Internet access and backbone technology

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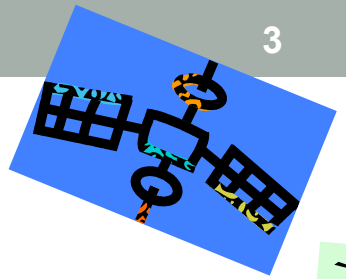
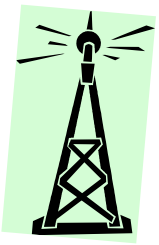
Columbia University
COMS 6181 – Spring 2015
03/30/2015

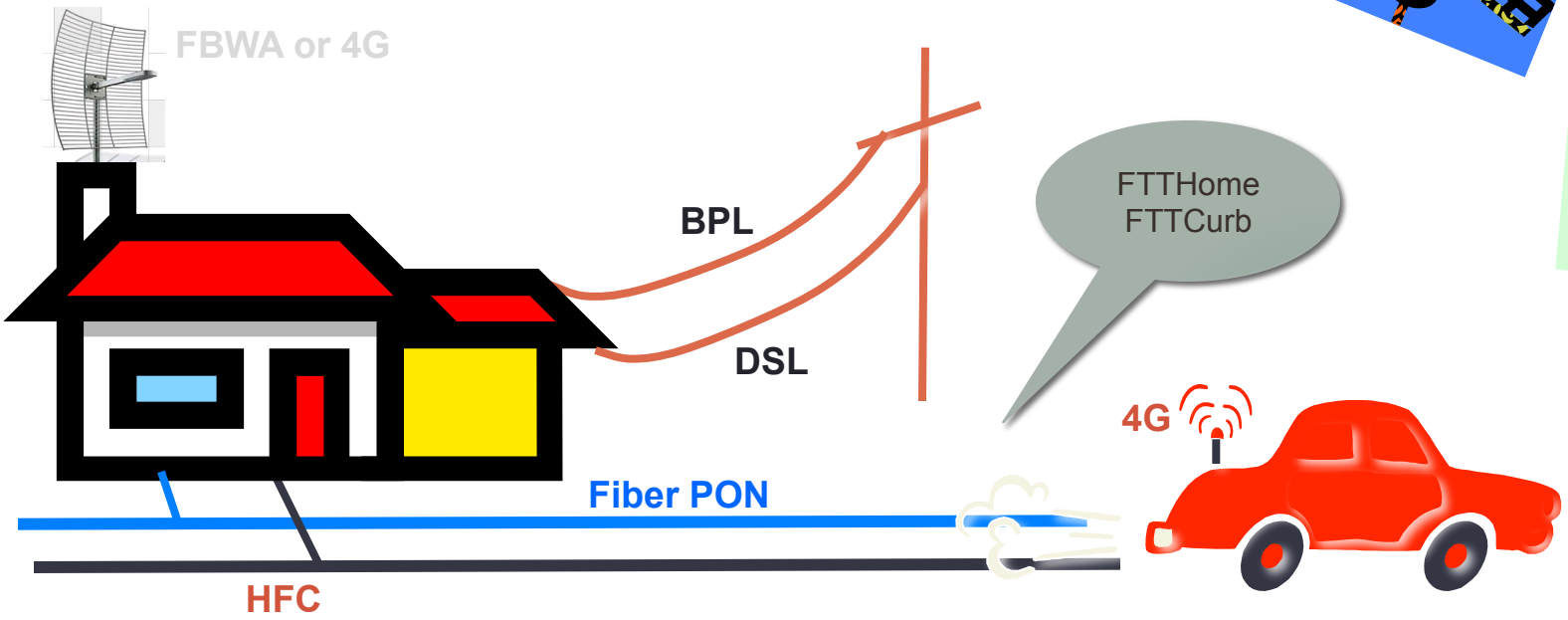
Key objectives

- How do DSL and cable modems work?
- How do fiber networks differ?
- How do satellites work?
- What is spectrum and its characteristics?
- What is the difference between Wi-Fi and cellular?

Broadband Access Technologies







Digital Subscriber Line
- Telco or ILEC
- 10s of Mbps
- Entertainment, data, voice

Hybrid Fiber Coax
- CableCo (MSO)
- Entertainment, data, voice
- 10s of Mbps

Fiber -- Passive Optical Network
- Telco or ILEC
- ~75 Mb/s
- Futureproof?

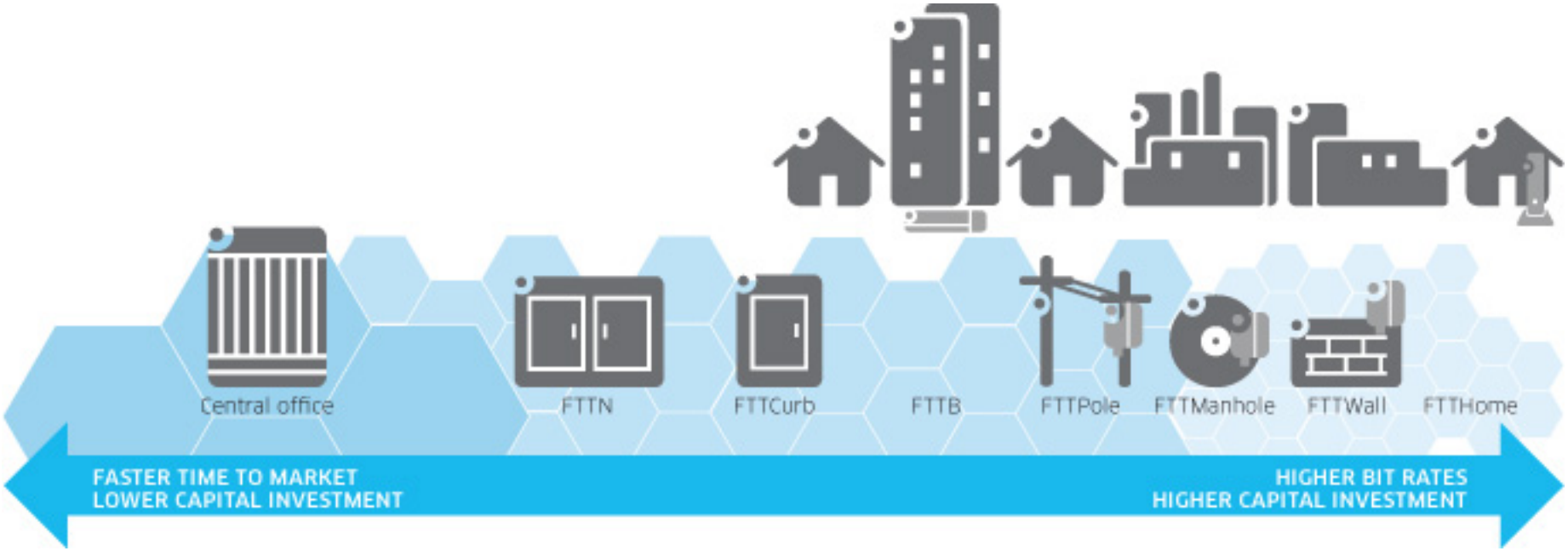
Broadband Power Line
- PowerCo
- Data, voice
- ~few Mbps

Fixed Broadband Wireless Access
- Wireless ISP
- WiMAX or LTE:
  -10s of Mbps
- Satellite: few Mbps

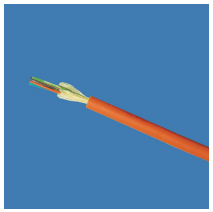
4G/LTE
- Cellular operators
- 5-10 Mbps (100 kph)

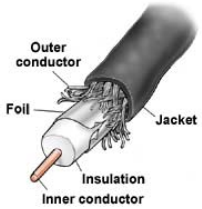
Paul Henry (AT&T), FCC 2009

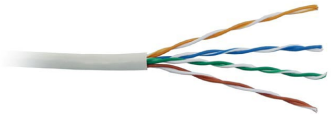
FTTx options



Available access speeds







marginal VOIP

100 Mb/s

20 Mb/s

10 Mb/s

5 Mb/s

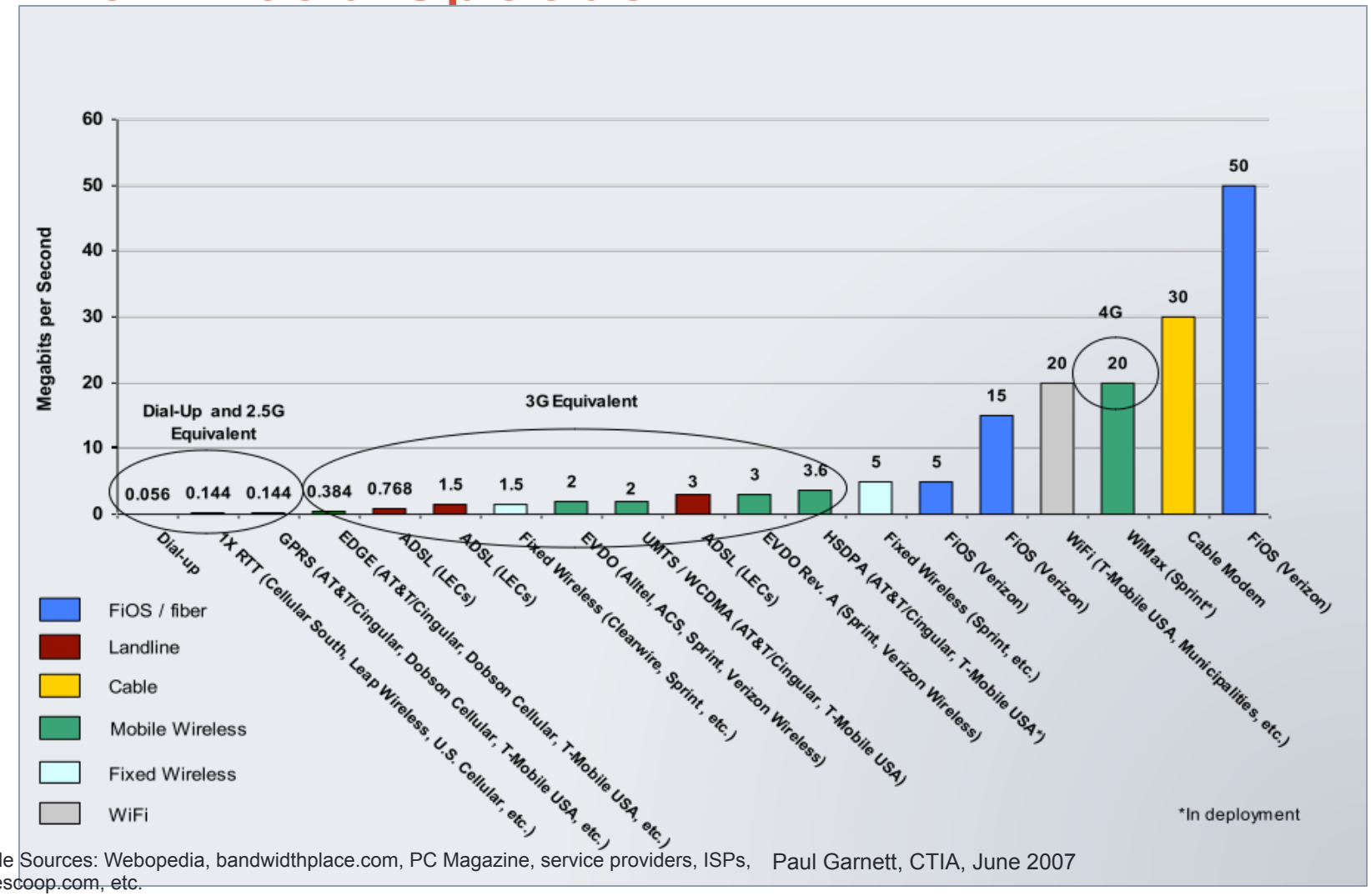
1 Mb/s

avg. sustained throughput

20% 80% 90% 97% 100%

of households (availability)

Maximum Theoretical Broadband Download Speeds



Multiple Sources: Webopedia, bandwidthplace.com, PC Magazine, service providers, ISPs, Phonescoop.com, etc.

