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Broadband Technologies: Understanding the Full Range of Technical Options and Opportunities

November 5, 2015

Agenda

- Overview of broadband access technologies
  - Cable (DOCSIS)
  - Fiber to the Premises (FTTP)
  - Digital Subscriber Line (DSL)
  - 3G/4G
  - Satellite
  - TV White Space
- Comparison of competing technologies

A few key terms

- *Spectrum:* the portion of the Radio Frequency (RF) or optical spectrum used for communications signals
  - Measured by frequency – how fast the wave is cycling in hertz (Hz)
  - Optical signals measured by the length of the wave period (wavelength) in nanometers (nm)
- *Capacity, data rate, and speed*: used interchangeably, and generally mean the number of bits per second (bps) carried over a link
  - More spectrum generally means more speed, but not necessarily on a 1:1 basis
  - Many factors impact "spectral efficiency" or bits per Hz possible with a given technology – interfering noise
- *Oversubscription:* amount of capacity offered to subscribers over a shared link beyond what is can support at any given time – generally referenced in terms of a ratio (i.e. 100:1)

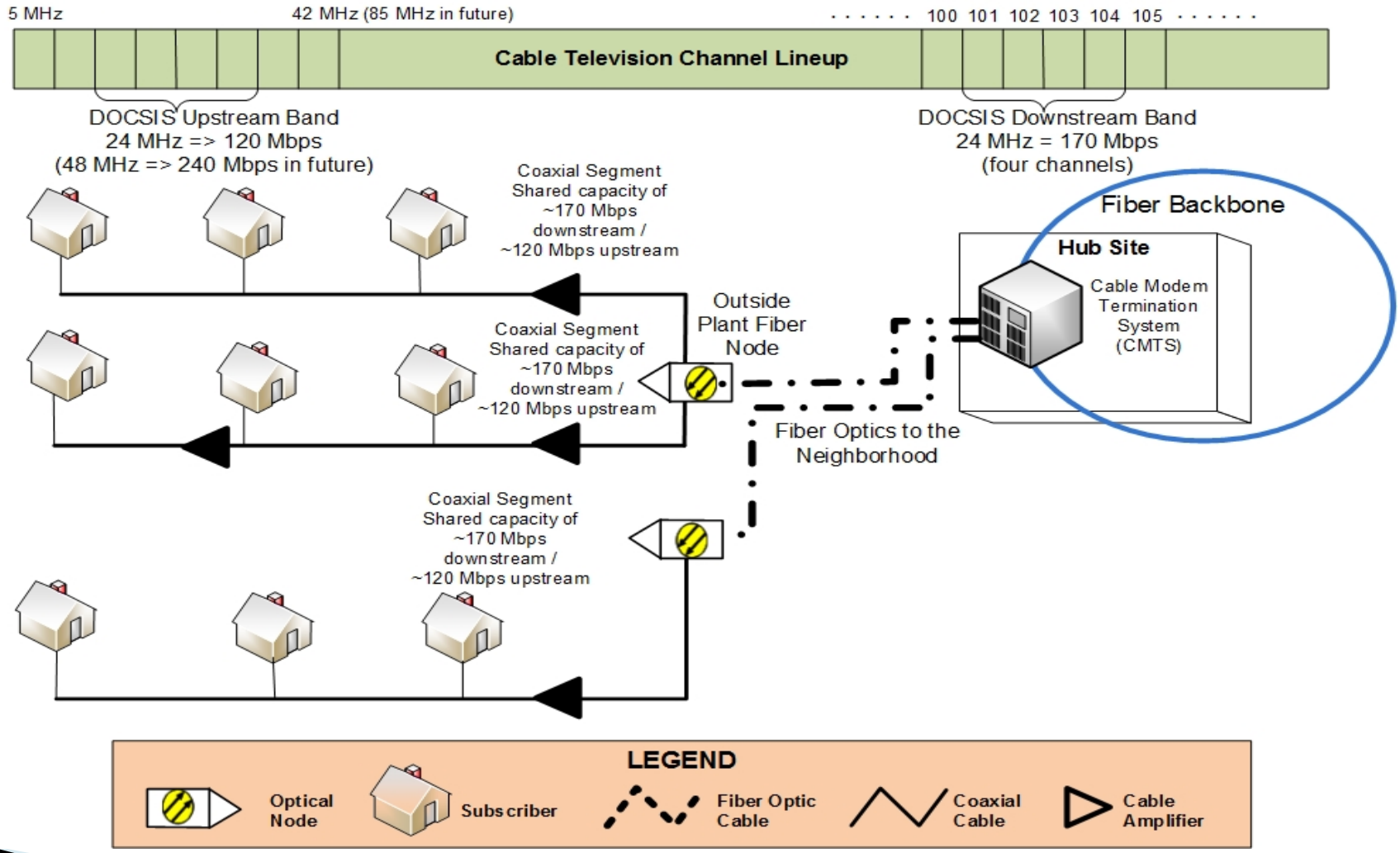
Cable

- Refers to hybrid fiber-coaxial (HFC) networks
  - Fiber from a headend or hub to neighborhood nodes
  - Coaxial cable in the “last mile” with active amplifiers along the way
- Data is transmitted in dedicate channels alongside video channels
- HFC active components provide a fixed amount of usable spectrum
  - 750 MHz and 860 MHz are common, 1 GHz and above available
- Fixed asymmetrical split of spectrum between upstream and downstream
  - Only from 5 MHz to 42MHz for upstream generally
  - Significant limitation to symmetrical services

