Town-wide broadband service for Middlefield: Budgetary design and cost estimate for a fixed wireless network

Prepared for the Town of Middlefield by Fred Goldstein, Interisle Consulting Group, Jan. 2016

Middlefield is one of the rural towns targeted by the Massachusetts Broadband Institute (MBI) for last mile assistance. The town's current broadband service picture is not good. There is no cable. Only 74% of residents live on roads served by Verizon DSL, but it is relatively slow (<3 Mbps) and has been grandfathered (no new subscribers). It is not clear how long Verizon will even continue to support existing DSL customers. There are no wireless ISPs in town, and cellular coverage is limited.

MBI has prepared cost estimates for town-wide Fiber to the Home (FTTH) across the region. According to an email from MBI Director Eric Nakajima to the Middlefield Selectboard, the total cost to build the town's FTTH network is estimated to be $1.59M. Over $1M of the total would be financed via town debt,[1] and the town would be liable for any costs exceeding the estimate. About 287 potential customer locations have been identified, not all of which are currently occupied homes. A more realistic estimate of the market size would be 60% of that, approximately 173 homes. An all-fiber approach would thus cost more than $8,000 per home served. Lower cost alternatives have thus been sought.

Two alternative scenarios have been posited. One, the least costly, is an all-wireless approach. A second is hybrid fiber-wireless, with fiber to the places where it can be most economically deployed (on a cost/subscriber basis) and wireless to the rest. This report details the former. Building an all-wireless network does not preclude the Town from building a hybrid network. Wireless can be deployed much more rapidly; customers can be phased over to fiber if and when it reaches them.

Challenges facing Middlefield and our approach to solving them

Many of the country's rural areas are now served by wireless Internet service providers (WISPs). The WISP approach is quite different from mobile wireless, and the cost is far lower.[2] WISP service has more in common with wireline services such as DSL than with mobile service, but unlike Verizon DSL, it is continuing to evolve both in speed and capability. However, WISPs are less common in the northeast than in the Midwest and plains states. This is largely because the microwave radio frequencies used by WISPs generally require "line of sight" paths that are impeded by both hills and trees. Middlefield, like most of New England, has plenty of both. This reduces the potential range of each access structure, thus raising the cost. WISPs thus invest where it is easier to break even.

However, even taking these challenges into account, all Middlefield can be reached, and at a cost much lower than fiber. It is simply a matter of precise network design, coupled with the advantages that accrue to the planned Municipal Light Plant ownership. An MLP has access to the rights of way along public roads. In most cases, the municipal land ownership extends well beyond the pavement's edge. This allows a utility pole or even a small monopole tower to be planted alongside the road and used as an antenna support structure. This is less costly than placement on private property, as it removes the cost of land leasing or procurement. Unfortunately, many of the town's hilltops are on state-owned land, not readily accessible, but enough high points are town-owned (mostly roadsides) to facilitate the network development. Note that the design is subject to modification, and if a private landowner offers a better

[1] http://middlefieldma.net/wp-content/uploads/comcom/lastmile/2015-03-04-nakajima-to-selectboard.png.

[2] For example, see *The Essential Role of Fixed Wireless in Universal Broadband Coverage* (same author) http://www.wispa.org/LinkClick.aspx?fileticket=ShArsaERDRk%3d&tabid=3757&portalid=37&mid=6536.

site, it may be worked into the design prior to construction. Another problem previously impacting rural access has been backhaul, gaining middle-mile access to the Internet backbone as well as other services. This has been fixed by the presence of MBI fiber, which now comes to both Town Hall and the fire station.

Finally, there are the operational issues of building and running a network. Middlefield itself has no interest in staffing up its own network operation, and frankly it is too small to sustain a standalone operation anyway. Thus the project will have to deal with both construction and network operation contractors.

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 while they are not making extensive use of it in or near Middlefield, they are allowed to "bank" it and keep others from using it.[3] Thus we are focusing on unlicensed or, at most, "lightly licensed" 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.

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 sees little new usage, even though it has decent non-line-of-sight properties and foliage penetration. 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. Middlefield is one such area. It has modest foliage penetration, and thus the 2.4 GHz band will be a workhorse for 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 thus requires radios to have radar detection, and to change frequency when radar is detected. The power level there is relatively low. Two other sub-bands have much 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 majority of Middlefield's homes.

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[4] in order to

[3] 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 2016) for other services, until the other service licensees put them into service.

[4] 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.

verify which channels are currently available at its location. As of this writing, four 6-MHz wide UHF TV channels are "white" in Middlefield. (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 Middlefield's dense foliage cover, this nonetheless appears to be best choice for about one-third of potential customers.