Paul Garnett, CTIA, June 2007

Access costs

- Fiber → GPON 200 Mb/s both directions
  - $200-400 for gear
  - Verizon FiOS < $700/home passed -- dropping
  - $20K/mile to run fiber
- Wireless LTE/WiMAX
  - 4-10 Mb/s typical
  - 95% of U.S. population 2013 (McAdam, VZ)
  - Shared 30-120 Mb/s, so heavy HD TV use a problem

Residential access: DSL

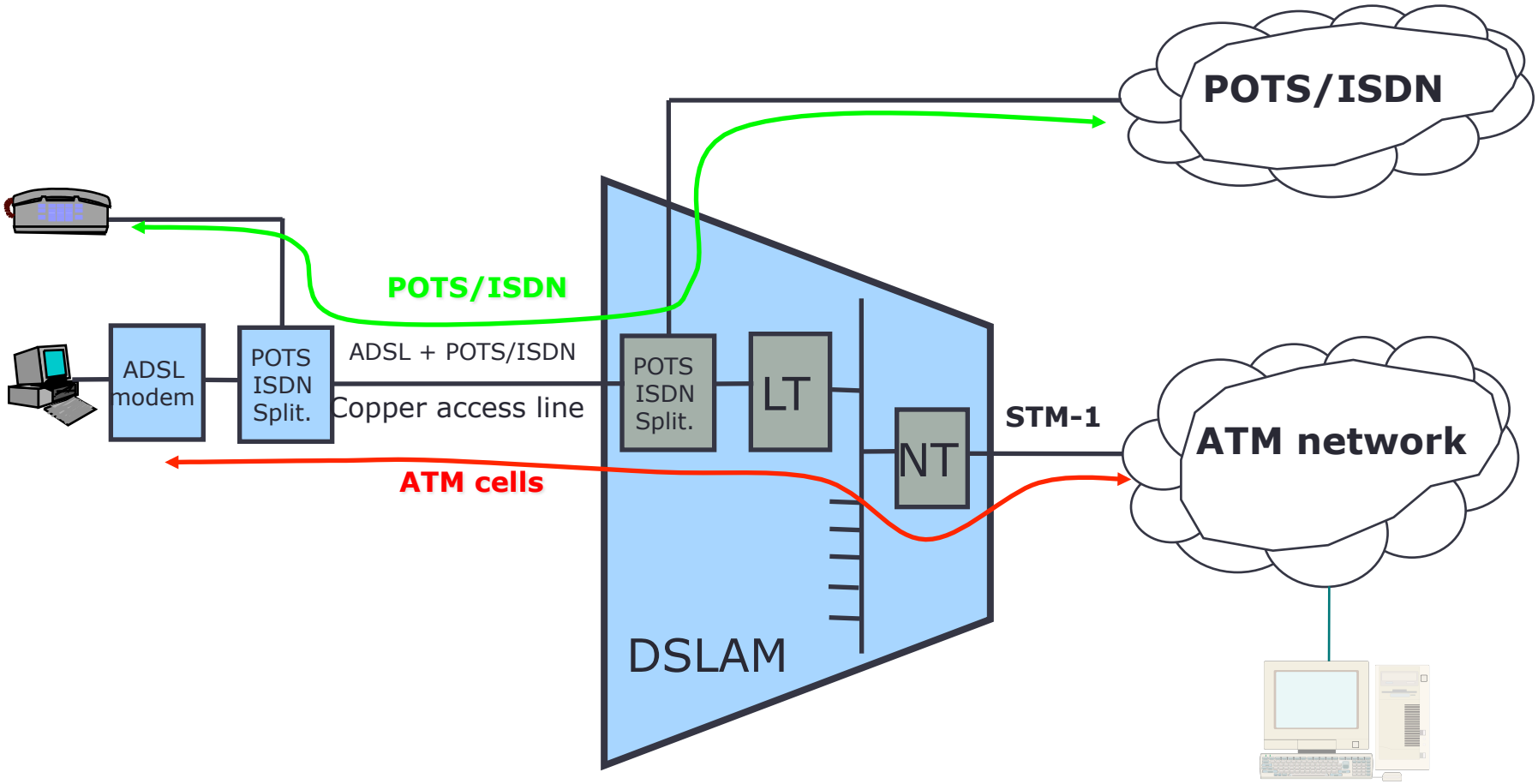
- Uses single copper pair
  - shared with analog phone service
  - but “bonding” proposed since most residences have 2 pairs
  - businesses may have 40-pair bundles
  - capacity depends on frequency range
- ADSL = asymmetric digital subscriber line
  - “web browsing”
  - but: sending photos, video conferencing
- Also need in-building technology:
  - coax: MoCA (100 MHz in 500-1650 MHz; 400-800 Mb/s)
  - Wi-Fi
  - copper: HomePlug AV (1.8 – 30 MHz; 200 Mb/s)
    - AV2 measured: ~60 Mb/s (99% of connections)

MoCA Multimedia over Coax Alliance

HOMEPLUG ALLIANCE

Functional scheme of a DSLAM

- DSLAM: Digital Subscriber Line Access Multiplexer



ADSL standards (current)

Standard name	Common name	Downstream rate	Upstream rate
ITU G.992.1	ADSL (G.DMT)	8 Mbit/s	1.0 Mbit/s
ITU G.992.2	ADSL Lite (G.Lite)	1.5 Mbit/s	0.5 Mbit/s
ITU G.992.3/4	ADSL2	12 Mbit/s	1.0 Mbit/s
ITU G.992.3/4 Annex J	ADSL2	12 Mbit/s	3.5 Mbit/s
ITU G.992.3/4 Annex L	RE-ADSL2	5 Mbit/s	0.8 Mbit/s
ITU G.992.5	ADSL2+	24 Mbit/s	1.0 Mbit/s
ITU G.992.5 Annex L	RE-ADSL2+	24 Mbit/s	1.0 Mbit/s
ITU G.992.5 Annex M	ADSL2+	28 Mbit/s	3.5 Mbit/s

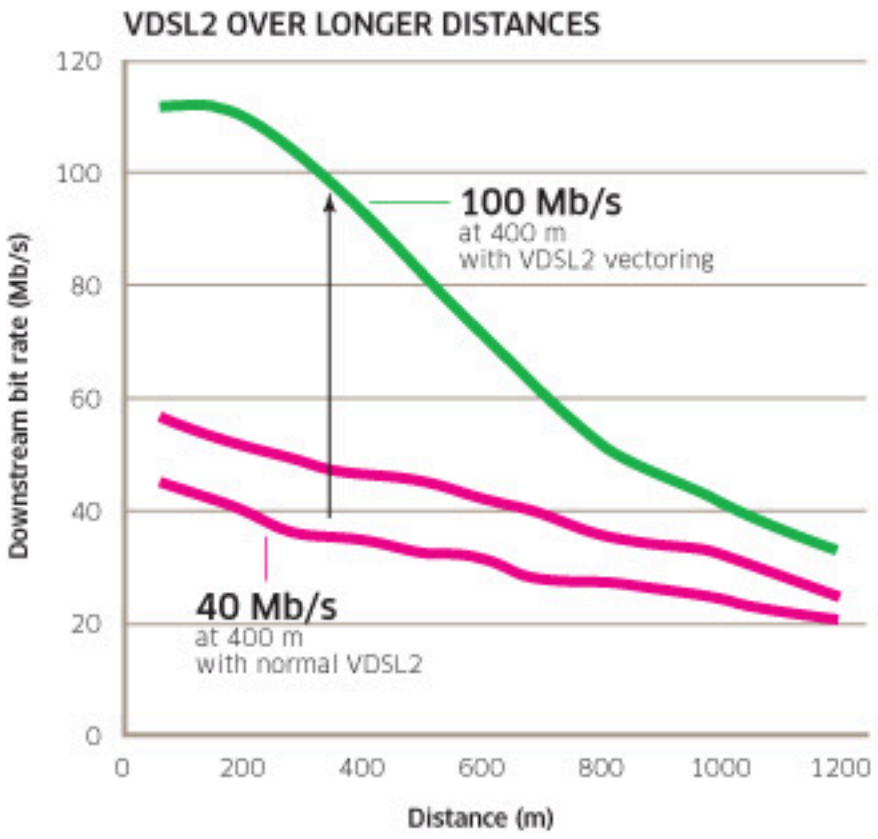
Michal, Angel, Igor

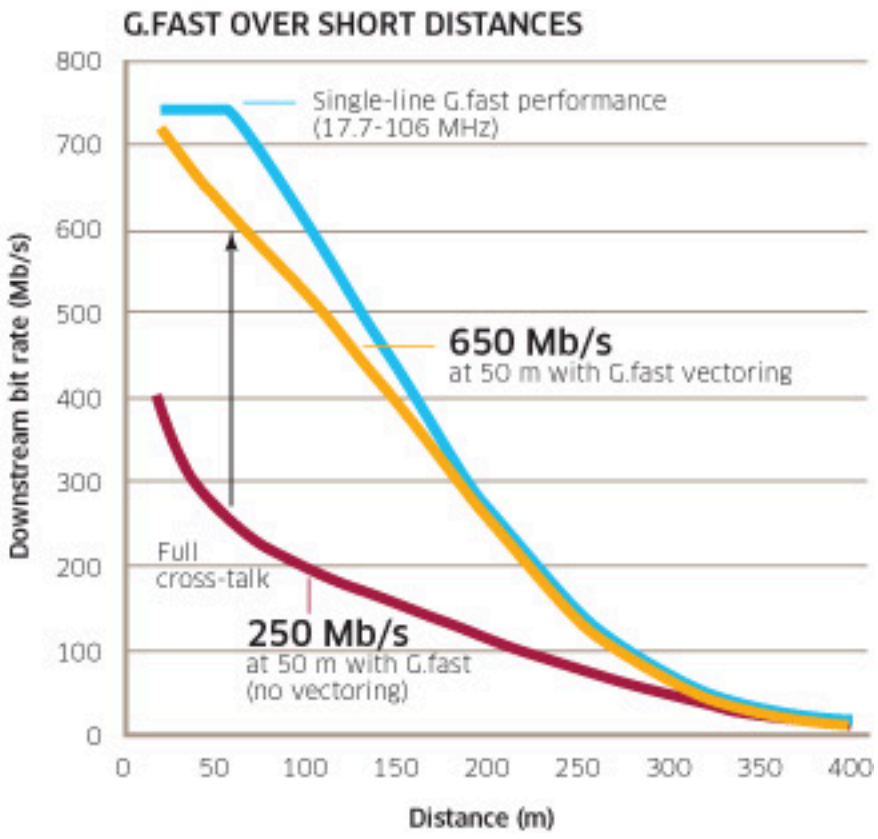
DSL frequencies

ITU-T G.993.2 (2005)