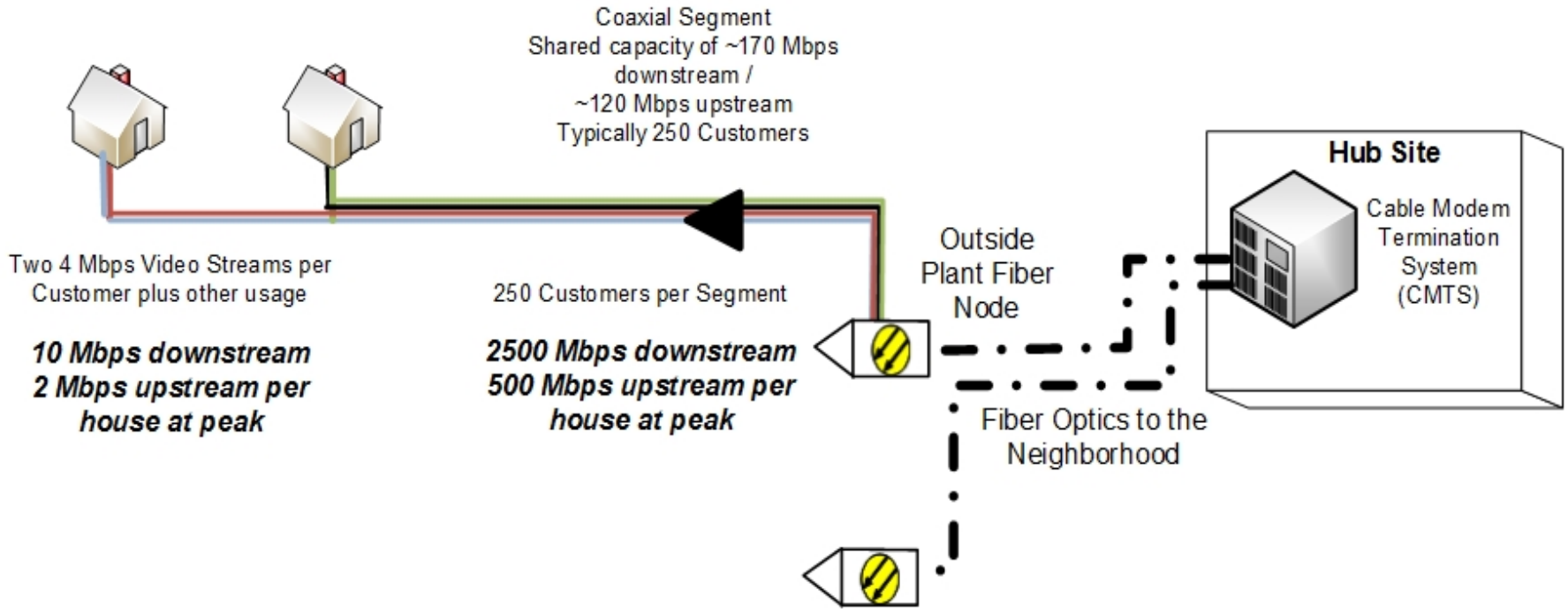
DOCSIS 3.0

- Data Over Cable Service Interface Specification (DOCSIS) is the industry-adopted standard for cable modem technology
- DOCSIS 3.0 is the current standard in the U.S. for advanced broadband services
  - Ability to dedicate per user capacity
- Bonding of 4 or more individual 6 MHz channels
  - Necessary to provide 100 Mbps and higher download speeds
  - Capable of providing “gigabit” service with more channels
  - 32-channels DS / 8 channels US provide 1.37 Gbps DS and 245 Mbps US

Example HFC / DOCSIS 3.0 Architecture



High oversubscription in cable networks

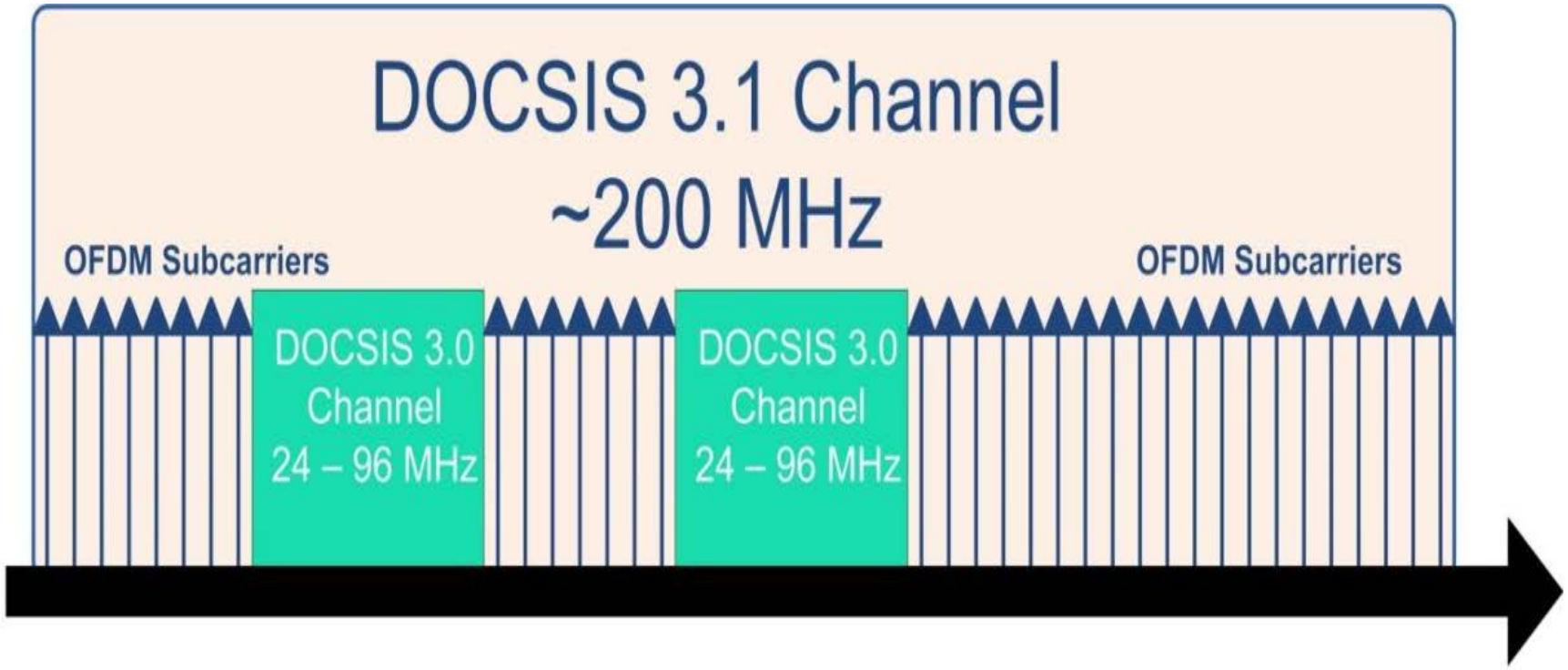


- Each node may serve several hundred customers each
- Not possible for all customers to simultaneously sustain transmission at even a significant percentage of the advertised "up to" speeds at the same time

The upgrade path to DOCSIS 3.1

- Can theoretically increase capacity to beyond 10 Gbps downstream and 1 Gbps
- Represents migration away from traditional 6 MHz cable TV concept
  - Requires large amounts, or all system capacity dedicated to data
  - Might require operators to migrate to IPTV
- Typically will require costly replacement of HFC infrastructure to get full benefit of the upgrade
  - Active components (amplifiers and nodes) – change spectrum split and increase total capacity
  - Passive components (drop cable and splitters)

