Fiber, wireless, and hybrid broadband options for Middlefield

(prototype)

Prepared for Massachusetts Broadband Institute by

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Options for addressing rural broadband

- More than one approach is possible for addressing last mile broadband connectivity
  - Each has its own advantages and disadvantages
- Fiber to the home (FTTH) would provide excellent service
  - But the cost of 100% fiber coverage may be challenging
- Projected FTTH costs for Middlefield
  - 33 miles of fiber in Middlefield, total network cost $1.32M
  - Additional $270k for legal, engineering, and project management
  - Middlefield would need to spend $1.59M to reach 292 premises ($5445/premise passed) all-FTTH
- An all-wireless solution has lower capital cost
  - But subscriber capacity is limited, and much of Middlefield, like other nearby towns, is a very difficult place to reach
- A range of hybrid fiber-wireless options is possible
  - Fiber to some locations, wireless to more remote sites
All fiber to the home (FTTH)

• The first option on the table is pure FTTH. It has technical and operational advantages.
  – Highest speed Internet service (1 Gbps possible)
  – Can easily provide competitive access to multiple ISPs, thus “neutral”
  – Also supports cable TV, telephone (full quality if configured correctly; over-the-top VoIP is lower quality)
  – Highest quality of service (if configured for it)
  – Long-term investment; largely future-proof

• It has some disadvantages
  – The big one: Higher cost to build
    • Cost is mostly per mile, so areas with fewer homes per mile cost more per home
  – Longer time to repair fiber breaks (from ice storms, falling trees, etc.)

• Two common approaches
  – Passive Optical Network (PON): One terminal port divided up to 64 ways
  – Active Ethernet: Separate strand from each subscriber to terminal
    • Usually requires more field terminals than PON, but more flexible
Wireless systems that are not rural broadband

• Satellite: Coverage almost everywhere but last choice
  – high latency (not for games, voice), often low speed
  – high usage cost, usually capped at a very low level of total monthly bytes transferred, then speed cut even more

• Mobile data has widespread coverage but not ideal
  – optimized for cell phones, with lower speeds
  – high usage costs and/or caps
  – limited to existing licensees and services they choose to offer
  – and there are still gaps in coverage in Middlefield and in many other towns in the west.

• Hotspot: Short-haul WiFi, picked up by laptops, adapters
  – Mostly in coffee shops, public places; some urban systems
  – Very short range (a few hundred feet or less), so not suitable for rural coverage
Rural broadband: Fixed wireless (WISP)

• *Thousands* of wireless ISPs (WISPs) provide Internet access to rural areas around the world using fixed wireless systems
  – Internet access, sometimes telephone, but not TV
  – Typical residential speeds in the 3-10 Mbps range; custom business services can be faster
• Base station (sector) antennas are mounted at high points (towers, poles, roofs) and serve customers within several miles radius, terrain permitting
  – customer-premise radio equipment (CPE) is required
  – uses unlicensed radio frequencies
  – a WISP “tower” is usually much smaller than typical cellular towers, which also can be rented when available
• But it is especially challenging in the New England hills
  – “line of sight” is required (microwave radio doesn’t penetrate hills)
  – most radio frequencies traditionally used by WISPs are blocked by trees
An example of a successful WISP

• Vistabeam, based in Scottsbluff, NE, serves parts of Nebraska, Wyoming, and a bit of Colorado
  – Established 2004, privately owned, profitable since 2006
  – Many rural/rustic areas have no other broadband service, but some have cable and/or DSL
  – Easier to serve than New England – fewer trees, less hilly

• Now has over 100 access locations (towers, grain legs, and other support structures)
  – Two 1G backbone links (in Colorado and Nebraska)
  – Microwave relay to most towers
  – Newer radio gear (Ubiquiti, MikroTik) replacing last decade’s leftovers
    • Which requires most CPE to be swapped out too

• Residential service plans from $29.95 (1 Mbps) to $99.95 (12 Mbps) plus installation fee, $5/month maintenance fee (or opt-out)
  – 4:1 oversubscription target on access points
  – Extra charge for public IP address
  – $14.95 for VoIP service
  – Customized business services

• About 2600 subscribers, $1.8M annual revenue
• 8 full-time employees, 3 FTE subcontractors
Market trends

• Fiber to the home is expanding in some urban areas, and in rural areas *where it is subsidized*
  – Old FCC-run Universal Service Fund was a blank check to small telephone companies, so many now have FTTH
  – ARRA BIP program financed additional one-time builds
  – New FCC Connect America Fund emphasizes low bids, model-based subsidies (vs. blank check)