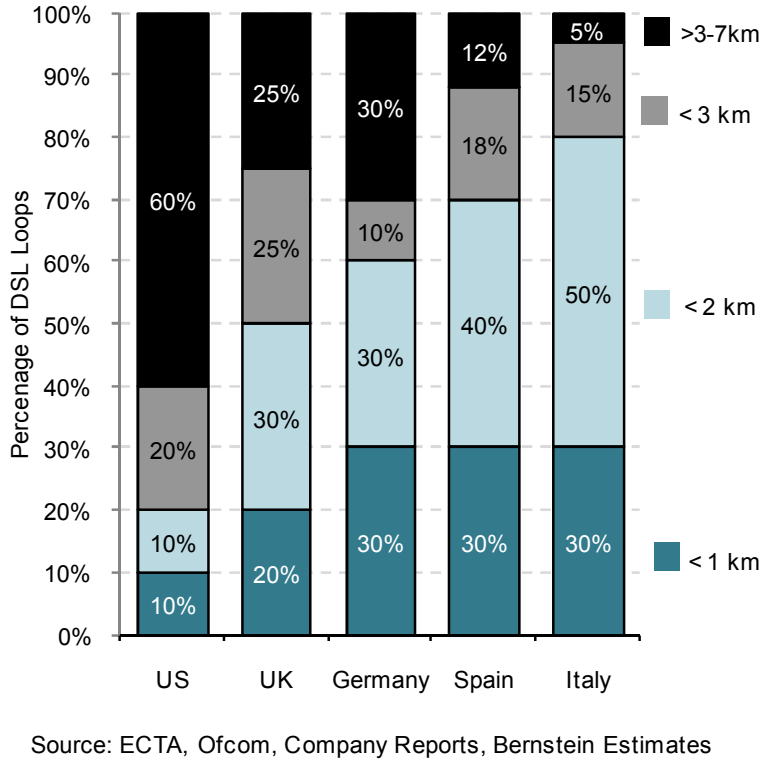
Wikipedia

VDSL and G.Fast





Copper loop lengths



Source: ECTA, Ofcom, Company Reports, Bernstein Estimates

DSL loop lengths

high-speed DSL

Copper loops → large-scale data competition (“unbundled network elements”)

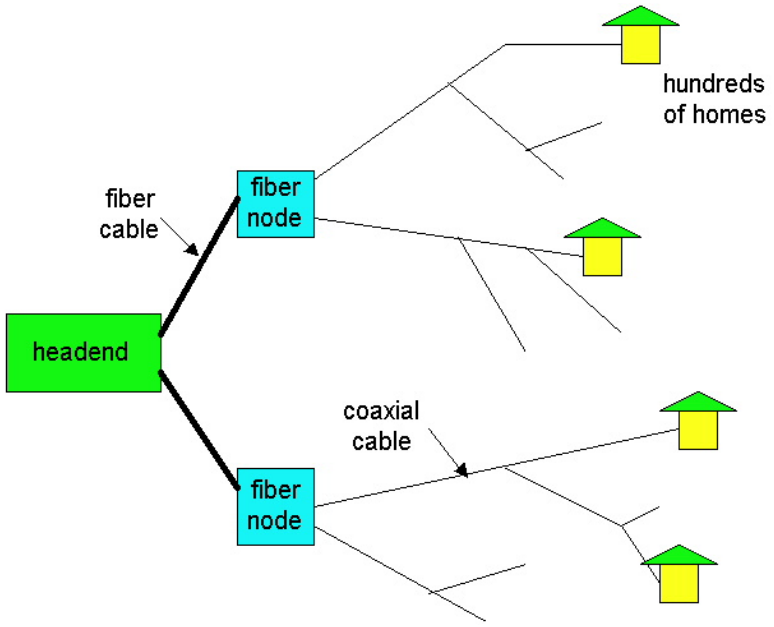
ADSL Range

- Range for DSL without a repeater: 5.5 km
- As distance decreases toward the telephone company office, the data rate increases

Data Rate	Wire gauge	Wire size	Distance
1.5 or 2 Mbps	24 AWG	0.5 mm	5.5 km
1.5 or 2 Mbps	26 AWG	0.4 mm	4.6 km
6.1 Mbps	24 AWG	0.5 mm	3.7 km
1.5 or 2 Mbps	26 AWG	0.4 mm	2.7 km

Residential access: cable modems

- HFC: hybrid fiber coax
  - asymmetric: up to 10 Mb/s upstream, 1 Mb/s downstream
- network of cable and fiber attaches homes to ISP router
  - shared access to router among home
  - issues: congestion, dimensioning
- deployment: available via cable companies



Residential access: cable modems

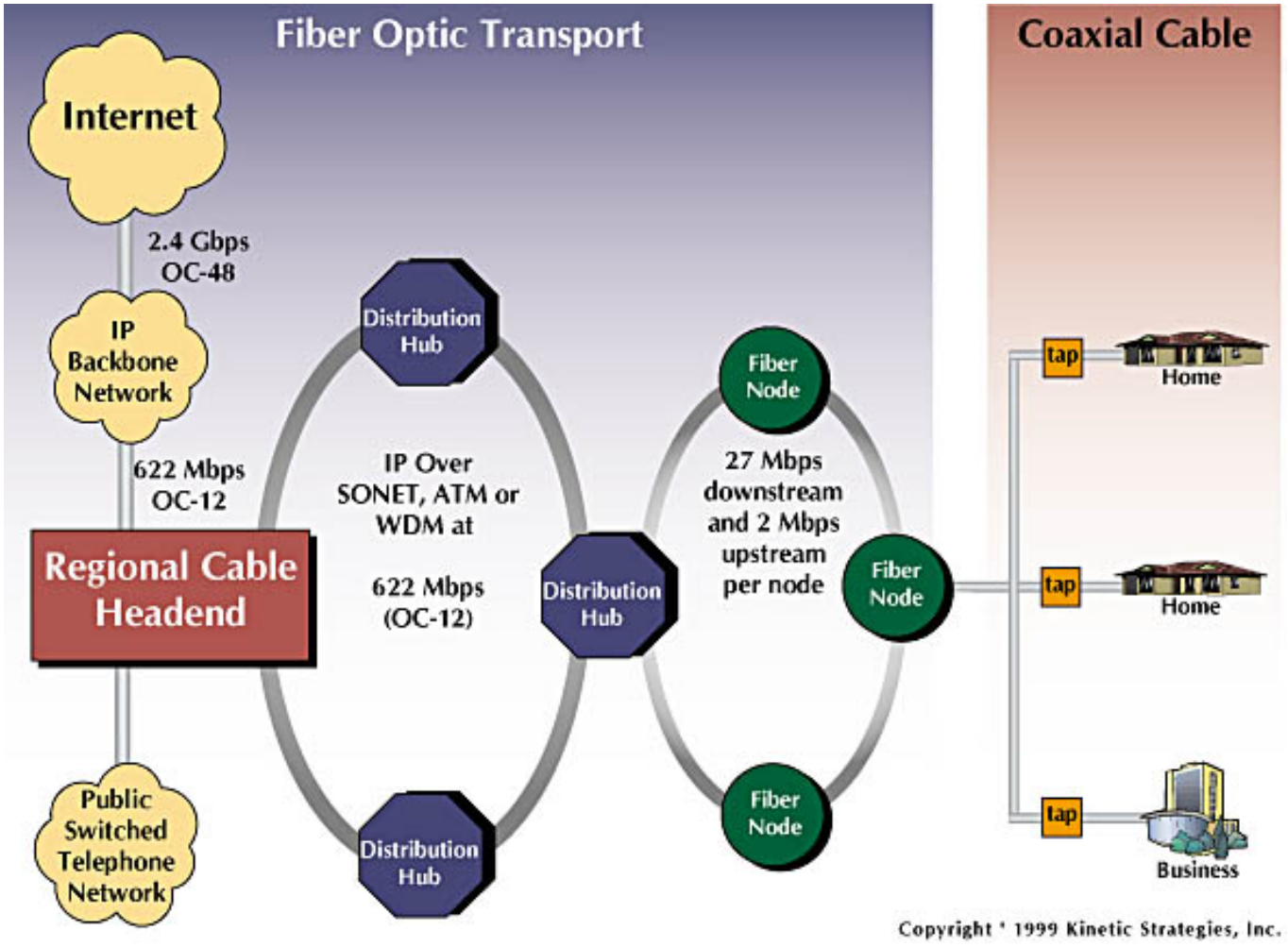
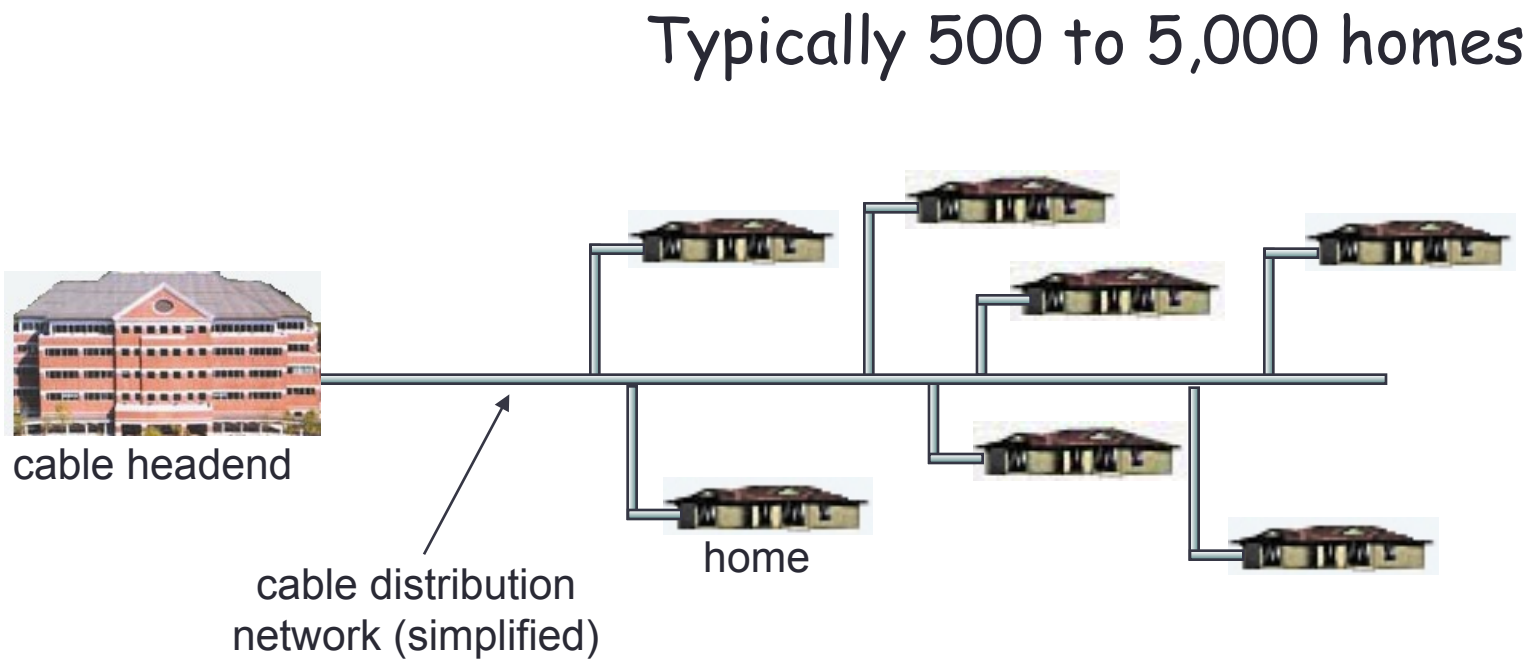
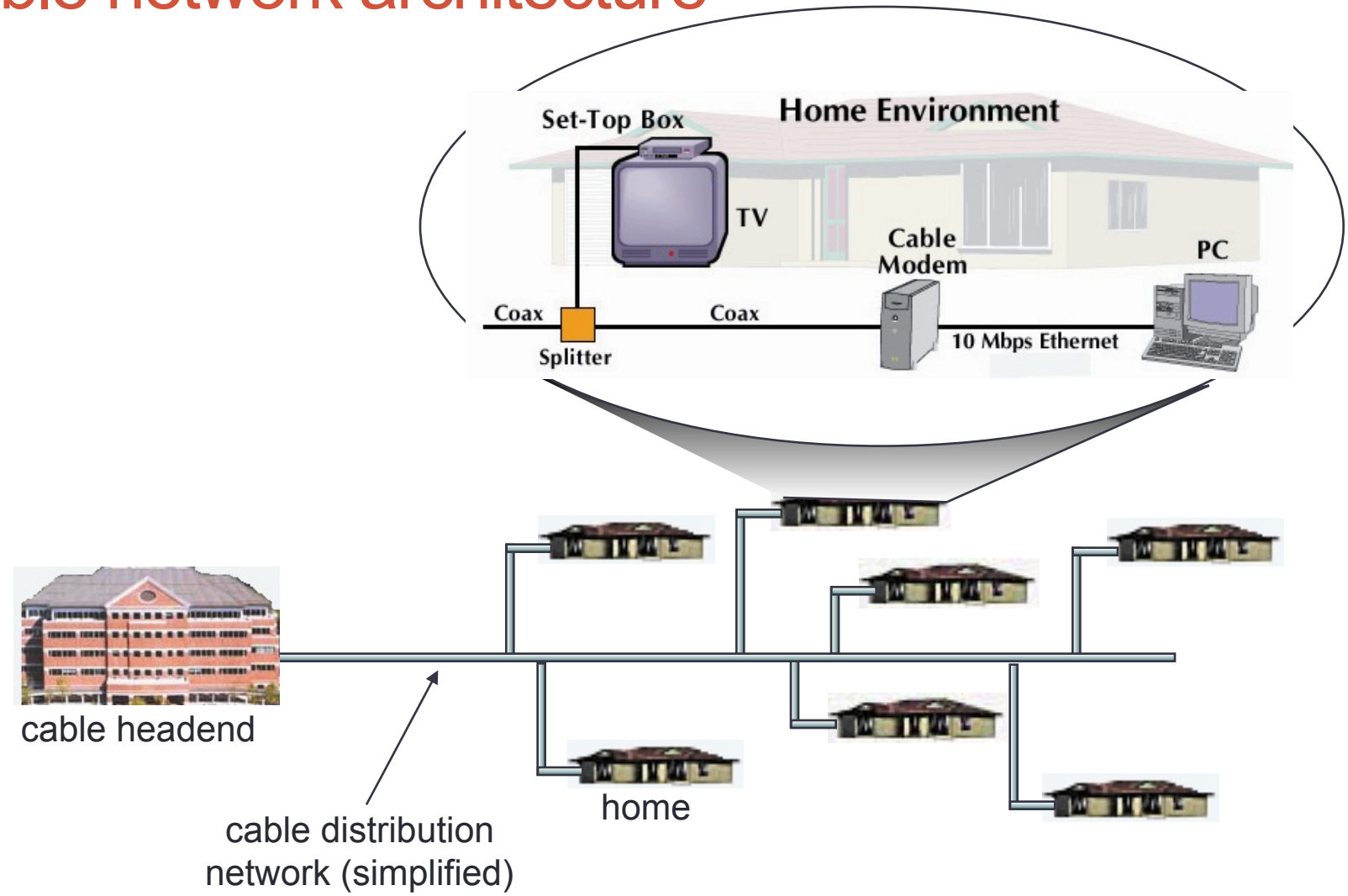