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 access points operating or applied for by then, and in service by April 2016, will be allowed to operate there at this time. 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 its availability depends on proximity to coastal base locations. While CBRS rules are in effect, they require a spectrum management system to assign frequencies to all access points, based on a three-tier priority system, and that system is many months from being available. It is somewhat more complex than the one used for TVWS. It is possible that this band will open up in 2017.

Higher frequency bands are available for point-to-point use, but do not appear to be needed in Middlefield.

Because the cost and performance of higher frequency bands is superior *when* the path is usable, the budgetary network design uses a "waterfall" method 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, and if none are strong signals, repeat comparing the three bands in the same order with lower signal strength thresholds. The final determination of which band to use at a given location will be verified at time of installation.

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.

Network design concept

The budgetary network design concept for Middlefield anchors the wireless network behind the Transfer Station, extending MBI fiber about 600 feet from the firehouse. A monopole tower about 100' tall will be erected there, to provide both access to the town center vicinity and backhaul to seven other locations. Each of these is either a pole or a tower. Some in turn have backhaul links to sites that do not have a direct line of sight path to the Transfer Station. Figure 1 illustrates the locations of the access points and the connectivity between them.

This table shows the working locations of the proposed access and backhaul relay structures. The named Worthington site is used only if a second MBI access is desired.

Unit name	Enabled	Latitude(°)	Longitude(°)	Elevation(m)	Tower ht. (feet)
Alderman Rd	1	42.3287	-73.0033	465.5	90
Becket Bridge (Bancroft)	1	42.30973	-73.0247	270	42
Chipman S	1	42.3491	-72.9902	418	42
ClarkWright	1	42.3496	-72.9678	332.2	65
East River S	1	42.3624	-72.9678	287	42
Skyline	1	42.362	-73.032	487.8	65
Skyline N	1	42.3718	-73.039	494.5	42
Town Hall	1	42.3446	-73.00935	506	30
TownHill Rd.S	1	42.3362	-73.0306	393.6	42
Chipman Near Root	1	42.36212	-72.99416	485.8	90

Transfer Station	1	42.34985	-73.0119	520.5	100
WASH: Middlefield Rd	1	42.3481	-73.0694	472	42
Chester Rd.	1	42.32765	-72.9989	423.4	42
Cone Rd.	1	42.3719	-72.98287	434.5	47
HPease&TownHill	1	42.3478	-73.0233	466	65
Contingency site					42
Relay-only sites:					
BCKT: Surriner Rd	1	42.3063	-73.0397	356.3	42
East River bend	1	42.3711	-72.9665	272.5	42
Optional MBI access					
WRTH: Old North@River	0	42.42355	-72.9864	457	42