• Verizon and AT&T are phasing down fiber builds
  – Cream-skimming highest-margin markets, emphasizing mobile investment elsewhere, leaving rest to cable
  – Thus existing Verizon plant in western Massachusetts is largely being abandoned, to the extent permitted, with no replacement planned

• WISPs are growing in rural areas
  – Mainly entrepreneurial, unsubsidized small businesses
  – Speeds are improving, comparable with DSL and sometimes cable (which are rarely available in such areas)
  – Large international market drives equipment innovation, volumes
The WISP ecosystem is maturing

• A number of vendors produce radio equipment for the WISP industry, with improving price/performance
  – Good radio equipment is now cheap (5 GHz CPE ~$100)
    • Major vendors in US: Ubiquiti (top dog), Cambium (Motorola spinout), Mimosa (new player), MikroTik (but losing interest in US)
    • Radios are now only a minor capital cost item, with facilities and installation costs dominant
    • It’s basically modified WiFi with better, focused antennas
    • Repurposed WiFi chips mean higher performance, lower cost
    • Technology still advancing: Higher-order MIMO (faster), electronically-steerable antennas coming to market soon
  – Users share each sector’s capacity
    • Typically 3-4 sectors on a tower (i.e., 90-120° sector coverage)
    • Typical 5 GHz sector: 50-100 Mbps shared among 30-40 users
    • Towers fed by fiber or point-to-point microwave backhaul
Examples of WISP equipment:

- **Mimosa 5 GHz CPE radio (10” diameter)**
- **Ubiquiti sector and 15” backhaul dish on hillside**
- **Carlson TV white space omnidirectional access point antenna**
- **Adaptrum TV White Space radio and antenna on house**
- **Cambium ePMP - GPS radio unit, sector antenna, and radio mounted on sector**
Unlicensed frequencies usually used by WISPs

- Fixed wireless typically uses unlicensed frequencies
  - Shared, with no protection against interference
  - but agile, so radios can shift frequencies to avoid interference
- 5 GHz band is the largest, most used by WISPs
  - Widely used where possible, allowing highest speeds
  - But signals can be blocked by even one or two trees in the path
    - Why WISP business is biggest in farm, ranch, and desert country
- 2.4 GHz band is the busiest for non-WISP applications
  - WiFi, Bluetooth, microwave ovens -> high noise level
- 900 MHz band can penetrate trees to a reasonable extent
  - But relatively narrow (902-928 MHz), so low total capacity
  - Widely used for utility meters, other devices, so too noisy in cities
  - TV White space will largely supplant it
- 3.65 GHz band is lightly licensed – non-exclusive, low cost
  - Still narrow and quite sensitive to foliage
  - rules may change soon – 3.55 GHz band may be added
Performance issues of fixed wireless

• Service quality depends on how good the radio path is
  – Clear line of sight over short distances (< ½ mile) gives best results, 50+ Mbps subscriber unit access on 5 GHz (but residential speeds are usually limited to improve sharing)
  – Marginal-strength connections might still be good for 3 Mbps or so
  – Links that work in winter may fail when the leaves fill in or trees grow
• Foliage and hills make western Massachusetts an exceptionally difficult area for wireless coverage
  – But far from impossible, especially thanks to TV White Space
• Delay and jitter (delay variation) are more variable than fiber
  – Some systems limit radio latency to <5 milliseconds, others much longer, which can impact VoIP quality
  – Some packet loss and retransmission is normal, leading to more jitter
  – Actual performance depends on load, interference
TV White Space

- TV White Space rules allow unused TV channels to be used for unlicensed broadband (as well as wireless microphones and other devices)
- Equipment now coming on market, likely average of $600-800/user (CPE plus share of sector) – *after* it reaches the next volume plateau
  - Considerably more than 2.4 or 5 GHz (~$200/user), but cheaper than FTTH
  - Early adopter prototypes now around $3000/access point and $1200/subscriber
  - Vendors: Carlson, Adaptrum, Runcom, 6Harmonics
- 470-692 MHz UHF TV spectrum penetrates trees (no one uses VHF TVWS)
- Access points must check in with an FCC-approved online database daily to verify that the channel is still free
  - Equipment vendors, not users, pay for using a database (from Google, SpectrumBridge, Ericsson and others)
- High enough power allowed (4 watts EIRP) to have a range of several miles, terrain permitting, *even in the woods* since the frequency is so low
- BUT 6 MHz-wide TV channels only support about 15 Mbps (or less) each, so much less capacity than radios on 5 GHz band (20+ MHz channels)
  - Should be adequate for 10-15 users/access point
Limited white space availability

• While Western Massachusetts isn’t famous for good over-the-air TV reception, its white space options are *surprisingly poor*, especially in the northern towns.

• TVWS devices must protect channels whose coverage ends nearby, even outside viewing range.