Diagram: http://www.cabledatacomnews.com/cmic/diagram.html

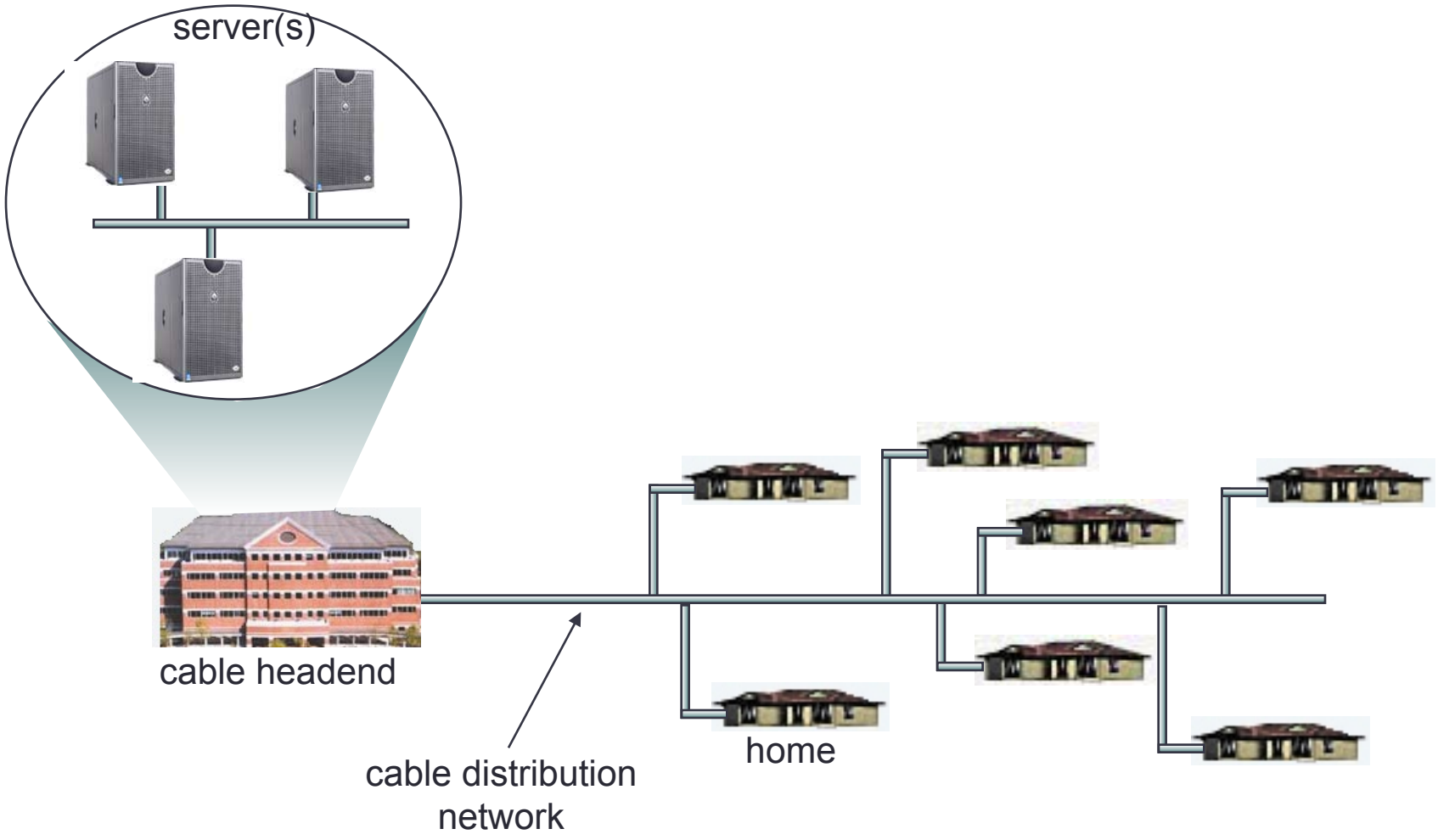
Cable network architecture



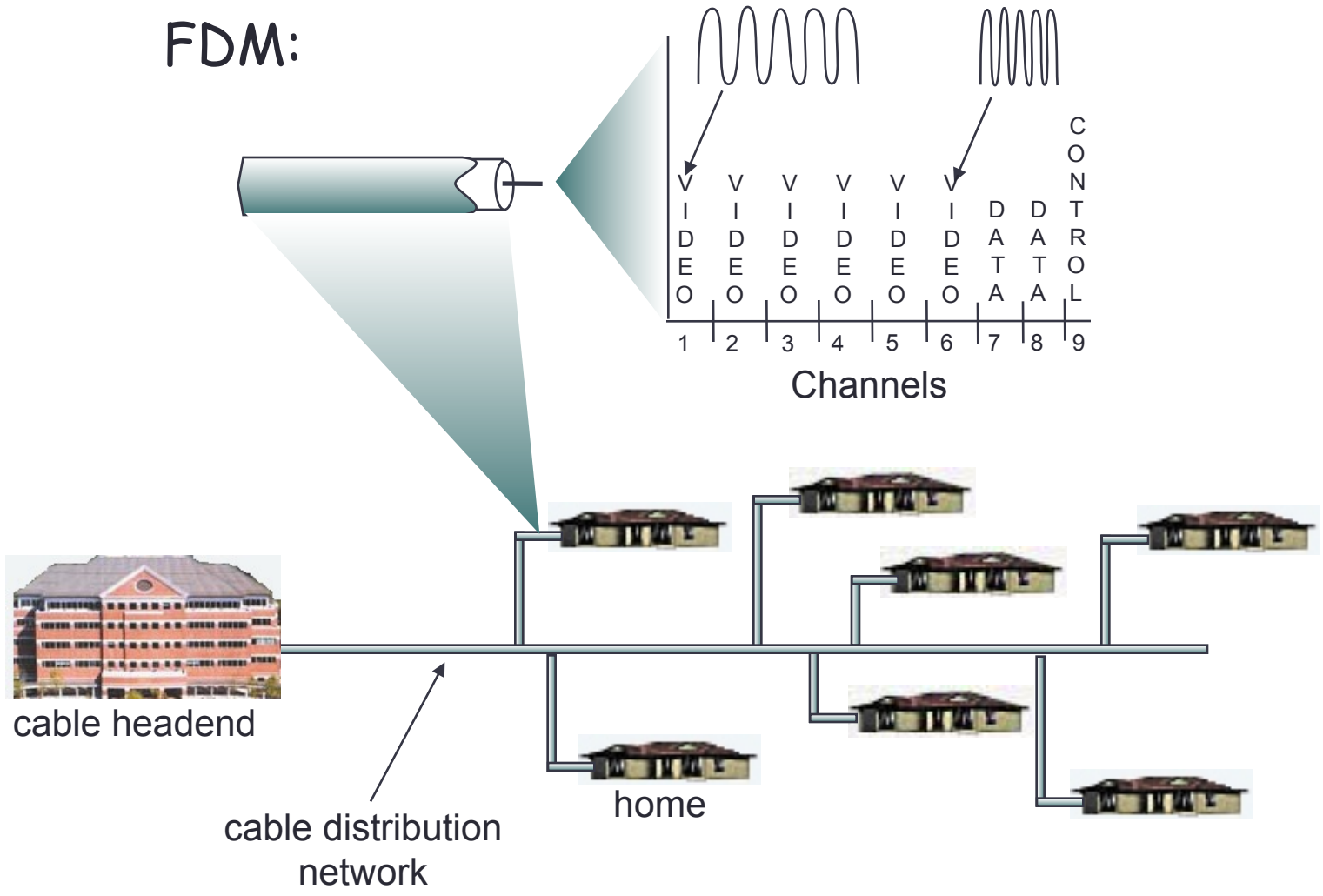
Cable network architecture



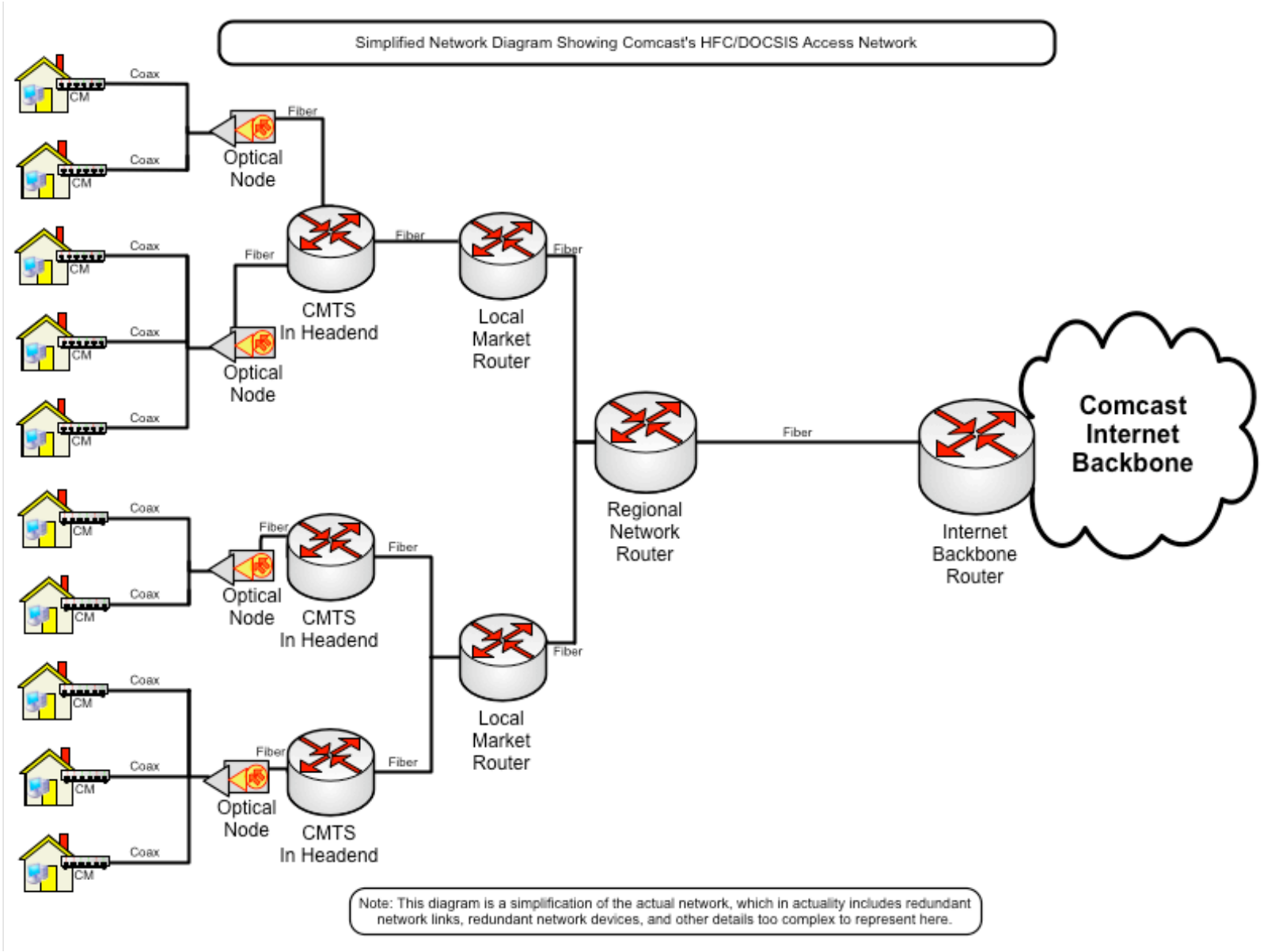
Cable network architecture



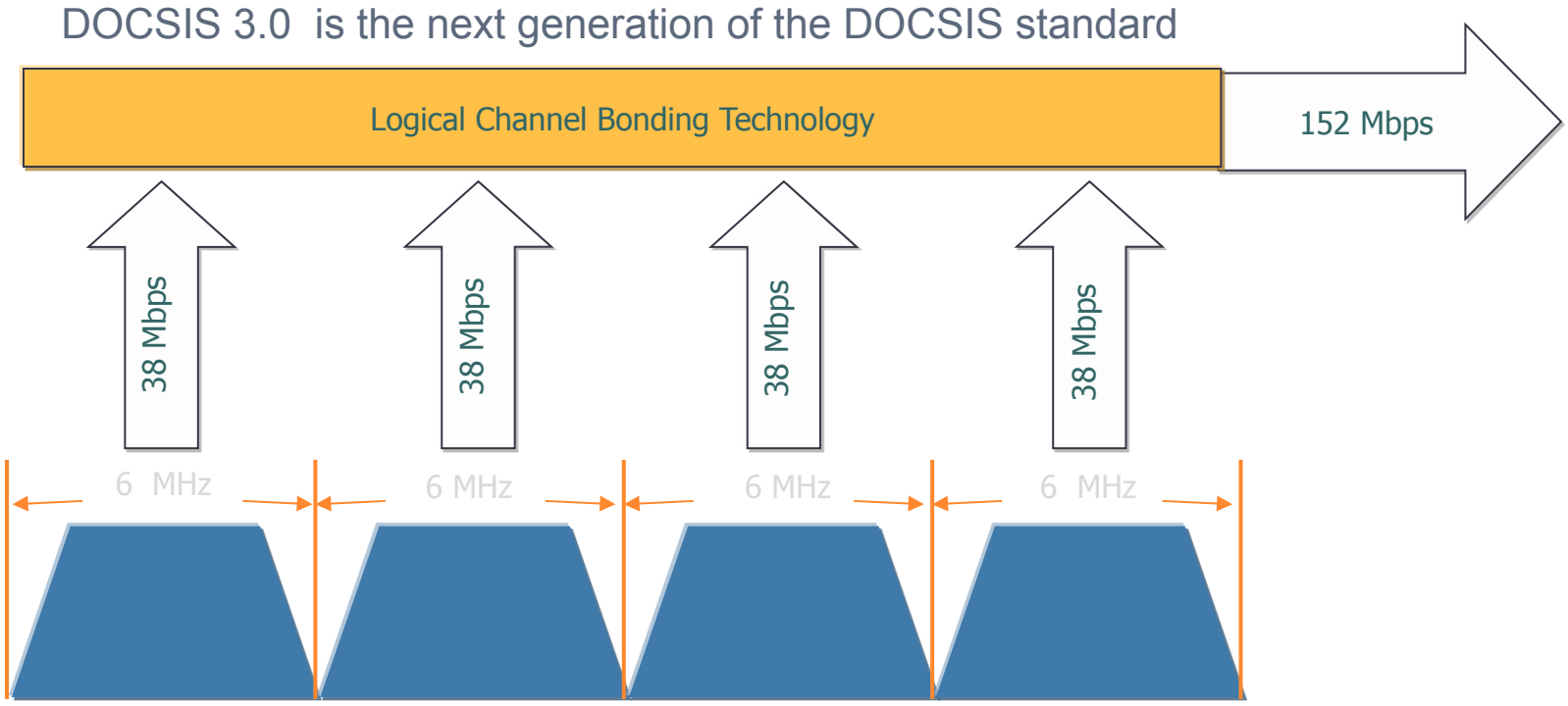
Cable network architecture



Simplified access network diagram



DOCSIS 3.0 Channel Bonding



- DOCSIS 2.0 is limited to single channel's capacity

- DOCSIS 3.0 employs packet bonding across multiple channels
  - Initially will bond 4 channels
  - 8 channel-capable silicon coming soon
  - Upstream bonding in 2010
  - Increased speeds 100Mbps+

Network cost

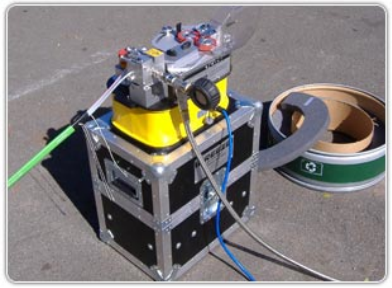
- Electronic and electro-optic costs are dropping rapidly