DOCSIS 3.1enables much more of the existing spectrum to be used



Cable Pros and Cons

Pros	Cons
At least 170 Mbps (down)/120 Mbps (up) with DOCSIS 3.0	Maximum speed limited by physics of cable plant
Potential to increase capacity even further by segmenting network	Capacity shared by all customers in a given network segment
DOCSIS 3.1 promises greater potential upgrades in capacity	Capacity upgrades require extensive physical improvements to the network

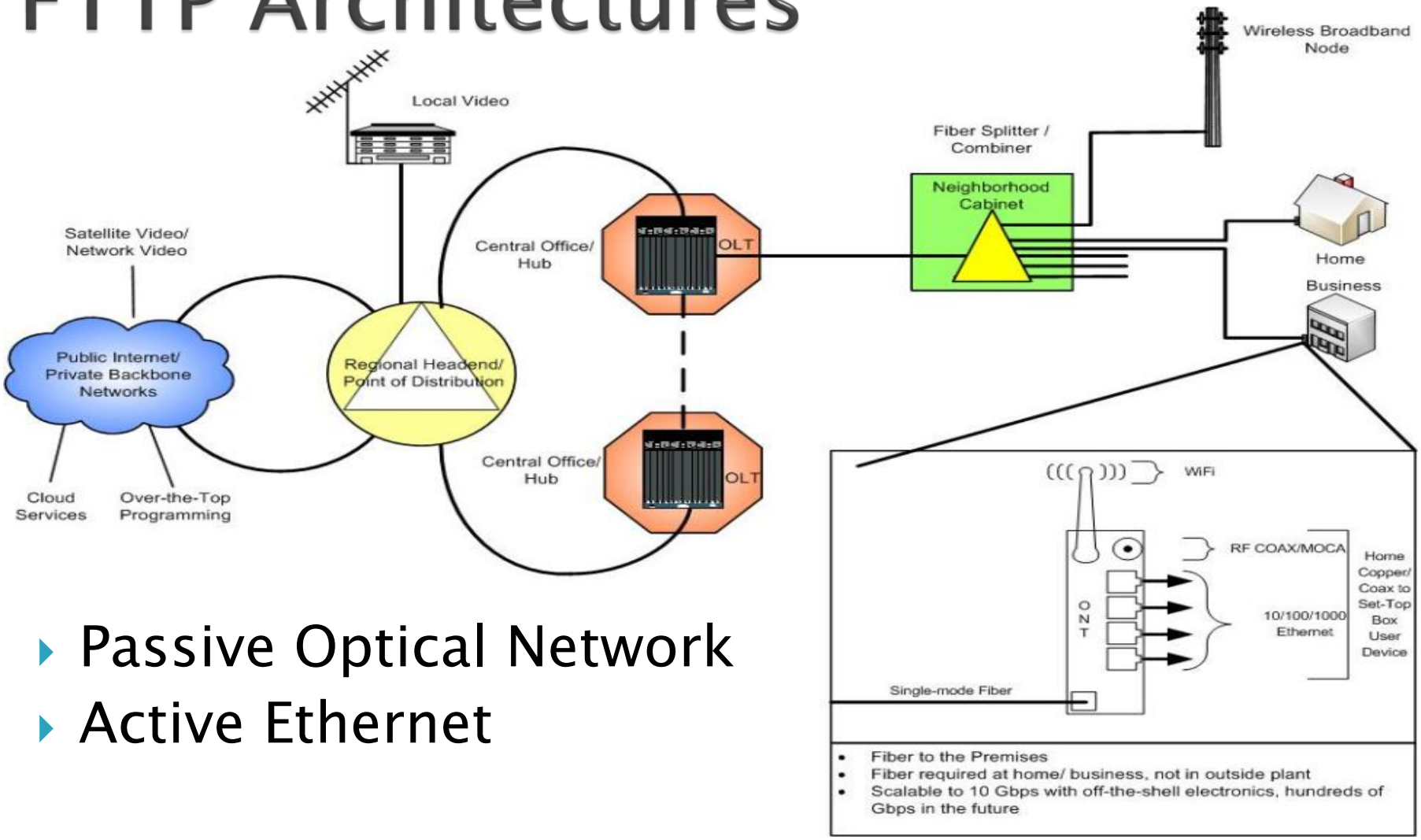
Issues for consumers and providers – Cable

Providers	Consumers
Potential to increase capacity by adding fiber (segmenting network) or bonding channels	Capacity shared by all customers in a given network segment
Upgrading to DOCSIS 3.1 will expand capacity	Speeds decrease during bandwidth "rush hours" when more users simultaneously use greater amounts of data
Maximum speed limited	Maximum speed limited

Fiber-to-the-Premises (FTTP)

