Band assignments

Using the waterfall methodology with predicted path quality from various sites, the following map was generated. It shows, via shape, which access site an end user is most likely to connect to, while color indicates frequency band.

It must, however, be stressed that this is merely a *prediction* giving the greatest *probability* of optimal service. In actual practice, some paths will be better than forecast, some worse. An installer should be prepared to swap radios to one on a different band, and redirect the radio to a different site, as required.

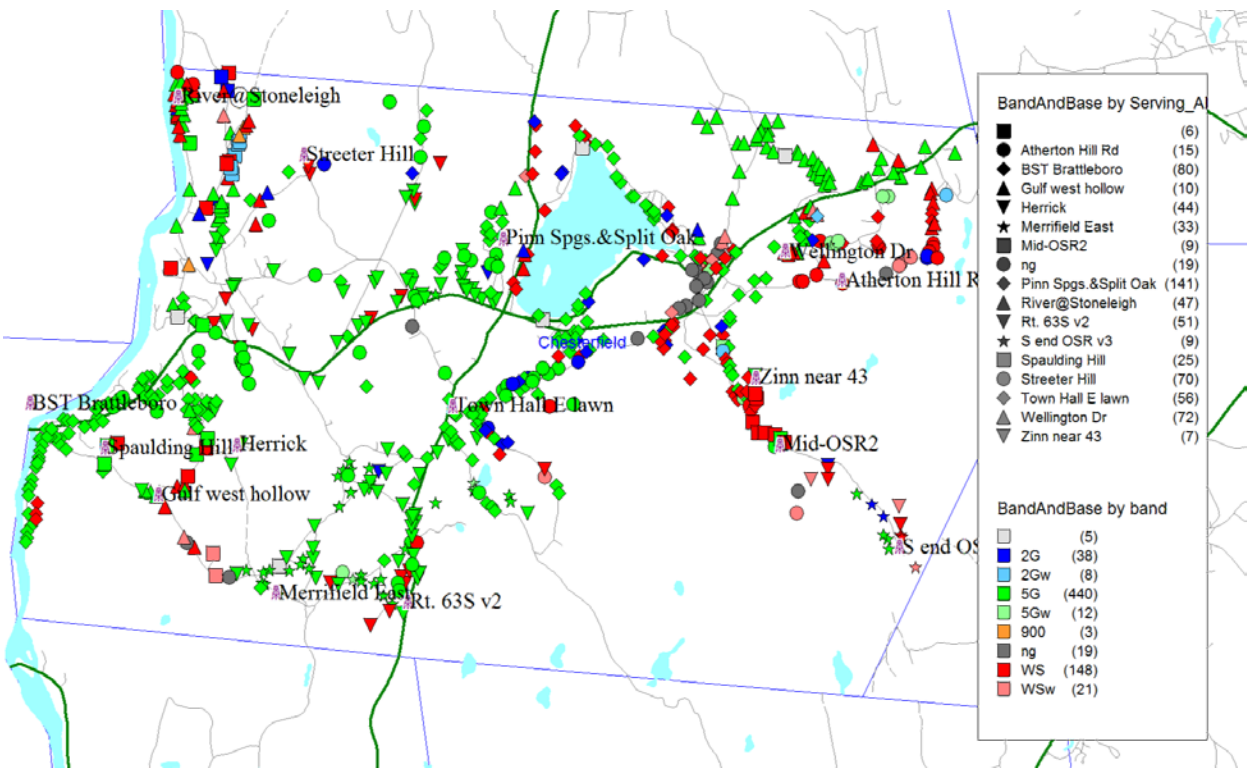

Figure 3 Predicted access sites and most likely bands to be used from each home. Unserved homes and a sampling of served homes are shown. Band assignments ending in ”w” are relatively weak signals, which may require larger antennas or may be unable to achieve 25 Mbps speeds.

The underlying spreadsheet data used to create the picture in Figure 3 can be provided, in Excel and/or KML form, and is included in the budget workbook. Note that the addresses in the spreadsheet may not apply the correct street numbers to each house.