  - GigE switch : 2001 - $15K 2003 - $1.2K 2009 - $600 (12 port)
  - GigE transceivers 2001 - $750 2003 - $180
  - CWDM transceivers $400-800 for 50-100km reach!
- Direct fiber cost is relatively low
  - $60/fiber-km in 80-fiber bundle
- But – fiber installation cost is still tall pole
  - Europe: >$20/m (or any populous wide-area)
  - U.S.: >$10m (in simplest desert environment)

A. Whitney (2003, modified)

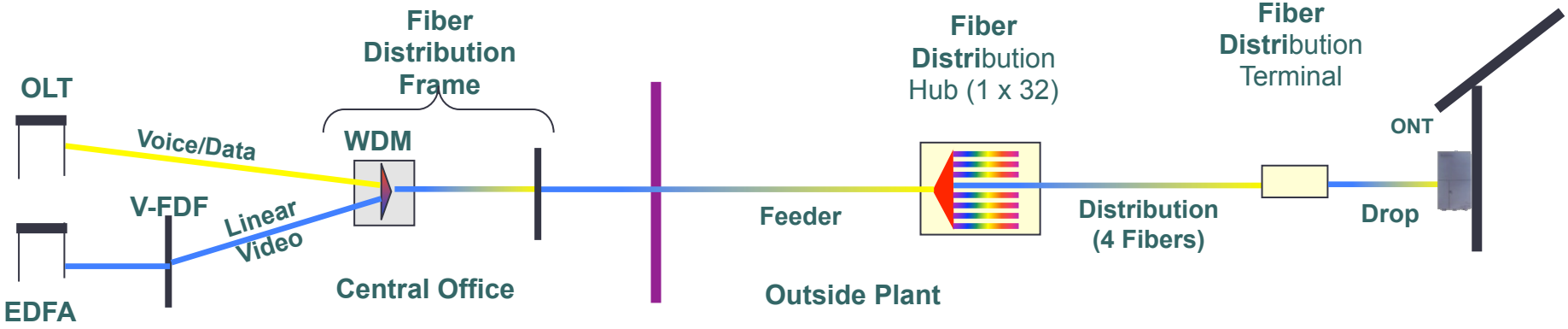
Fiber installation cost

- Construction cost (Oct, 2008) estimate for Northern California for a 1" fiber optic cable where aerial infrastructure (poles) are already in place

Method	Cost
Aerial	$3.30/ft
Open trench	$10/ft
Rockwheel (24” depth)	$28/ft
Light underground (trench or bore)	$38.93/ft
Heavy underground (backhoe asphalt)	$72.93/ft