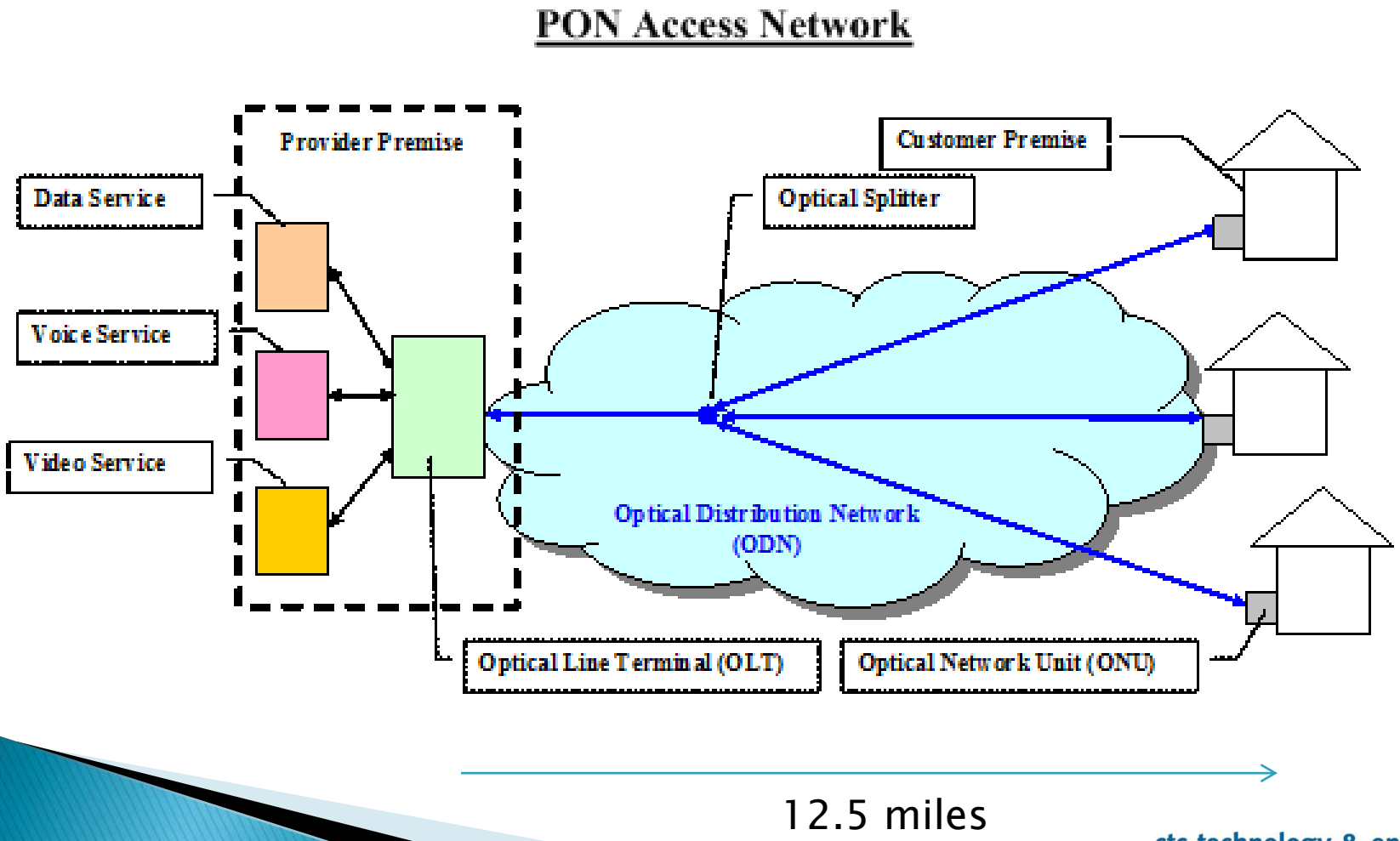
- FTTP more capable than previous wireline communications technologies
  - Capacity to 1 Gbps and beyond
    - Can support any foreseeable residential and business needs
    - Can support cell site interconnection
- Capacity scalable without new construction
  - An individual fiber strand can support 10 Gbps, 100 Gbps, etc. – virtually limitless, constrained only by the electronics
- Low maintenance (limited or no external electronics)
- In greenfield– construction cost same as any other medium

FTTP Architectures



- Passive Optical Network
- Active Ethernet

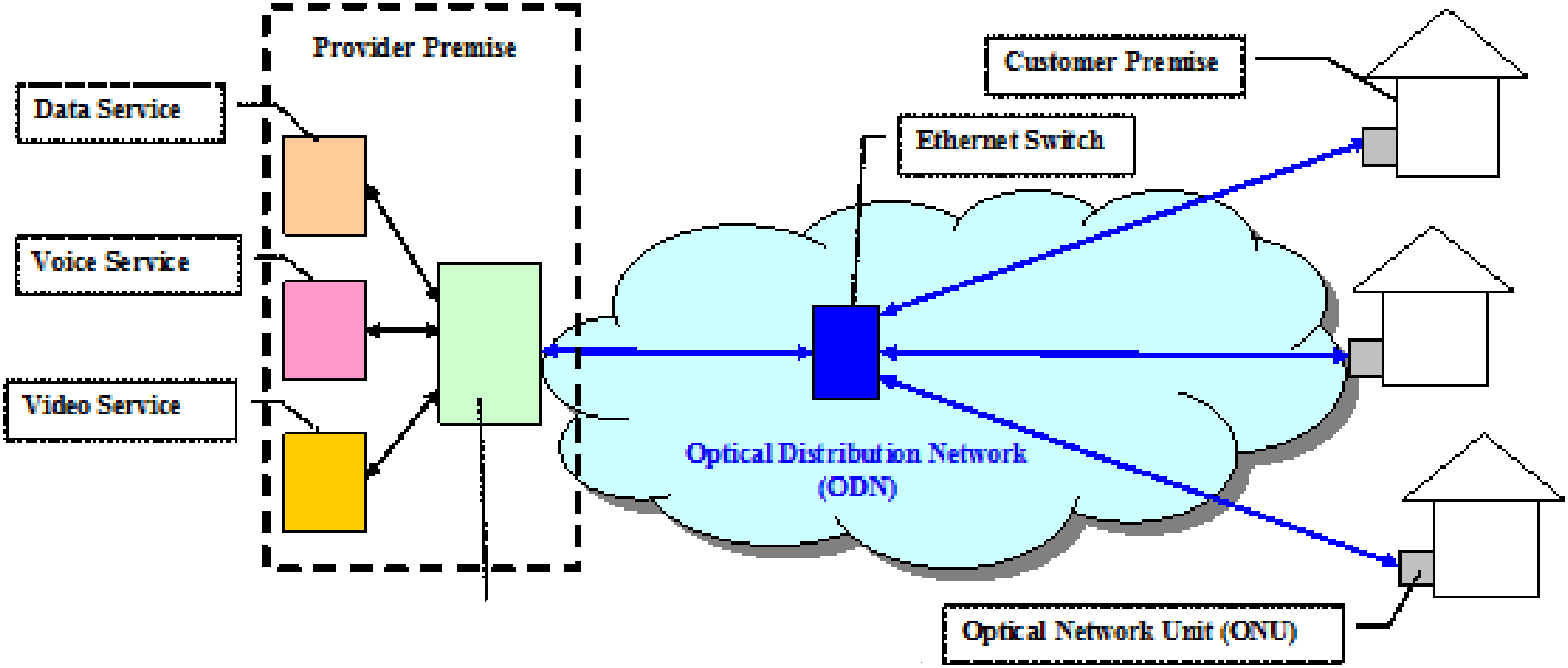
FTTP Architecture: Passive Optical Network/ Distributed Tap



Passive Optical Network/ Distributed Tap

- Fiber shared by multiple users from the CO or fiber distribution cabinet (FDC) to a splitter near customer
  - Reduces construction and electronics costs
- Individual fiber from splitter to customer premises
- Splitter is a passive, non-powered component
- Range of technologies
  - GPON: 2.4 Gbps DS, 1.2 Gbps US, 10-GPON: 10 Gbps DS, 2.5 Gbps US (timeslotting)
  - WDM-PON (different wavelengths)
- Standard PON: 32- or 64-way symmetrical splitter
- Distributed tap splits optical power unevenly – drops off one customer at a time
  - Same electronics architecture, but more cost effective in rural deployments