Tower construction issues

The current design contemplates the construction of one new antenna tower, in addition to a series of poles. While a pole and tower are functionally similar and mainly differ in height, the process of installing them differs dramatically.

A pole is processed from a single tree, and is delivered in one piece. It is *set* into the ground by a truck, after a hole is drilled. (Dig Safe, of course, must always precede any underground work.) The process is relatively quick. The 50 to 80 foot poles noted herein have a suggested underground depth of 8 to 15 feet, though this may vary slightly based on soil conditions.

Tower erection is far more elaborate, though it varies somewhat depending on the type of tower. There are three broad categories of tower:

- Guyed lattice towers.
- Free-standing lattice towers
- Monopoles

Guyed lattice towers are generally the least expensive. They typically are constructed from uniform 10’ or 20’ sections. Most are galvanized steel: While aluminum towers exist, they are brittle and more prone to failure. The tower base is typically a fairly small cube of concrete, as small as 1 cubic yard for a small tower. The tower is supported by three sets of guy wires. These are anchored at strategic positions, in buried concrete blocks (or in rock supplemented with concrete), to support the tower against winds from any direction. Often two or more sets of guy wires are required, especially when the tower is more than 60’ high. The most popular guyed tower is probably the Rohn 45G, based on a 16 ¾ inch equilateral triangle design. Guyed towers work well in open fields, but placing the guy wires can pose a problem in wooded areas, where trees may have to be removed. The cost of a guyed tower rises slightly faster than linearly with height.

Free-standing lattice towers do away with the requirement for guy wires. In exchange, most have much less wind-load capacity than guyed towers, though they can be engineered to any requirement. They typically take a pyramidal form, wider at the bottom than the top. As they are engineered to be taller, the incremental sections are added at the bottom, meaning wider, and thus the cost rises much faster than linearly with height.

Monopole towers are free-standing towers that essentially take the form of a hollow metal (or fiberglass) pole. The diameter is narrows only slightly towards the top. The structural support for the tower is in the underground tower base. One form of monopole base, *direct embed*, also called a *caisson base*, is much like a pole – a base section is embedded in a deep, round hole. For a steel monopole this is typically about 20% of the above-ground height. (Fiberglass, being lighter, requires a somewhat smaller hole.) It is easy to install these in soil, but not in ledge rock. The other type, the *mat base*, uses a large volume of reinforced concrete, typically 10 to 30 feet square, buried about 4’ below surface level, to anchor the tower. Monopoles are generally more expensive than alternatives, but are also seen as less obtrusive, and are more easily disguised with "stealth" decorations (fake tree parts).

Tower installation must be carefully engineered, especially for freestanding towers. Typically this begins with a geotechnical survey, in which the ground is drilled down to bedrock to determine its composition. A Professional Engineer then prepares a report, which the tower manufacturers use. The tower base is then engineered to suit the ground. The ground can then be excavated to support the base, and the base is built with concrete. The tower is then erected over the base. A monopole is typically installed, section by section, by a crane. Guyed towers and fiberglass monopoles can, however, be installed by hoisting one section on top of the next using a gin pole or similar rigging.

Hence a tower site does require a small clearing for the trucks, as well as a truck road to provide access. The Streeter Hill site already has one guyed lattice tower present, and a good access road, so the only issue will be locating it on the site, especially avoiding a conflict between guy wires and the roadway and power lines alongside it.

If a tower is built on the hilltop off of Old Swanzey Road or Zinn Road, it will require an access road good enough to bring up construction trucks, and to provide year-round access for maintenance. Power, of course, will also be required. It is likely to be easier to bring in power aerially, perhaps via short poles along the access road, than to trench under the typically hard, rocky ground. Off-grid power via wind chargers and solar is possible, but requires additional types of engineering.

Hardware selection

Performance of the network is in large part dependent upon hardware selection. The radio gear needs to be appropriately selected for each of the three access frequency bands plus backhaul, and the network switching gear also needs to be properly configured. Each radio site also needs a power system.