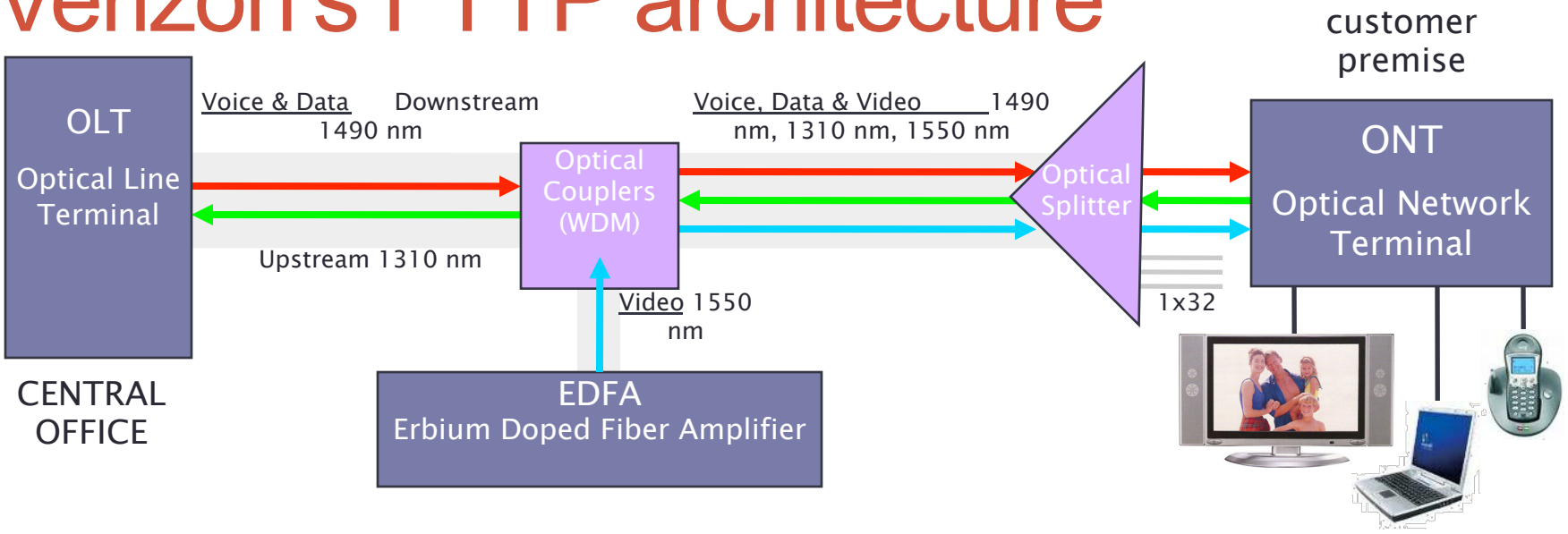


Typical Fiber GPON Access Architecture for providing voice, data and video

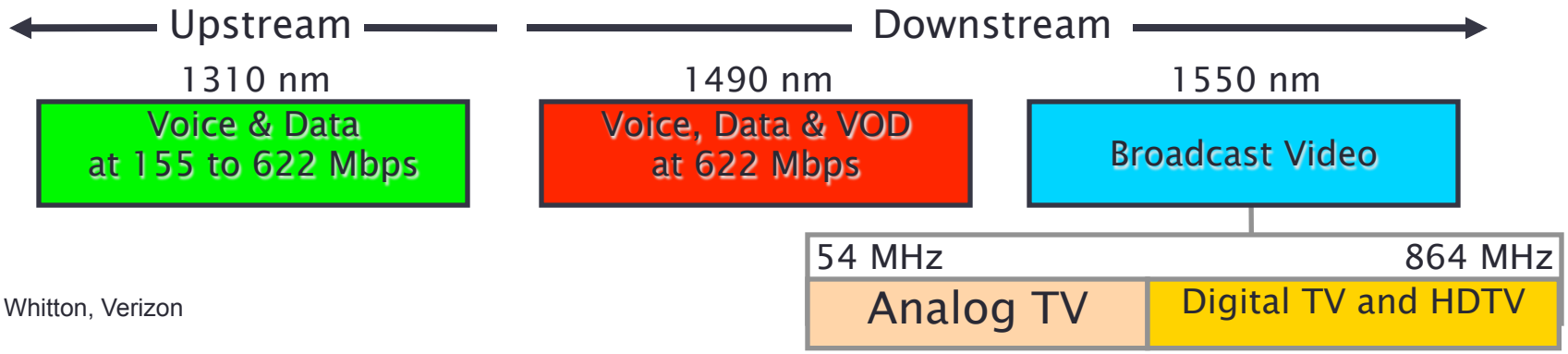


- OLT (Data) and EDFA (Video) output are combined using a WDM in the Fiber Distribution Frame (FDF) and transmitted to the Outside Plant over a feeder fiber
- A splitter located at the Fiber Distribution Hub (FDH) splits the optical power evenly to be shared between 32 or 64 customers
- Each 1x32(64) splitter feeds 32(64) distribution fibers to serve 32(64) homes in a neighborhood. The drop fiber connects the ONT to the distribution fiber at the Fiber Distribution Terminal (FDT)
- Separate wavelength for linear video (1550 nm)
- Voice and data carried as cells/packets (1490 nm down/1310 nm up)

Verizon's FTTP architecture

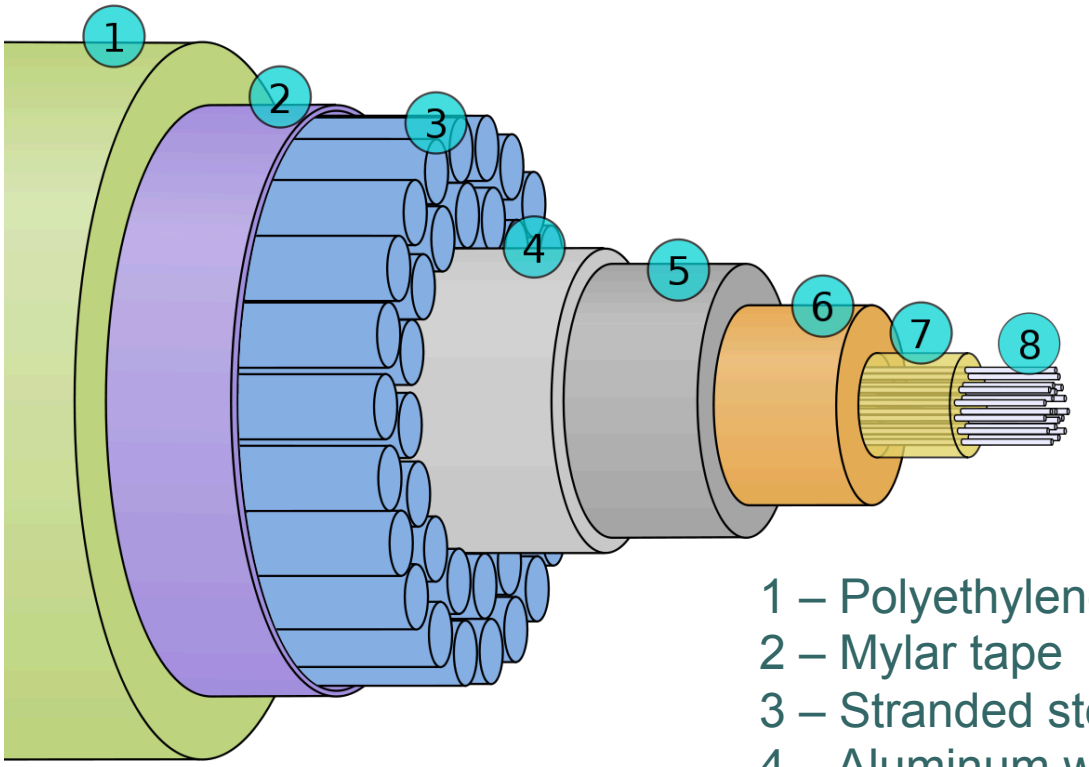


Bandwidth & Services



Brian Whitton, Verizon

Undersea fiber cable

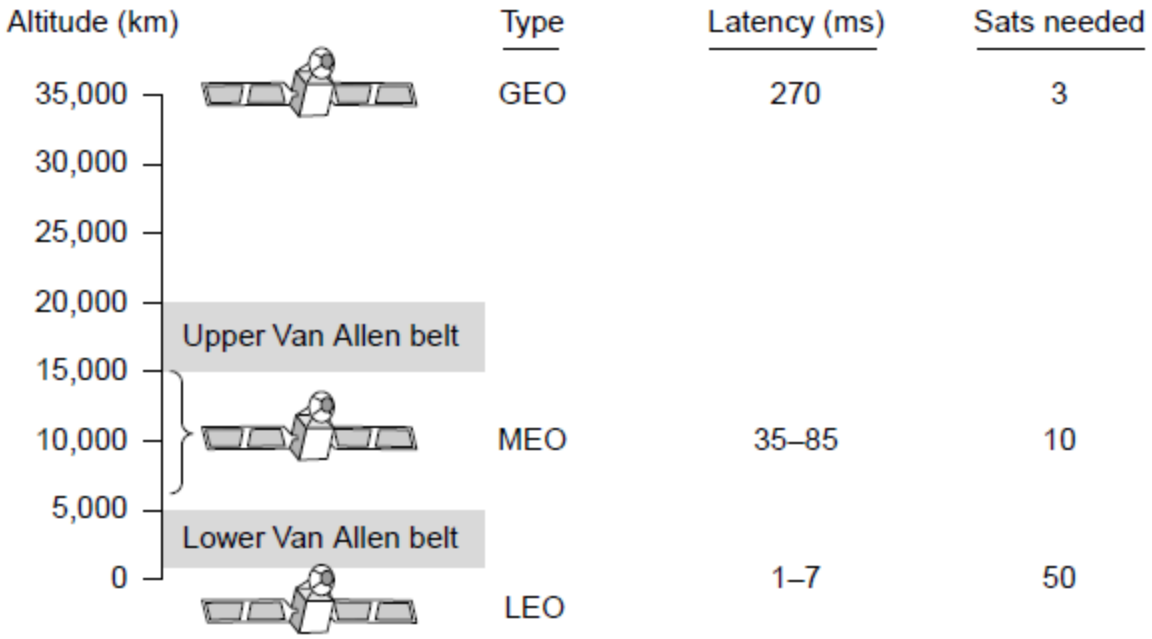


1 – Polyethylene
2 – Mylar tape
3 – Stranded steel wires
4 – Aluminum water barrier
5 – Polycarbonate
6 – Copper or aluminum tube
7 – Petroleum jelly
8 – Optical fibers

Wikipedia

SATELLITES

Communication satellites



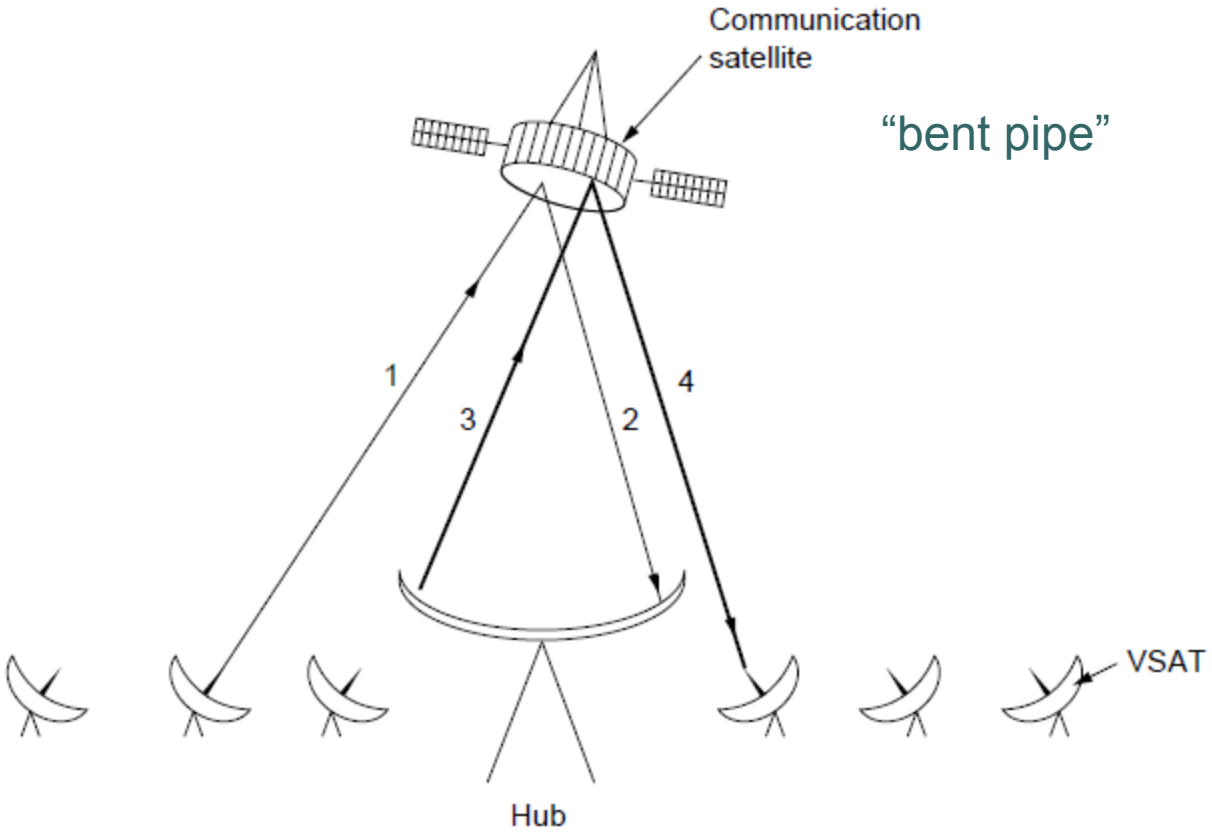
Communication satellites, some properties, including: altitude above earth, round-trip delay time, number of satellites for global coverage.