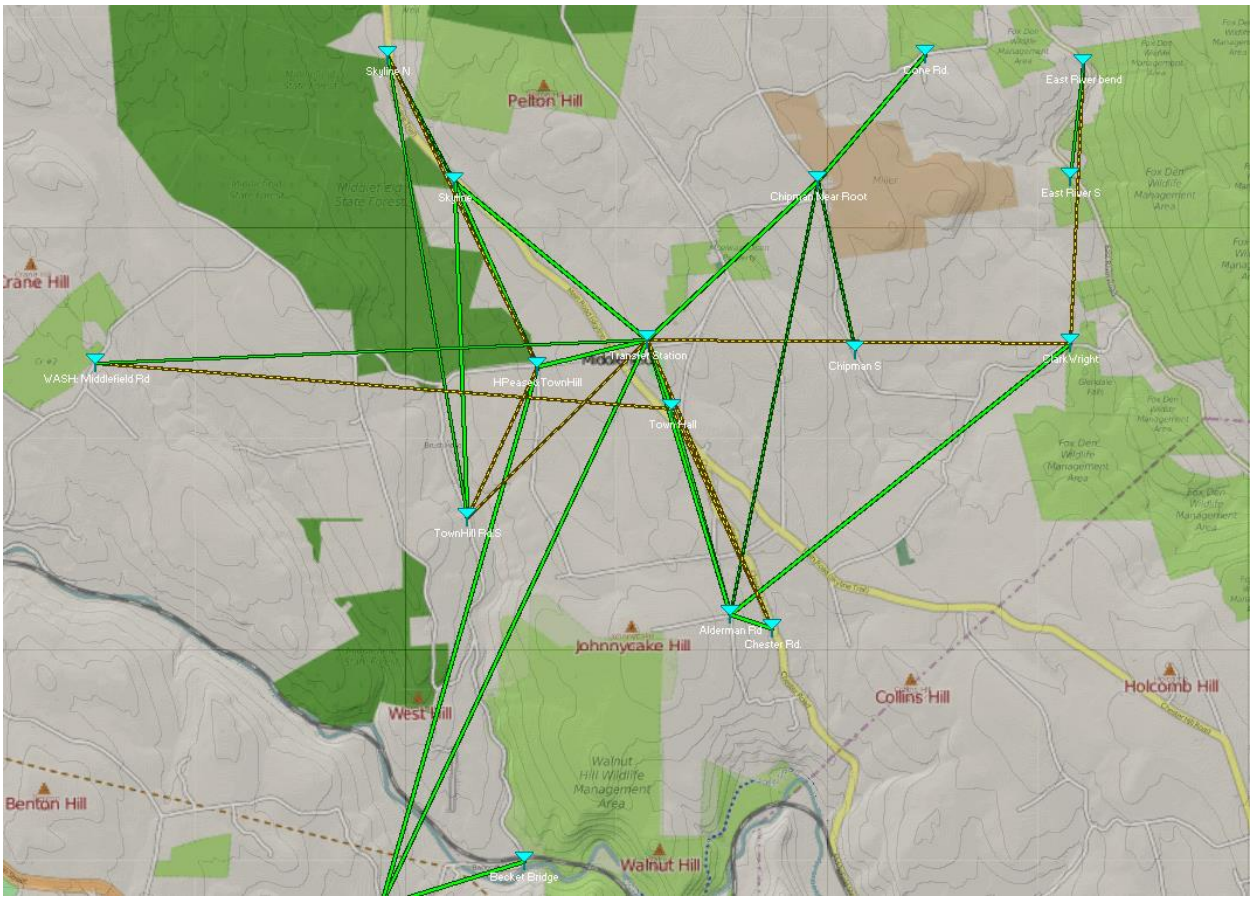

Fig. 1. Connectivity paths between sites in backhaul network. Solid green lines are full speed paths; dotted lines may be weaker. Not all paths will be used. (Surriner Rd. relay site not shown.)

The backhaul network could be significantly simplified if Middlefield gains access to the DCR fire tower on Holcomb Hill in Chester. This is already festooned with many antennas, and while the highest locations would not be needed, gaining any space on the structure is uncertain. Hence the current plan works around its absence. But it merits investigation.

Radio equipment

A final selection of radio equipment will be dependent on pilot results and current vendor offerings. Among the radio systems currently considered:

- 5 GHz backhaul: Mimosa B5 / B5c (integrated dish/connectorized), Ubiquiti AF5X (AF2X for 2 GHz)
- 5 GHz access: Mimosa A5-360, Cambium ePMP, Ubiquiti Rocket M5 or Rocket AC
- 2.4 GHz access: Ubiquiti Rocket M2, Cambium PMP450
- TVWS: Carlson RuralConnect 3G, Runcom RNU4000, 6Harmonics GWS

Each of these has advantages and disadvantages that will be considered in the final design. Some of these devices have not commercially shipped yet (they are in trials) and thus further test results may be needed.

Site switching hardware

A cabinet 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). The leading candidate for a switch in most sites (Netonix WS-12-250-DC, under $400) provides programmable, remotely controllable PoE insertion, reducing the required space and allowing devices to be remotely rebooted. It also monitors and conditions battery voltage. Due to its larger number of backhaul radios, the Transfer Station site may require two such units.

Core hardware

The network will converge at a central location where it will meet the MBI fiber. This could be a cabinet at the firehouse, or the Town Hall, carried by fiber back to the Transfer Station. MBI's contractor, Axia, generally installs its own Juniper switch as a demarcation device. The Internet Service Provider who contracts directly with Axia on the Town's behalf, and who provides the upstream connection at Springfield, also installs a small switch of its own. Finally, the MLP network installs a small router 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), now in use in Royalston. An uninterruptible power supply is also required.

Budgetary cost

A capital budget has been estimated based on a total count of 173 subscribers, based on a 60% take rate, and town-wide coverage. This budget has choices that impact cost, based upon the specific selected equipment; higher-priced radio equipment may provide performance advantages on some difficult paths and thus be worthwhile. The total capital expenditure will be approximately $515k, as detailed on the CapEx page of the accompanying spreadsheet. *This allows for a good margin for contingencies, provided the town receives its full $580k share of broadband funds.*

However, this is based on a total cost of $112,000 for four *installed* monopoles, of which $40,000 is installation cost and the rest is material. The cost of installing a monopole varies widely depending on ground hardness. On soft ground, a tower can be installed rapidly by drilling a 20' deep, 3' wide hole; the bottom piece is inserted and aggregate is poured around it. On ledge rock, drilling such a hole is a major effort. It may thus be more economical to use a different type of tower base. Typically this would be reinforced concrete 4' deep and 10' square. The Transfer Station site is known to sit on ledge. Other sites where monopoles are suggested are in areas suspected to have softer soil.