Site switching hardware

A cabinet or pedestal will be installed at each tower or pole, housing an outdoor-rated Ethernet switch and a power subsystem. All of the equipment is DC powered, using Power over Ethernet (PoE). The site cabinet will include a rectifier to produce DC power and batteries needed to provide reserve power for some period of time (tentative design goal: 8 hours, but critical sites may warrant more). The optimal candidate for a switch in most sites appears to be the Netonix WS-12-250-DC (under $400), which provides programmable, remotely controllable PoE insertion, minimizing the required space and allowing devices to be remotely rebooted. It also monitors and conditions battery voltage. Category 5E or 6 shielded twisted pair outdoor-grade Ethernet cable is then run up the pole or tower.

Core hardware

The network will converge at a central location where it will meet the upstream ISP. A small router is installed there to act as the hub of its network. That router also manages the rate caps assigned to each subscriber account. An example of such a device is the Ubiquiti EdgeRouter Pro (under $400). An uninterruptible power supply with extended battery life is also required.

Radio hardware

The radio hardware used by Wireless ISPs generally falls into two broad categories. Some systems are fully proprietary and based on highly customized hardware. Others make use of commodity Wi-Fi chips. The latter are far less expensive and nowadays some perform quite well. These are *not* Wi-Fi *per se*; Wi-Fi is designed for short-haul indoor use and does not work well when many radios that do not hear each other share an access point. WISP-oriented vendors thus customize the firmware to have better long-range operation, and surround the chip with a higher-power transmit amplifier and low-noise receive amplifier. Unfortunately, each vendor's approach to this is proprietary, so different vendors' Wi-Fi-derived radios do not interoperate unless they are set into Wi-Fi compatibility mode. Customer Premise Equipment (CPE) radios thus must correspond to the same product line's sector (access point).

The following units are suggested as the best selections in the late 2016- early 2017 time frame.

5 GHz access: Two vendors have state-of-the-art radios first shipped in 2016 that take very different approaches to using Wi-Fi chips.

- Cambium Networks makes the ePMP family. The ePMP 2000 ($400-600, plus about $200 for the sector antenna), announced in mid-2016, is the latest 5 GHz access point, with an optional beam forming antenna to reduce interference (not needed in rural areas). These are discrete GPS-synchronized sectors; GPS synchronization allows a degree of frequency reuse at a site and may reduce interference between sites. The CPE includes the small (16 dB gain) Force 180 and large (25 dB gain) Force 200. Due to the lower cost of Force 200 (under $150) compared to the C5c, and the need for high-gain antennas, this appears to be the most cost-effective solution. However, final selection may need to await future reports on side-by-side testing.
- Mimosa Networks makes the A5 family of access points and the corresponding C5 CPE. The $1000 A5-360 puts four 90 degree sector antennas into a single small package, making it the easiest to deploy in a multi-sector site. However, the $100 C5 is a fairly lame radio for a deep-woods operation, with a 20 dB gain integral antenna. The $120 C5c is connectorized and can use an external high-gain antenna, but the combination is much costlier and installation more complex. No actual matching high-gain antenna has been shown yet, either.

2.4 GHz access: The Cambium ePMP 1000 appears to be the best choice here. The $500 GPS-synchronized access points can make the most effective use of this narrow band (essentially only 3 20-MHz channels wide, one of which is needed for Wi-Fi at the home). The Force 200 CPE for 2.4 GHz is inexpensive and offers high gain.

TVWS access: The Carlson Wireless Rural Connect Gen3 is unproven, but promising. It is the first radio to make use of the new IEEE 802.11af standard, which is designed for long-range TVWS use. Carlson's earlier products were costly and limited to about 10 Mbps, but the Gen3 family should support 25 Mbps subscriber access. The base station radio serves up to four sectors from one box ($5000) ; the CPE (expected to be about $200) uses an external antenna. This is far more cost-effective than earlier TVWS gear and is probably the most cost-effective non-line-of-sight system, if in fact it works as promised and can be delivered as promised.