Geostationary satellites (1)

Band	Downlink	Uplink	Bandwidth	Problems
L	1.5 GHz	1.6 GHz	15 MHz	Low bandwidth; crowded
S	1.9 GHz	2.2 GHz	70 MHz	Low bandwidth; crowded
C	4.0 GHz	6.0 GHz	500 MHz	Terrestrial interference
Ku	11 GHz	14 GHz	500 MHz	Rain
Ka	20 GHz	30 GHz	3500 MHz	Rain, equipment cost

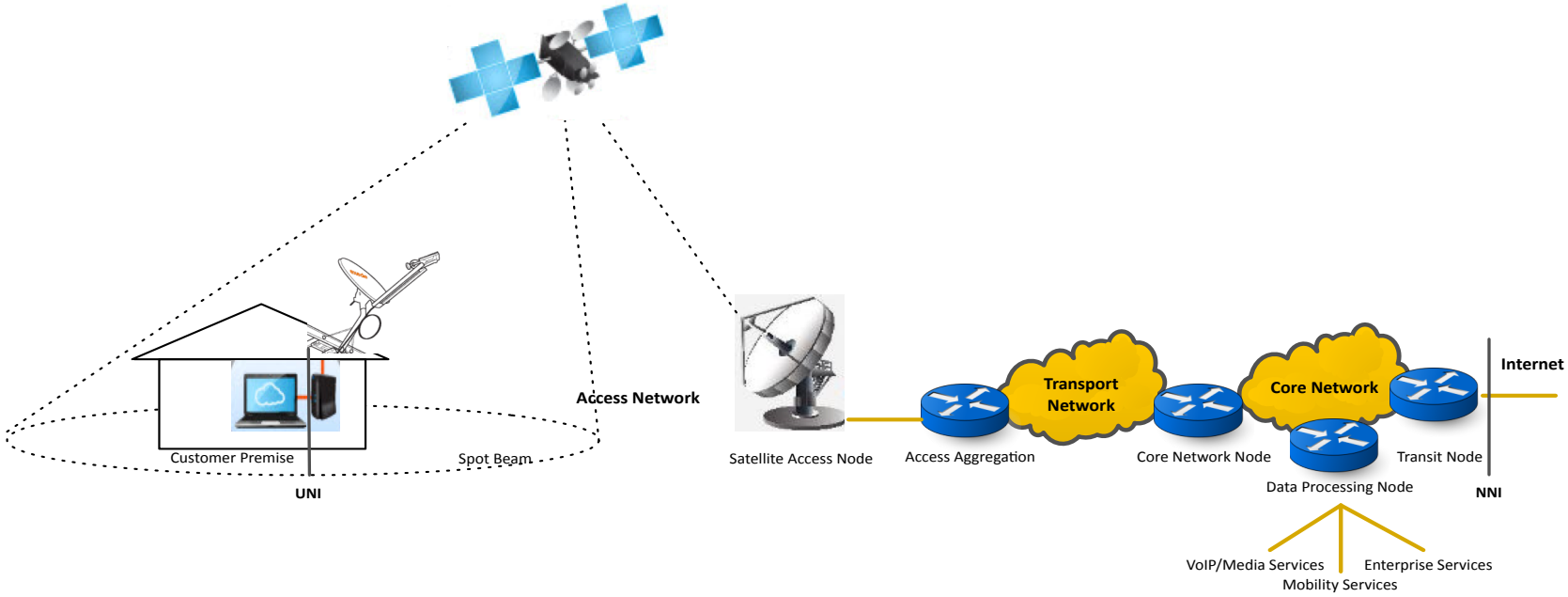
The principal satellite bands

Geostationary satellites (2)



VSATs using a hub.

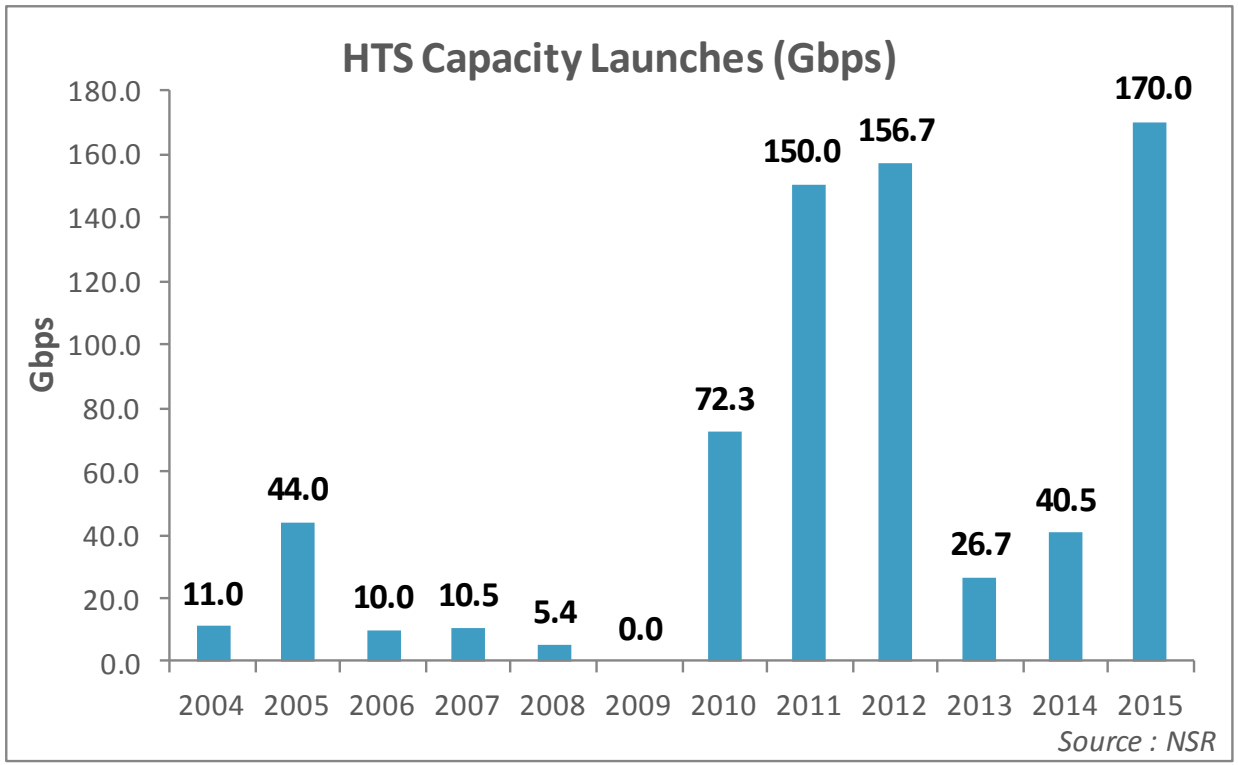
Satellite broadband architecture



- Thousands of customers within a spot beam (a spot beam is like a sector in LTE)
  - Ka-band beam bandwidths are typically 500 MHz but can be significantly larger

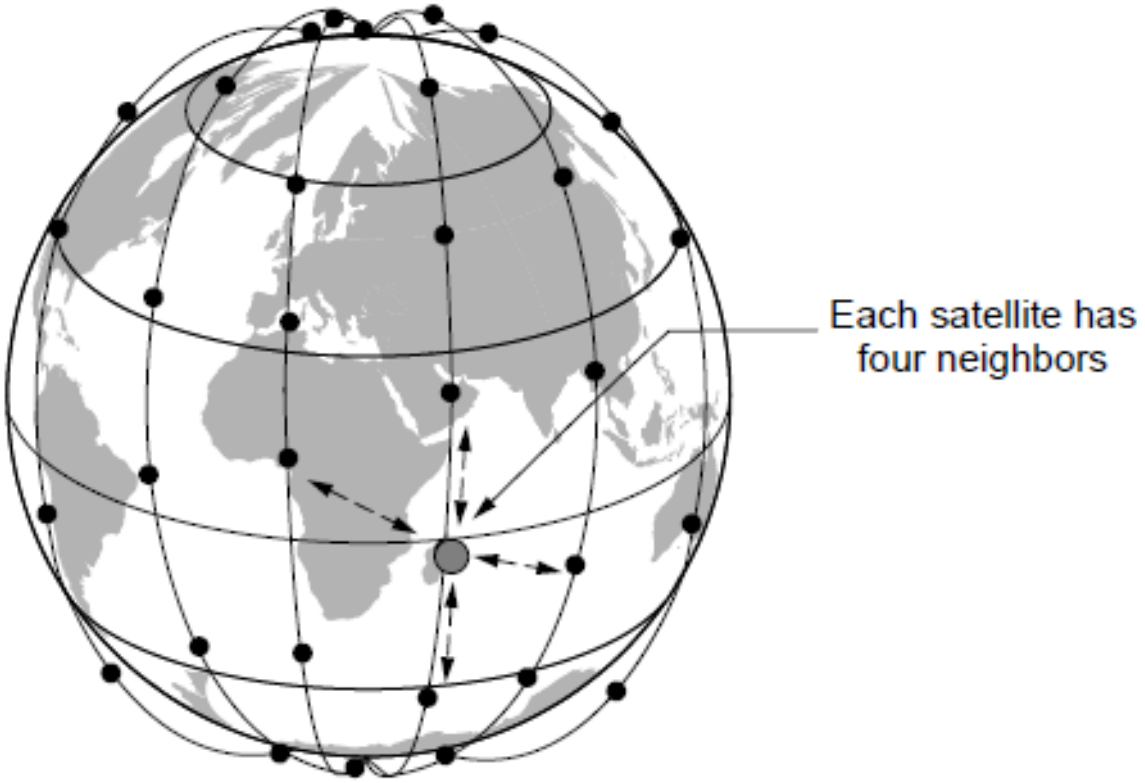
HTS launches per year

Dedicated HTS	Hybrid Payload HTS
Thaicom 4	Anik F2
WildBlue 1	AMC-15
Spaceway 3	AMC-16
Ka-Sat	Ciel-2
ViaSat-1	Hylas 1
Jupiter-1	Arabsat 5C
Inmarsat 5F2	YahSat 1B
Inmarsat 5F1	Hylas 2
Inmarsat 5F3	Hispasat AG1
NBN Co 1A	Express AM5
GSAT-11	Astra 2F
NBN Co 1B	Express AM6
	Amazonas 3
	Astra 2E
	Thor 7
	Astra 2G
	Jabiru-1