FTTP Architecture: Active Ethernet



Active Ethernet

- Dedicated fiber from CO/substation/cabinet to each customer
- Requires power at cabinet
- Higher capacity, longer range
- Typically greater cost per customer
- Possible to operate a hybrid network
  - Premium customers receive Active Ethernet
  - Others get PON
  - Both can offer symmetrical gigabit services (albeit with different levels of oversubscription)

FTTP Pros and Cons

Pros	Cons
Higher capacity and more reliability than cable systems	Capacity limited by the processing power of the networking equipment connected to the fibers
Optical light signals can travel great distances (up to 50 miles between electronics) with minimal signal deterioration	Highest-capacity connections require direct fiber connections to customer premises
Optical fibers do not conduct electricity and are immune to electromagnetic interference	

Issues for consumers and providers – FTTP

Providers	Consumers
Fiber networks are more reliable and require less maintenance than cable networks	Some FTTP operators (e.g., Verizon FiOS) split the fiber capacity in a neighborhood cabinet to connect 16 to 32 customers
Fiber can be deployed where conductive materials would be dangerous, such as near power lines	Actual "dedicated" capacity per customer is less than maximum advertised speed due to splitting of signal
Fiber can provide a flexible, high-speed backbone for wireless services	Even shared signals are generally able to sustain a constant 100 Mbps to all users in the downstream direction, simultaneously

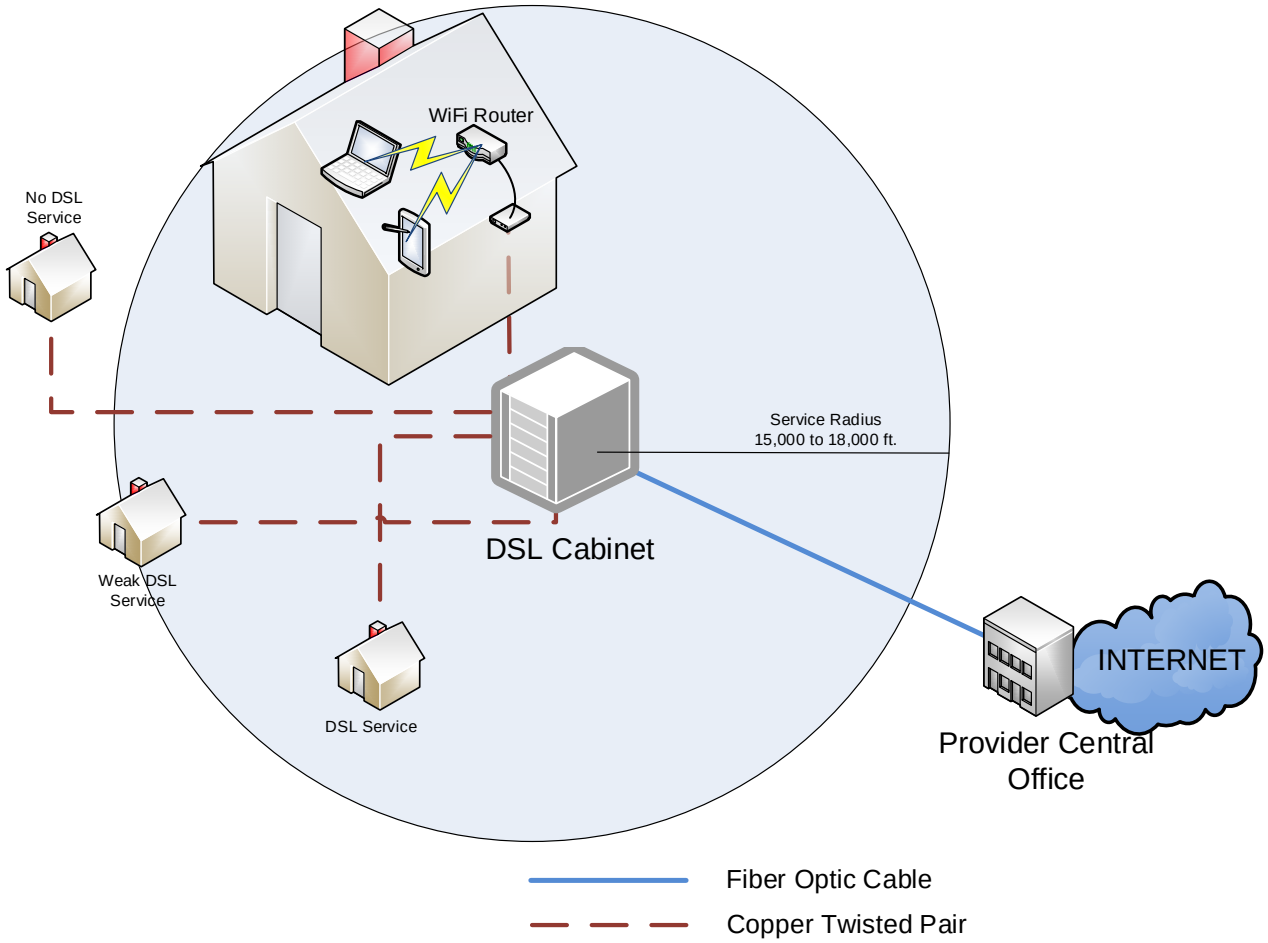
Cable vs. Fiber

Factor	Technology	
	Cable	Fiber
Availability	Ubiquitous in populated areas	Limited deployment
Typical Speeds	Download speeds up to 150 Mbps (300 Mbps in some markets); lower upload speeds	Symmetrical speeds of 100 Mbps to 1 Gbps or more
Sustainability of Peak Speeds	Not sustainable for long periods or for large percentage of users	Sustainable for all users simultaneously
Scalability	Requires more expensive physical and electronic upgrades	Requires minor equipment upgrades