900 MHz access: A backup solution for non-line-of-sight use is the Cambium PMP450i 900 MHz radio. The 900 MHz band is small (902-928 MHz) and in many areas suffers noise from power meters and the like, but had reasonably good foliage penetration. The 900 MHz PMP450i, introduced in late 2015, can provide 25 Mbps connections over a 10 MHz-wide channel. The sector (with antenna) costs about $2700 and the CPE around $300, making it fairly expensive. This may also be more cost-effective than TVWS for small base stations where only one sector is needed.

Backhaul (5 GHz): The performance leader in reasonably-priced 5 GHz backhaul radios, and likely choice, is the Mimosa B5 (about $600). This is built into an integral 25 dB dish-like antenna and, unlike almost every competitor, divides the data across two separate frequencies to provide maximum speed and resilience. It can theoretically operate at 800 Mbps, if not faster. As these have integral GPS synchronization, a set of these on a tower can share some frequencies without mutual interference. A connectorized version (B5c) can use an external antenna, if required for higher gain or a more customized installation. A second option in the same price range is the Ubiquiti AirFiber 5X, a connectorized (separate antenna) radio capable of similar speeds, and also synchronized. However, neither shares its synchronization with Cambium ePMP products, so the 5 GHz sectors will need some frequency isolation from the backhaul radios. The Cambium Force 110 PTP does sync with the ePMP line, as it is actually a repackaged ePMP sync radio with a 25 dB dish, but it lacks the capacity of the Mimosa and AirFiber lines.

Business model

The Town of Chesterfield cannot afford to build the entire network out of municipal funds; New Hampshire towns are also not allowed to issue multi-year bonds for projects of this type. It thus will require the assistance of a partner to both operate and pay for the network. That partner, the Network Operator, will be responsible for installing the network, maintaining it, providing or procuring upstream Internet service, handling customer service, and billing. Because the Network Operator will be funding most of the network, it will also own profit and loss responsibility. The Town should, however, have some supervisory role over the pricing and service offerings. The Network Operator should probably be selected via an open RFP process, but the selection is not based on price, but upon qualifications, experience with rural fixed wireless systems, and willingness to work flexibly with the Town.

The unserved areas are, to be sure, unserved precisely because they are not profitable to serve. Thus the Town will need to bear some of the expense, in order to make the business viable. This would most likely be a one-time expense to the Town.

The anticipated capital budget for the entire network is approximately $450,000. This includes the cost of installing customer premise equipment radios for approximately 200 subscribers, based on a 60% take rate of the unserved homes. Just over $100,000 would be for vertical assets – towers and poles. The single greatest contribution the town can make to a private network operator also is the one that costs it nothing – the rights of way to the town roads, so that poles can be erected at roadside locations. If the Town were to also pay for (and own) these vertical assets, the private operator's cost of construction would be lowered by this roughly $100,000, and any issues of right of way use would be avoided. The Town can thus work with the selected Network Operator to install the vertical assets at the optimal points, and lease them to the Network Operator for a minimal (e.g., $1/year) sum so long as they are being used to provide the desired service.

Retail services to be delivered

The network will deliver broadband Internet access service at speeds superior to the current DSL service available to part of the town, with service quality far superior to satellite options. Typically it will support "25/3" access rates. However, homes with weak signals may not be capable of full-speed operation. They would be more likely to get 10 Mbps service. About 7% of homes to be newly served are currently estimated to be able to receive usable, but weak, connections. This may or may not prove out in the field, as exact signal strength is hard to predict on a path that has foliage in the way. The new TV White Space radios should however be able to match the 25 Mbps speed in most cases, again excepting the weakest paths, predicted to be about 20% of TVWS. This is a higher percentage because TVWS is only used where trees already are in the path.