• Fixed devices not allowed higher than 250 meters above average terrain (measured from 2-10 miles).
  – Some Berkshire mountain areas are higher, but few if any homes that high up.

• Boston, New York, Hartford, Albany, and Vermont markets all converge in the west…
  – So a few places have no TVWS channels available.
  – Middlefield, though, currently has 5 available channels (more in some parts of the town), enough to be usable.
  – Personal/portable low-power devices have access to more channels than full-height fixed devices.

• TV Incentive Auction in 2016 will rearrange channels, could reduce availability (but very unlikely to go to zero).
Western MA fixed white space map (Google)
Wireless vs. fiber life cycle

• Fiber’s cost is mostly outside plant (fiber on poles), which has an estimated 30+ year lifetime
  – Electronic devices on fiber have a 5-10 year lifespan and declining costs
  – Original FiOS gear pre-2007 is now obsolete (~100 Mbps BPON)
    • But the fiber can be upgraded with GPON equipment (current FiOS)
    • Next generation PON (XGPON) 10 Gbps is even easier upgrade

• Wireless cost is in infrastructure, radio gear
  – Radios can mount on anything that clears the trees – metal tower, tall wooden utility pole, high rooftop.
    • Towers outlast the radios that use them
  – Power is required (about 30-80 watts/tower), so off-grid sites (e.g., hilltops) may need wind and/or solar + battery systems
  – Radio gear economic lifespan is 5-7 years
    • General lack of compatibility may mean adding a second sector-type at the tower before beginning to install a new type of CPEs
Wireless vs. fiber capacity, bottlenecks

Fiber: 1 Gbps
Upstream to ISP facilities

Fiber: 1-10 Gbps

Wireless backhaul: 100-500 Mbps capacity

Individual subscribers typically 5-10 Mbps

Wireless: Pooled of capacity is shared by users on a sector

Fiber: Two types of connection:
- PON splits one strand up to 64 ways, passively (in field)
- Active Ethernet assigns a strand per user

Fiber terminal

PON Splitter

2488/1244 Mbps shared

GPON ONT

Ethernet ONT

Ethernet ONT

100/1000 Mbps dedicated strands (Active Ethernet)

5-1000 Mbps

GPON ONT

5-10 Gbps
Pitfalls to avoid in wireless broadband

• Don’t use the wrong kind of equipment
  – Urban hotspots aren’t appropriate for rural use
  – Vendor lack of full FCC approvals can limit access to most 5 GHz unlicensed frequencies
• Don’t overpay – prices and quality are *not* always correlated
• Don’t fall into the “mesh” trap (single-frequency WiFi-based) – it doesn’t scale
• Don’t overload the towers – engineer for worst-case ice and wind
• Don’t oversell end user capacity (beyond reasonable oversubscription)
  – The laws of the FCC and of physics combine to limit capacity
  – Video may need to be “managed” to keep it from crowding out everything else; purely “neutral” WISPs could collapse under its weight
• Don’t design around town lines; radio waves don’t respect them
• Weak, slow connections slow others down – they use more sector *time*
• Do cooperate with other band users to avoid mutual interference for the benefit of all users.
A hybrid option may be optimal

• Fiber and wireless can be treated as *complementary* rather than as purely competitive
  – Fiber customers have access to additional options
  – Load on wireless network is reduced, and per-user performance improved, by *not* using it for everyone
• Even if wireless were preferred, some locations are already passed by MBI fiber; lighting it would be relatively inexpensive
  – If this is not permitted, then overlashing those routes may be possible
• Cost of fiber is based on premises/mile, so fiber is less costly on more developed roads
  – Middlefield all-FTTH baseline is 33 miles, of 42 miles of road total
• Cost of wireless is based on number of towers and sectors needed, more a function of capacity and terrain
• Fiber can be built on busier roads and to key wireless tower locations, with TVWS or other wireless to users not on fiber
Hybrid fiber-wireless example in Middlefield

- An *example* network adds about 10 miles of fiber alongside existing 3.4 miles of MBI routes in Middlefield
  - Only about a dozen homes seem to be along the MBI route itself
- 13 miles of fiber then passes almost 60% of buildings, probably a larger percentage of year-round homes
  - Estimate 165 out of 292, leaving 127 off fiber, to be served by wireless
- 11 “towers” strategically located, mostly on roadsides or public land, appear to reach 95% of others using TV White Space and/or 900 MHz
  - 9 towers within Middlefield, two on high sites in adjacent towns
  - Largest landowner to deal with: Mass. Division of Fisheries & Wildlife
  - Three towers directly on fiber, others fed by high-speed 5 GHz microwave backhaul, some redundantly
- TVWS should allow “8/1” Mbps burst rates to most users
  - But limited capacity would be stretched by Netflix-quality video
  - 5 GHz conventional WISP would need many more towers due to foliage, but may be useful in some spots (much cheaper where it works)
  - 900 MHz conventional WISP will add low-cost capacity into wooded areas
Middlefield fiber + 11 tower TVWS/900 coverage