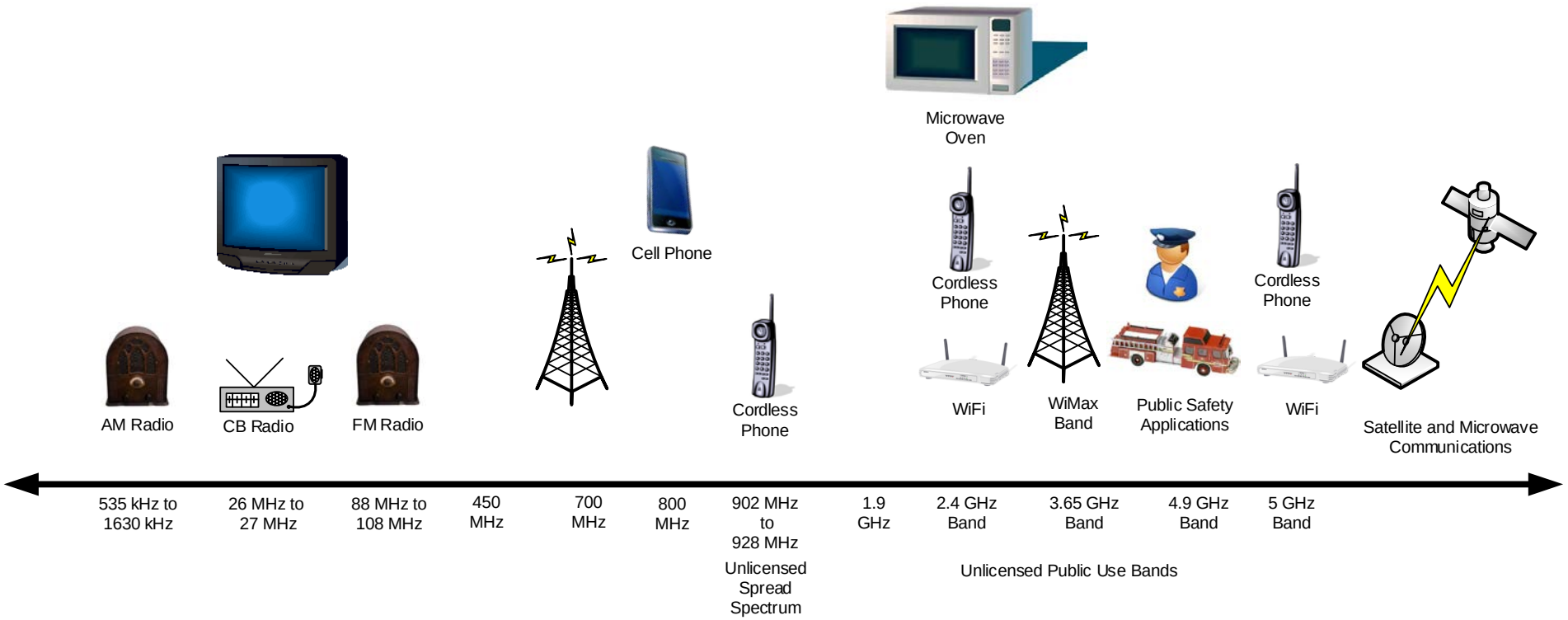
Digital Subscriber Line (DSL)

- Deployed standalone or as a compliment to fiber-to-the-curb (FTTC)
- Uses legacy twisted pair copper wires (telephone wires)
- Uses modulation technology similar to LTE, Wi-Fi, DOCSIS 3.1 (OFDM)
  - Twisted pair wire is a dedicated connection (not shared spectrum), but comparably unhospitable to data communications (noise)
- Availability and speeds limited by distance to the CO
  - Typically less than 15 Mbps within 15,000 feet
  - Very-high-bit-rate digital subscriber line 2 (VDSL2) can offer 50 Mbps to 250 Mbps within 1 km to 0.5 km (best case)

DSL


WiFi Router
No DSL Service
Service Radius
15,000 to 18,000 ft.
DSL Cabinet
Weak DSL Service
DSL Service
INTERNET
Provider Central Office
Fiber Optic Cable
Copper Twisted Pair

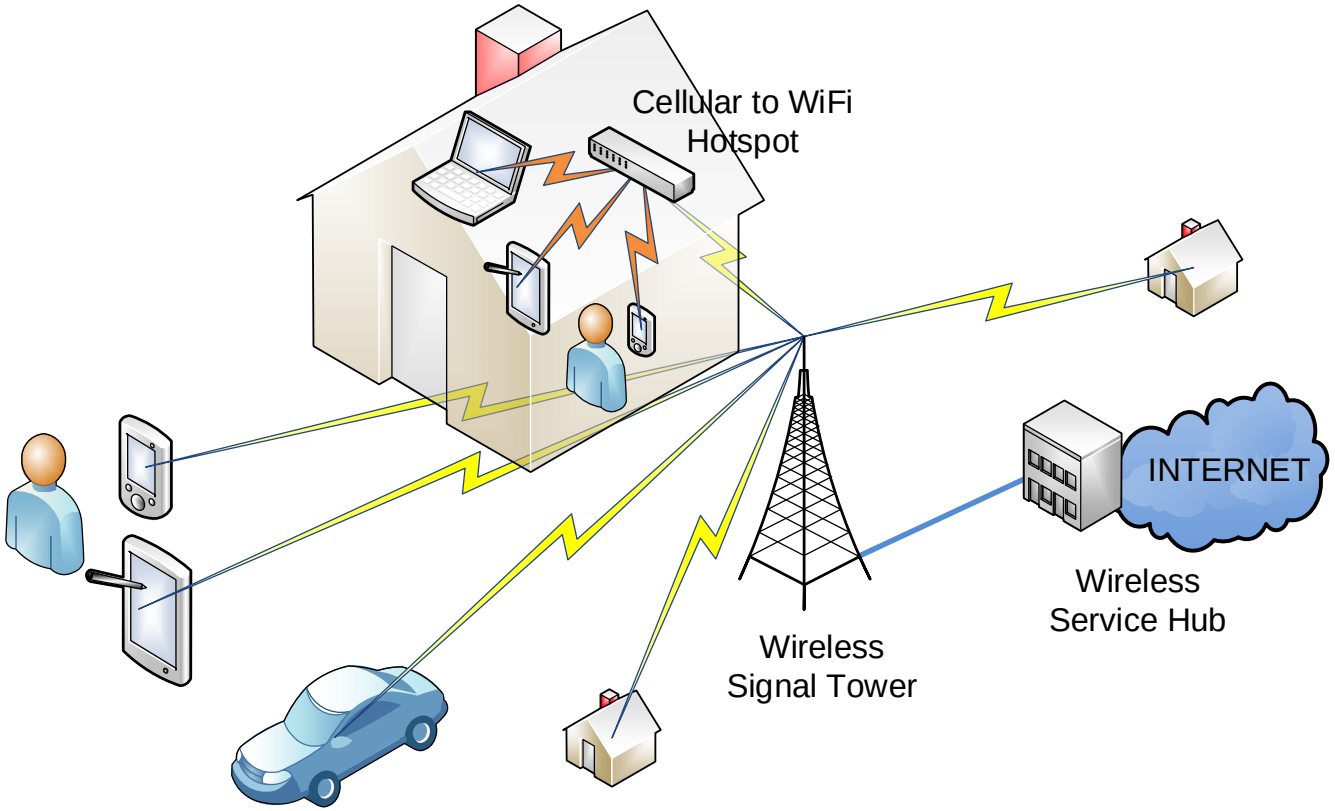
Wireless spectrum is a limited, shared resource