Business services can be delivered on a customized basis. Should a business in an unserved area require a "bigger pipe", it is possible to build a customized connection via point-to-point tower access similar to the high-speed backhaul, to provide symmetric service speeds of 100 Mbps or higher. Most of the Town's business, however, is in "served" areas, and addressing the needs of high-bandwidth business users is beyond the scope of this report.

Telephone service

Telephone service is not included in this plan per se. *However* it can easily be added as an incremental service. The proposed network is likely to have sufficiently good connection quality to most, if not all, locations to be able to support acceptable telephone service. It bears noting that there are two very different types of "voice over IP" (VoIP) telephone service. One, typified by Vonage, is "over the top" or "parasitic". It is simply an application subscribed to by the end user, with no involvement by the ISP. Thus, there is no prioritization of voice packets and no means to assure quality of service (QoS). These services are likely to work across the planned network, but will probably not be competitive, in terms of quality, with FairPoint's wireline options (which is not a high bar). Because the ISP is not involved, there is no budgetary impact; nor is anything done to improve its quality.

A second type of service is better referred to as "voice *using* IP" (VuIP). This is what cable companies such as Comcast offer. The network gives priority to voice packets, and connects to the telephone network through a local voice service provider, entirely *bypassing* the public Internet (which does not handle voice well). This provides high-quality connections (usable for fax and other non-voice applications as well). The network operator should be able to offer this in conjunction with a local voice provider. Such services typically have a retail price of about $20-25/month/line, including domestic long distance, which offers a decent profit margin over its wholesale cost, which is typically $10-12/line.

Note that for VuIP service to work, the network must be engineered *from the beginning* to support prioritized service. All major equipment vendors have the capability in their equipment, though it may need to be configured. This also works best over a "Layer 2 switched VLAN" network, which can assign phone service to a separate VLAN and does all routing at the core, vs. a "Layer 3 routed" network that does routing in the field. The recommended Netonix switches are Layer 2 VLAN-compatible and should be adequate for this.

Budget

In budgeting the capital cost of the network, the band and site assignment model was used to determine how many unserved homes would ideally be served on each band. The totals used for budgetary purposes are:

	In range	eq. take	rev take	
5G subscribers	215	129	124	64%
2G subscribers	25	15	14	7%
900 MHz subscribers	6	4	3	2%
TVWS subscribers	91	55	52	27%

The In Range number is produced by the model. The equipment take number is based on a 60% take rate. The revenue take number, used by the Operating budget, derates this slightly to account for a guesstimated 8% of homes being seasonal and used on average 50% of the year. They still need equipment all year, though. Thus revenue is based on 4% derating.

A very large share of the capital cost is in the vertical assets (poles, towers). Sector radios mounting on the towers and poles are also a significant expense, though on a per-subscriber basis they are quite reasonable. This table shows the field-network expenses, including vertical assets and the equipment associated with them:

	Material Price	Install Cost	Count	Material Total	Install Total	Total cost	Notes
50' wood poles	$1,400	$1,400	6	$8,400	$8,400	$16,800	Class 1 wood
55-60' wood poles	$2,400	$2,300	2	$4,800	$4,600	$9,400	Class 1 wood
70-80' wood poles	$4,700	$2,800	6	$28,200	$16,800	$45,000	Class 1 wood
90' towers	$12,000	$11,000	1	$12,000	$11,000	$23,000	with appurtenances
Lit sites/cabinets	$2,500	$1,000	16	$40,000	$16,000	$56,000	for box, switch, batteries, etc.
Sites needing power installed	$200	$600	15	$3,000	$9,000	$12,000	short trench to metered pole
Sites w/TVWS	$5,000	$300	9	$45,000	$2,700	$47,700	Multi-sector APs
5 GHz sectors	$600	$250	23	$13,800	$5,750	$19,550	ePMP 2000 (most Lite)
2.4 GHz sectors	$600	$250	5	$3,000	$1,250	$4,250	ePMP 1000 sync
900 MHz PMPi sectors	$2,700	$250	1	$2,700	$250	$2,950	
TVWS sector antennas	$300	$125	19	$5,700	$2,375	$8,075	
Backhaul radios	$600	$250	36	$21,600	$9,000	$30,600	Point to point, used in pairs
MiniPOPs	$950	$650	2	$1,900	$1,300	$3,200	Fill in gaps using CPE backhaul
Field Network Total				$190,100	$88,425	**$278,525**	

The tower is budgeted as a guyed lattice tower such as Rohn 55G. A freestanding monopole would be significantly costlier, but a valid price estimate would require a site survey.