Some further cost reduction may be found by replacing one or two more towers with jumbo wood poles. Wooden utility poles up to 80' long are available, though not as common as the standard 50' size. Given

required planting depth, these result in 65' and 42' above-ground heights, and by attaching a mast to the top of the pole, some antennas can go above the top of the pole. A 65' pole may not, however, have the structural strength to support the number of antennas needed at some sites.

The proposed capital budget of $515k breaks down as follows:

- $160k for towers and poles.
- $1755k for network equipment (primarily electronics), including about $33k for installation, if the most costly options are used. These include access points, sector antennas, backhaul radios, and site hardware.
- $92k installed for customer premise radio equipment (subscriber modules). This assumes 35% TVWS, 35% on 2.4 GHz, and 30% on 5 GHz. The final mix of bands, however, will be determined after the Middlefield pilot.
- $17k for network infrastructure.
- $70k for project management (final design and engineering costs, tower siting paperwork, project administration and consulting). It is assumed that the MLP will act as a supervisory entity but virtually all of the technical efforts will be undertaken by contractors.

These numbers are intentionally imprecise, and are for the most part rounded up in order to accommodate some degree of uncertainty in the estimates. Actual prices for the new-generation of TVWS equipment that we intend to use are not yet released; current-generation prices have been used.

As wireless delivery continues to advance rapidly with new spectrum and technologies, the budget references a possible 2017 trial of soon to be available LTE technology that may have superior price/performance over existing bands, particularly TVWS.

A hybrid fiber-wireless design is also possible, of course, and has been outlined in the past. Fiber would essentially be incremental to this cost. As such, it is not included in this project plan, but could be designed as a separate project. Should the Town decide that its initial network will have a fiber component, the capital construction contract would necessarily be considerably larger and the project would take far longer.

Operating model

The proposed wireless network will need to be operated under contract by an existing Wireless ISP. Proposals will be invited from multiple candidate entities. While no existing WISP has personnel "on the ground" in the immediate vicinity of Middlefield, it is likely that a network operator will be able to station an employee in western Massachusetts who can support multiple town networks. Most administrative functions can be handled remotely; only installations and some repairs need on-site visits. The network operator can bill customers in the MLP's name, as billing is typically a capability of ISP operational support software.

The Wireless ISP network operator will, in turn, purchase some number of Mbps total capacity from an upstream (backbone) vendor on the MBI network. Access Plus and Crocker are two such entities; others may be available.

We suggest that the network operator contract with the MLP be based on a fee for service basis, with fixed monthly fees for supporting each subscriber and each access point. The MLP will have P&L responsibility for the overall network and will define the service plans and prices. This model reduces the risk exposure of the network operator and simplifies vendor management by the MLP. (Experience has shown that a division-of-revenue model increases complexity and creates both risks and conflicts.) The network operator contract will specify target times for various types of response (minor repair, major repair, installation, etc.). The network operator will manage the network through its Network Operations

Center and will take calls from customers. It will periodically send reports to the MLP. The MLP will have real-time access to the network operations software, in order to monitor network performance and loading.

Retail services to be delivered

The MLP 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. The Town can determine what pricing plans to implement.[5]

Subscribers on TV White Space are unlikely to be offered a plan faster than 10 Mbps, due to the limits of the available spectrum. While western Massachusetts does not have good television reception from many channels, it is *near* the protected coverage areas of many stations, which limits which channels are officially "white". It is however possible that sufficient channels space will be available to allow 20 Mbps plans; it is simply too early to promise it. Also, a few subscribers with only marginal connections to 5 or 2.4 GHz access points, based on tree cover or terrain, may not be able to get top speeds.

Business services can be delivered on a customized basis. While Middlefield has little business now, broadband service is practically a prerequisite to some types of business activities, as well as a boon to working professionals. Should a business require a "bigger pipe", it is possible to build a customized connection via point-to-point tower access similar to the high-speed backhaul, or via fiber in the vicinity of the firehouse, to provide symmetric service speeds of 100 Mbps or higher.