Fixed cellular wireless (3G/4G)

- Third / Fourth generation (3G/4G) cellular technologies
  - Represents an evolution of very different cellular technologies – separate CDMA and GSM tracks
  - 4G refers to a range of competing technologies: Evolved High Speed Packet Access (HSPA+), WiMAX, and Long-Term Evolution Release 8 (LTE)
  - The aptly named LTE has become defacto standard for nearly all commercial carriers
- The same network supports fixed and mobile services
  - Represents a competitor to wireline services
  - CPE consists of mobile gateway with Wi-Fi hotspot or wired Ethernet port for local connection

Fixed cellular wireless illustrated



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Fixed cellular wireless (3G/4G)

- Theoretical 4G speeds
  - 42 Mbps 100 Mbps downstream
  - 11.5 Mbps – 50 Mbps upstream
- Real world 4G speeds vary greatly
  - 5–10 Mbps downstream and 1 –2 Mbps upstream
  - Number of users connected to a given base station
  - Physical obstructions and distance cause signal attenuation
- Spectrum is limited
  - Deployed in expensive, licensed bands, typically comprised of 5 – 20 MHz channels
  - Capacity is expanded by reducing power and shrinking the coverage area of each base station (reuse of limited spectrum)
  - Data caps limit usefulness as a wireline replacement – expensive if used for more than casual web browsing

Application performance over cellular wireless options

Applications	Technology (Download/Upload Service Speeds)		
	2G/2.5G-EDGE/GPRS, 1xRTT (128 Kbps-300 Kbps/ 70 Kbps-100 Kbps)	3G-EVDO Rev A, HSPA+ (600 Kbps-1.5 Mbps/500 Kbps-1.2 Mbps)	4G - WiMAX/LTE (1.5 Mbps-6 Mbps/500 Kbps-1.2 Mbps)
Simple text e-mails without attachments (50 KB)	Good (2 seconds)	Good (1 second)	Good (1 second)
Web browsing	Good	Good	Good
E-mail with large attachments (500 KB)	OK (14 seconds)	Good (3 seconds)	Good (1 second)
Play MP3 music files (5 MB)	Bad (134 seconds)	OK (27 seconds)	Good (7 seconds)
Play video files (100 MB for a typical 10-min. YouTube video)	Bad (45 minutes)	OK (9 minutes)	Good (3 minutes)
Maps and GPS for smartphones	Bad	OK	Good
Internet for home	Bad	OK	Good

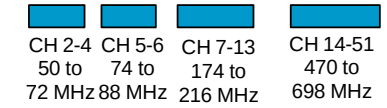
Satellite Broadband

- Available in the most rural or urban environments
  - Anywhere you can mount a dish with line of site to satellite
- Fundamentally constrained by physics and number of users sharing capacity
  - High latency (~250 ms round trip) makes it unsuitable for VoIP and videoconferencing
  - Susceptible to rain fade
- 15 Mbps DS, 1-2 Mbps US
  - Data caps in the 25 GB range (1/10th that of wireline options at 3x the price)

TV White Space Technology

- Slowly emerging technology using unlicensed technology in spectrum freed up by digital TV transition
  - UHF/VHF spectrum represents the “sweet spot” in terms of capacity and propagation characteristics
  - Despite being unlicensed, operates a higher power for transmission distances of up to 10 km
  - TV Band Devices (TVBD) must lookup available channels in national database to avoid interference
- Only viable in markets with open channels
  - Could be a key option in rural markets where wireline and even cellular infrastructure is underdeveloped and costly
  - Not widely deployed, but starting to see some rural WISP’s use TVWS

TVWS spectrum

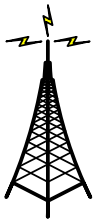


TV White Spaces
(Broadband Over
Unused Channels)