Breaking those numbers down into vertical assets and electronics:

Material	Installation	Total	
$56,400	$49,800	$106,200	Vertical assets: towers, poles
$131,000	$38,375	$169,375	Field network equipment
$182,850	$89,000	$264,850	Network+CPE eq. total

As discussed as part of the business model, the vertical assets may be a line item to be owned by the town while the other equipment, both field network and customer premise, might be owned by the partner Network Operator. The CPE totals included in that table are computed next.

The CPE radios themselves (also called Subscriber Modules, especially by Cambium) are budgeted according to the expected take rate. The cost of installing them, and possibly of acquiring them, may potentially be recovered from subscribers via an installation charge, but this capital budget does not discount based on anticipated revenues. An inexpensive ($25) Wi-Fi router, such as the MikroTik hAP, is also budgeted, to function as a demarcation and in-home access point.

	Users	Spares	Material	Labor	Total
5 GHz Force 200	129	3	$19,800	$25,800	$45,600
2.4 GHz Force 200	15	3	$2,700	$3,000	$5,700
900 MHz PMPi SM	4	1	$1,875	$1,000	$2,875
TVWS subscriber units	55	3	$17,400	$13,750	$31,150
Wi-Fi in home (if selected)	203		$5,075	$5,075	$10,150
total take	203		$46,850	$48,625	$95,475

There may also be a significant cost to bring AC power to the poles. It is presumed that the wood poles will all be set somewhere near where existing AC service exists, hence the low ($800 per pole) *very rough* estimate. The poles only draw about 50 to 200 watts each. Power will need to be trenched from the nearest electric utility pole to the antenna pole.

Finally, certain common costs apply, both for core hardware and for overhead. The Administrative line is for oversight, RFPs, business operation, project management, tower siting paperwork, marketing, etc. Actual costs depend, of course, on how much is done by the network operator, and how much is done by the Town, how much is volunteered vs. paid, etc.

		h/w	labor	total
Core routing/switching		$5,000	$2,000	$7,000
Spare common equipment	4%	$5,440		
Design/engineering/integration			$20,000	
Administrative			$30,000	
Commercial tower setup fees			$2,000	
Upstream IbSP installation			$4,000	
project mgt total			$56,000	

Adding it all up:

$442,440	**Total CapEx**
$ 2,292	total CapEx/revenue subscriber
$392,440	Total CapEx without admin overhead

Operating Expense

At this stage, operating expense is more speculative. The Network Operator will take this into account when setting prices. Naturally, the more subscribers that the cost can be divided among, the lower the per-subscriber cost. Thus providing some competition to existing cable and DSL services is likely to help serve the rest of the Town, even though that is not a goal per se.

The Network Operator's expenses will include, among other things, the cost of Internet backbone service including backhaul to a major site such as Manchester or Boston. It will also include labor, break/fix replacements, network operation/billing software, insurance, and tower rental (Blue Sky Towers).

Depreciation should also be figured into the Operating Expense. The poles and towers can be treated as 30-year assets, but the electronics has an economically-useful life of 5 years. The actual useful life of a piece of gear may vary, of course, depending on what comes long next, but 5-year depreciation seems prudent or even on the long side today, given the rapid rate of progress.

It seems reasonable at this point to estimate that the Average Revenue per User will need to be in the $60-70 range in order to cover all expenses, including depreciation. But this remains to be seen after the Network Operator contract is negotiated.