Telephone service

Telephone service is not included in this plan. *However* it could 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 "voice over IP" (VoIP) telephone service. It bears noting that there are two very different types of VoIP 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 current wireline options (should they continue to exist). Because the ISP (in this case the MLP) is not involved, there is no budgetary impact; nor is anything done to improve its quality.

A second type of service is "voice *using* IP". This is what cable companies such as Comcast and Charter 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 Middlefield MLP or its network operator should be able to offer this in conjunction with a local voice provider, such as Crocker, after the initial network construction is complete. Such services typically have a retail price of about $20/month/line, including domestic long distance, which offers a decent profit margin over its wholesale cost.

Coordination with nearby towns

While not specifically part of this plan, Middlefield should see about working with other nearby towns to coordinate wireless ISP activities. Radio waves do not respect town lines. Just as two corners of Middlefield are best served from adjacent towns, some adjacent areas may be easily served via extensions

[5] Royalston offers a 20/5 Mbps service for about $119/month, a 10/5 service for $79/month, and a "snowbird/seniors" 5 Mbps plan for $44/month. The 10 Mbps plan is likely to be adequate for the majority of subscribers, with the faster plan (20 or 25 Mbps) available for power users and families with a heavy video habit.

of the Middlefield network. Towns developing their own networks could interconnect to Middlefield's to gain redundant access to MBI's backhaul, and vice versa.

Operating expense

There is little operating experience behind small municipal networks such as this and others that are proposed in the MBI area, but estimates are available from WISP experience elsewhere. A typical WISP makes a profit with an average revenue per user (ARPU) under $50. But per-user expenses are higher in areas with a relatively low count of subscribers, such as these town-by-town networks. The relatively low number of users per access point also raises costs. However, estimates still show the potential for Middlefield's wireless network to be self-supporting at projected user counts. See the OpEx page of the accompanying spreadsheet for details.

A substantial portion of the "fiscal" operating expense is depreciation. Equipment will need replacing eventually, so cash flow alone does not sustain a long-term operation. If 5-year depreciation is applied to equipment and 30-year depreciation to the towers and poles themselves, fiscal OpEx at the 173-subscriber level will be under $80/month, while cash flow OpEx will be below $60/month. Given that an ARPU of around $75 seems reasonable even without adding a telephone service, the network seems sustainable, though not contributory to the Town.

Implementation path

Assuming that the state funding is arranged and the Town grants the necessary approvals to begin work, the implementation of the network requires multiple contractors selected by the MLP:

- A consulting firm to provide oversight of the design, final engineering, and technical aspects of the contracting process.
- A network operator, who will also do most of the subscriber-side installation and electronics work, under the supervision of the MLP.
- A company to construct the towers, poles, and other hard assets. This latter contract will most likely be managed by the network operator.

Pilot project

Actual construction of the network will take place in two phases. The first proposed phase is the pilot, in which the performance of the latest hardware for the three frequency bands on a selected variety of paths. The Transfer Station tower will be built as part of this phase, along with the second site (presumably Alderman Road). In order to activate the Transfer Station site, fiber will also need to be run from the firehouse to the new tower, about 600 feet.

Once the pilot is running, the network operator, along with the MLP and its consultant, will employ measurement data to refine the final design. These results should not take long, once the system is running; it is however important that the pilot take place during the months when the trees have full foliage, as paths that may work in wintertime may fail once the leaves come in. The Town should have the results of this pilot before it commits to the final town-wide construction.

The budgetary cost of the pilot is approximately $90,000, which is *part of* the capital budget above. However, uncertainties regarding the construction of the Transfer Station tower, which site sits on ledge rock, could impact the pilot cost.

Town-wide installation

After the pilot has been evaluated and the Town votes to proceed, town-wide construction can commence. This will involve setting the remaining towers and poles, along with the radio equipment selected after the

trial. It is likely that a WISP installation team can install about 4-5 subscribers per day, once the access points are running. Thus an initial round of customer sign-ups, likely to number around 100-150, should take less than two months, or even less time if two teams work simultaneously. Some potential subscribers may wait some time before signing up, however, either because they want to wait and see how others like it, or because they have satellite service with time left on a contract.

A small number of homes (~10) may not be immediately served from the initial build because they require access via other towns. Two of the proposed pole (not monopole tower) sites are in Washington and Becket. The cost of these is included in the budget; the main issue is arranging permission. Alternate solutions will be required should the Town fail to obtain permissions. Should Also, a handful of potential customer locations may require custom engineering to serve. One additional (not sited) pole is budgeted for this purpose.