Network Broadcast
Unlicensed "White Space" Frequencies

Microwave
Oven

Cell Phone

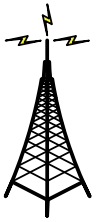


Public Safety Radio

Cordless
Phone

Cordless
Phone

WiFi

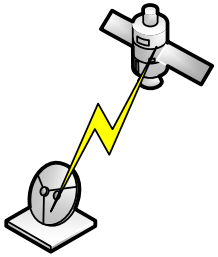


WiMax
Band

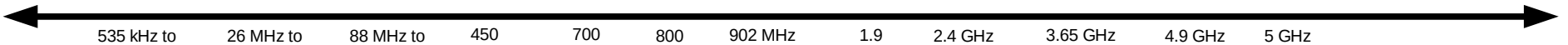
Public Safety
Applications

Cordless
Phone

WiFi

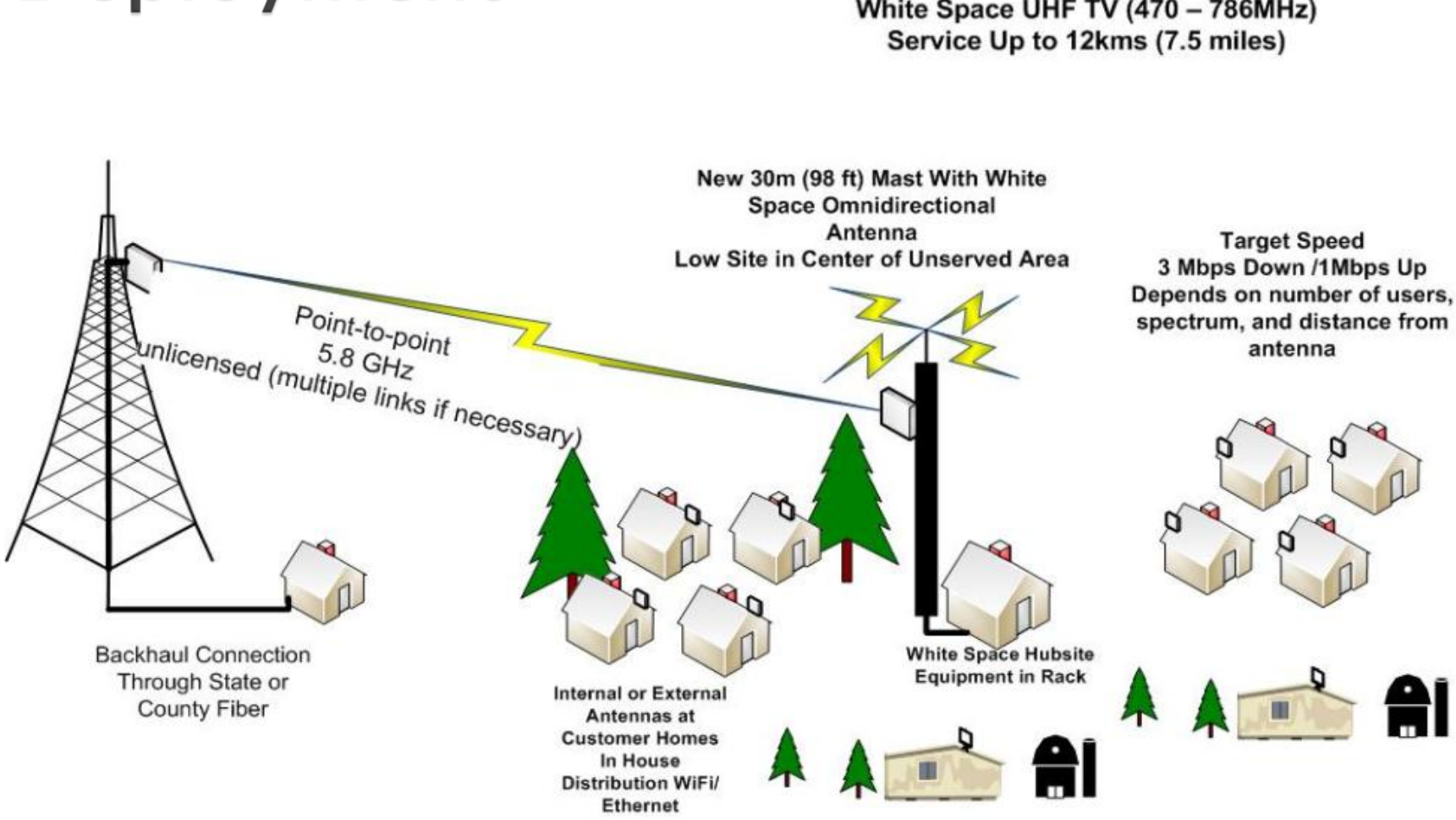


Satellite and Microwave
Communications

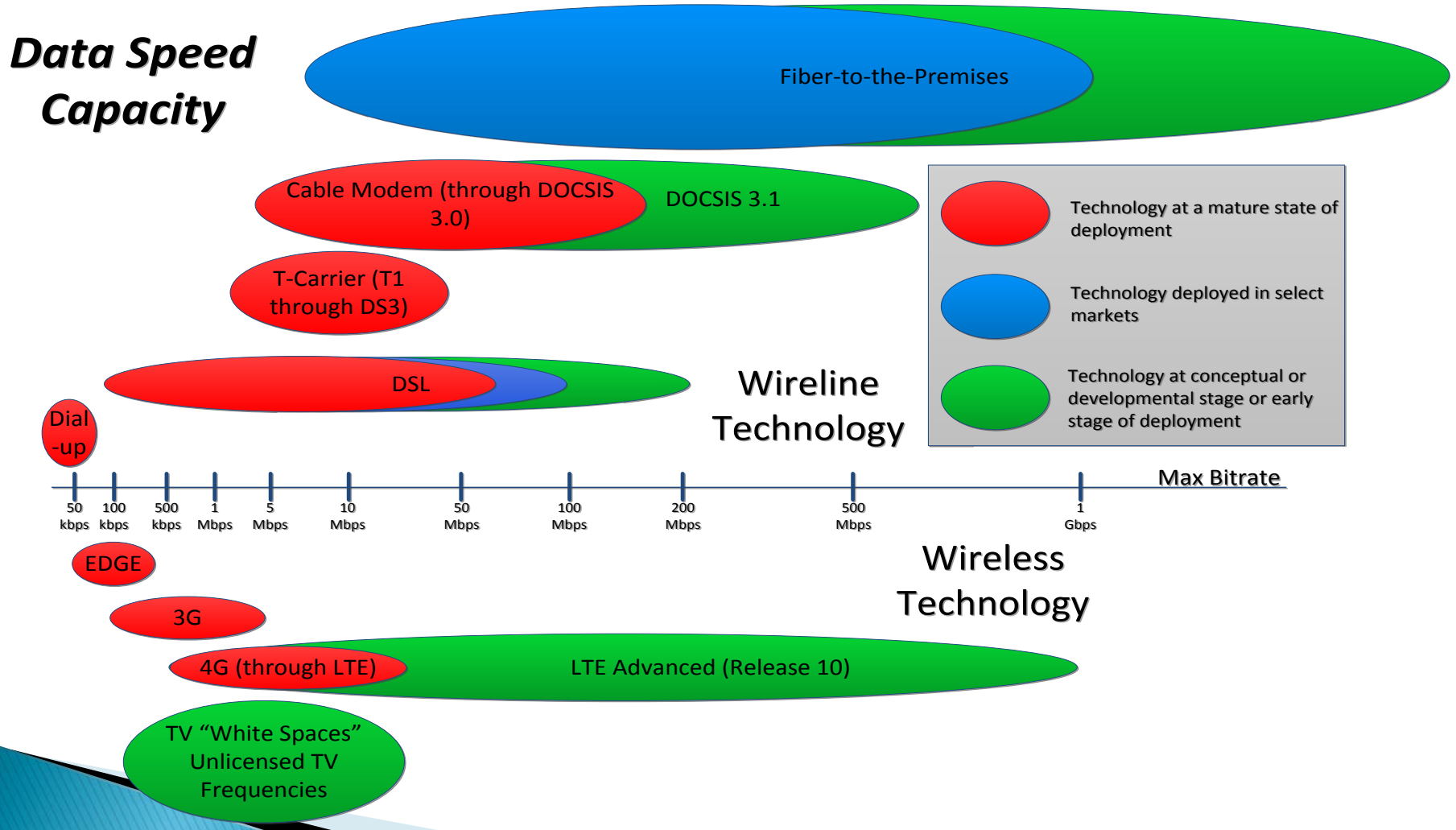


535 kHz to 1630 kHz	26 MHz to 27 MHz	88 MHz to 108 MHz	450 MHz	700 MHz	800 MHz	902 MHz to 928 MHz	1.9 GHz	2.4 GHz Band	3.65 GHz Band	4.9 GHz Band	5 GHz Band
						Unlicensed Spread Spectrum	Unlicensed Public Use Bands				

TV White Space Sample Deployment



Technologies and Speeds: *Fiber Ahead of All Others*



Minimum Time Required for Downloading and Uploading a 5 GB File