This is potential coverage, if sectors were deployed at all towers with 360° coverage.
5 GHz would not work as well – tree cover worsens coverage

But an “overlay” may be cost-effective in some spots, offering higher speeds using cheaper gear than TVWS, and it may be optimistic.
Cost of building FTTH

- Fundamental cost is installing fiber on the poles
  - About $35,000/mile for outside plant in proposed towns
  - Only a small share of cost is incremental per home served
- Fiber actives are not terribly expensive
  - Typically about $200/subscriber at each end
- Actives require power, but fiber carries signal 10+ miles, so only a few fiber terminal sites are needed
  - Could be one/town by using PON to share strands
    - Up to 64 users on a fiber terminal port, split up to 8:1 twice in field
    - More typically serves 20-30 users per port (e.g., FiOS)
  - Active Ethernet likely to have some powered remote terminals
    - One dedicated strand from a terminal to each served premise
- Fiber builds usually take longer to complete than wireless
  - A few difficult spots along the route can delay construction
    - Wetland protection, bridges, etc.
Fixed costs of building a wireless system

• Towers or high sites are needed, to put antennas above tree tops
  – Height is needed to clear treetops, probably 60-80 feet in most areas
  – Could be a utility pole, if tall enough, especially for roadside installation
    • Poles can reach up to about 50’ above ground
  – A 70-foot self-supporting steel tower costs about $4000-$15,000 plus installation
    • Not as costly as mobile towers (which often reach 195 feet)
    • “Stealthier” towers and monopoles cost more than conventional metal
  – WISPs often trade service for free use of rooftops, silos, etc.
• About $1000/tower site for switching/routing gear, etc.
• 5 GHz backhaul or sector radios with 500 Mbps+ capacity, antenna are around $1000 each (average 2-2.5/tower)
• 5 GHz or 900 MHz customer premise radios are only around $100 apiece
• 900 MHz sectors with ~50 Mbps capacity are under $500 apiece
• TVWS systems expected to fall to around $750/subscriber for both radios
  – Plus UHF TV antennas
• Solar power for off-grid locations adds around $3000/site
Approximate wireless totals for Middlefield

- **Rough estimate of** wireless costs for Middlefield with 200 TVWS subscribers:
  - $100,000 for 10 towers (also uses one existing fire tower)
    - Solar power may be needed at one or two (estimated) off-grid sites
  - About $100,000 to install towers (*very* rough, but generous, estimate)
  - $25,000 for backhaul radios
  - $10,000 for tower-site switches (4 with fiber)
  - Fixed total of towers and backhaul $140,000

- $100,000 for 100 subscribers’ worth of TVWS gear + $25,000 for 100 subscribers worth of 900 MHz gear in full-wireless mode (2/3 take rate)

- $60,000 for 90 wireless subscribers’ gear if mixed fiber/wireless

- Grand total for all-wireless thus around $365,000, or around $300k for wireless share of mixed network, *plus*
  - About $200 to install each subscriber ($40,000 for full wireless, $18,000 for mixed)

- Fiber cost declines to $400,000 for 10-mile partial FTTH
  - Thus around $720k for mixed fiber-wireless, vs. $1.32M for full FTTH
Operational costs of wireless ISP

• WISP requires occasional use of a tower climber
  – Certified, if on a cell tower, otherwise just well trained
• Installation at subscriber premises requires ladder or truck, comparable to installing a fiber drop
  – Align radio instead of splice fiber
  – Occasional tree trimming (but fiber needs it too, along roadways)
• Ongoing monitoring, like any ISP
  – Prepare for weather-related issues
• Usual retail ISP issues are not really the ISPs’ fault
  – Home WiFi issues, configure email client, etc.
• Not really much harder than a dial-up ISP
  – But different; some work must be done outdoors in any weather
In conclusion

• A wireless option is practical
  – The cost of all-wireless is roughly a third of what all-fiber costs
  – The cost of the example mixed fiber-wireless design is roughly half of what all-fiber costs

• Wireless technology is still evolving, more rapidly than fiber, but is advanced enough to deploy

• Wireless provides Internet access and telephone
  – but it lacks the capacity for video
  – top speed is limited on frequencies that tolerate trees in the way

• Most of the wireless investment is infrastructure (access points at high sites)
  – Often can serve parts of more than one town, so a regional approach is best
  – High sites may be useful for other services