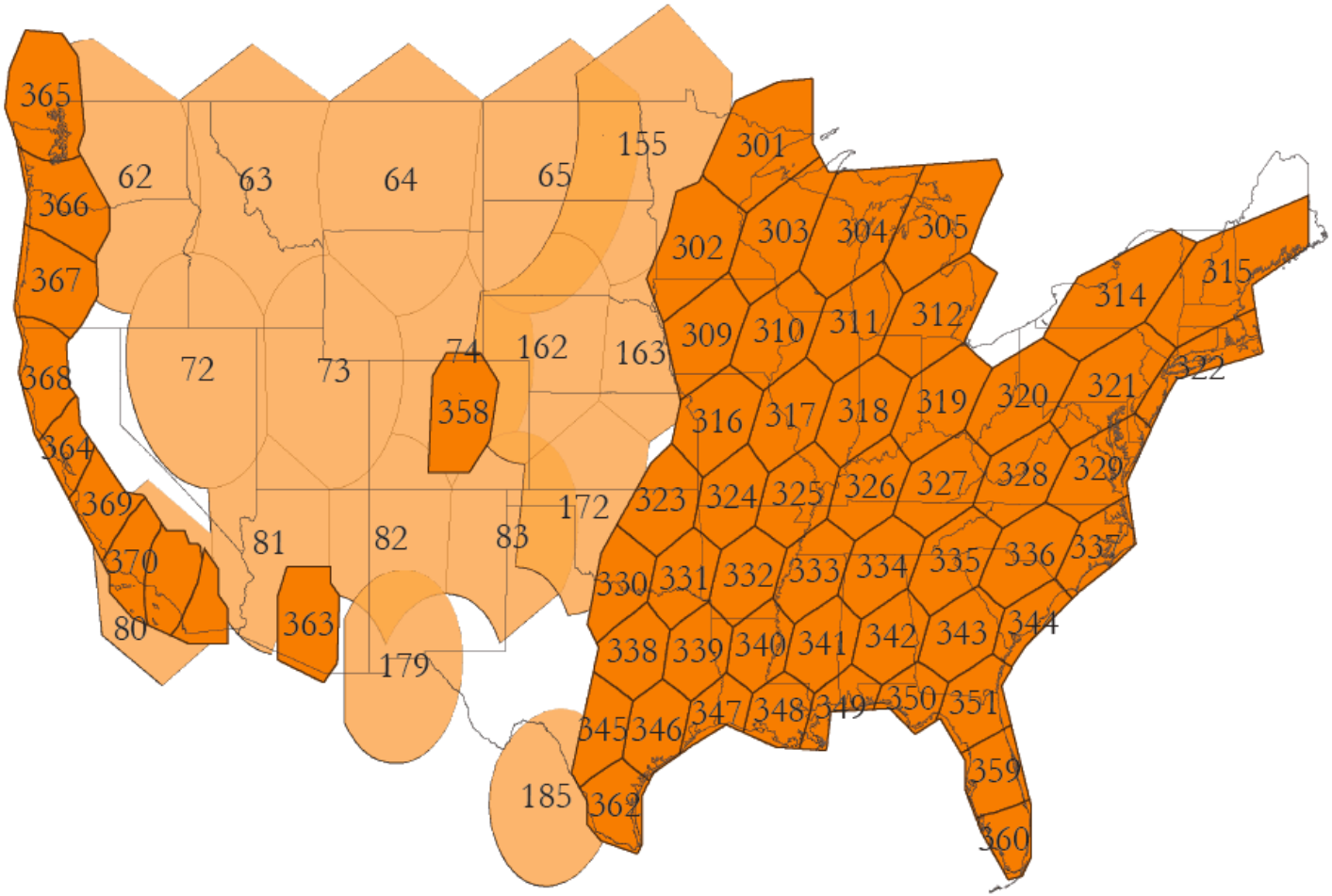
NSR NORTHERN SKY RESEARCH

Low-Earth orbit satellites



The Iridium satellites form six necklaces around the earth.

Exede beam map



http://www.wildbluetools.com/content/dealer/email/Beam_map-high-mid-low.html

Satellite

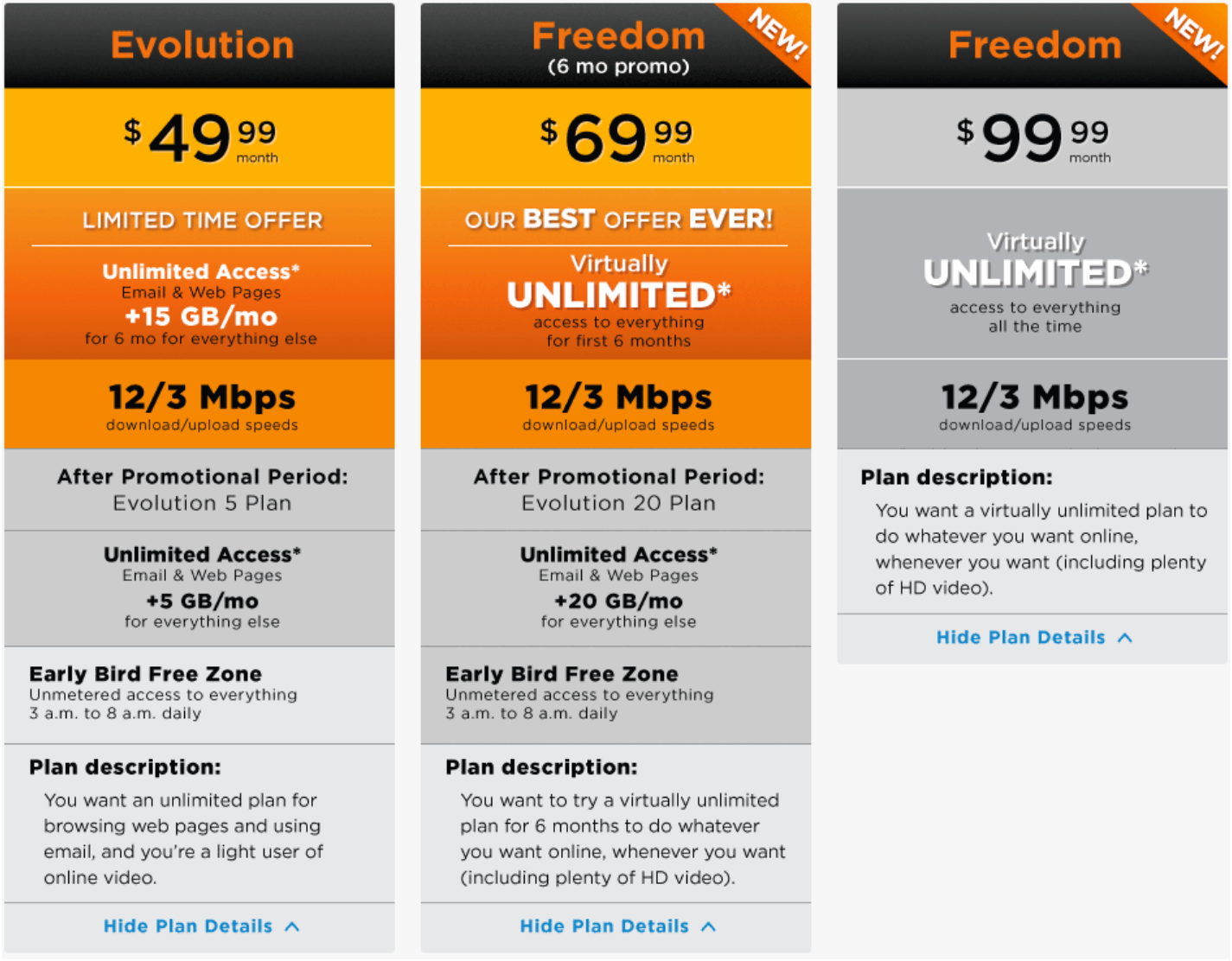
Advantages

- Near-universal geographic availability
  - low incremental cost
    - satellite terminal + installation
- Resilient after natural disasters
  - often used as backup

Disadvantages

- Latency
  - MBA 2014: RTT 671 ms
- Temporary disruptions
  - sun alignment
  - rain fade
- Capacity
  - Viasat-1: 140 Gb/s (for 300,000 customers)
  - usually, usage-capped

Example: Exede



Evolution

$49.99 month

LIMITED TIME OFFER

Unlimited Access*
Email & Web Pages
+15 GB/mo
for 6 mo for everything else

12/3 Mbps
download/upload speeds

After Promotional Period:
Evolution 5 Plan

Unlimited Access*
Email & Web Pages
+5 GB/mo
for everything else

Early Bird Free Zone
Unmetered access to everything
3 a.m. to 8 a.m. daily

Plan description:
You want an unlimited plan for browsing web pages and using email, and you're a light user of online video.

Hide Plan Details ^

Freedom NEW!
(6 mo promo)

$69.99 month

OUR **BEST** OFFER **EVER!**

Virtually
UNLIMITED*
access to everything
for first 6 months

12/3 Mbps
download/upload speeds

After Promotional Period:
Evolution 20 Plan

Unlimited Access*
Email & Web Pages
+20 GB/mo
for everything else

Early Bird Free Zone
Unmetered access to everything
3 a.m. to 8 a.m. daily

Plan description:
You want to try a virtually unlimited plan for 6 months to do whatever you want online, whenever you want (including plenty of HD video).

Hide Plan Details ^

Freedom NEW!

$99.99 month

Virtually
UNLIMITED*
access to everything
all the time

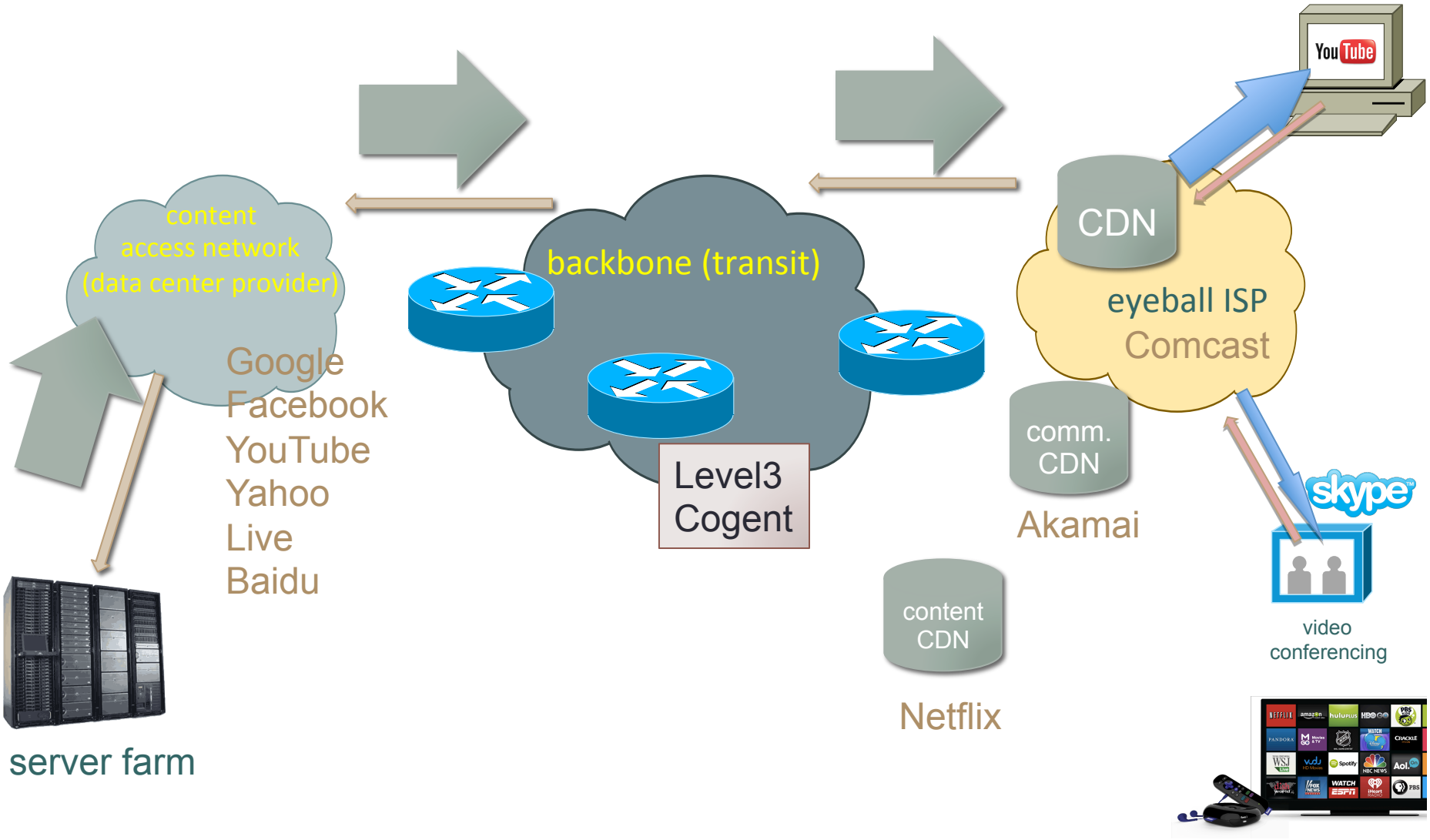
12/3 Mbps
download/upload speeds

Plan description:
You want a virtually unlimited plan to do whatever you want online, whenever you want (including plenty of HD video).

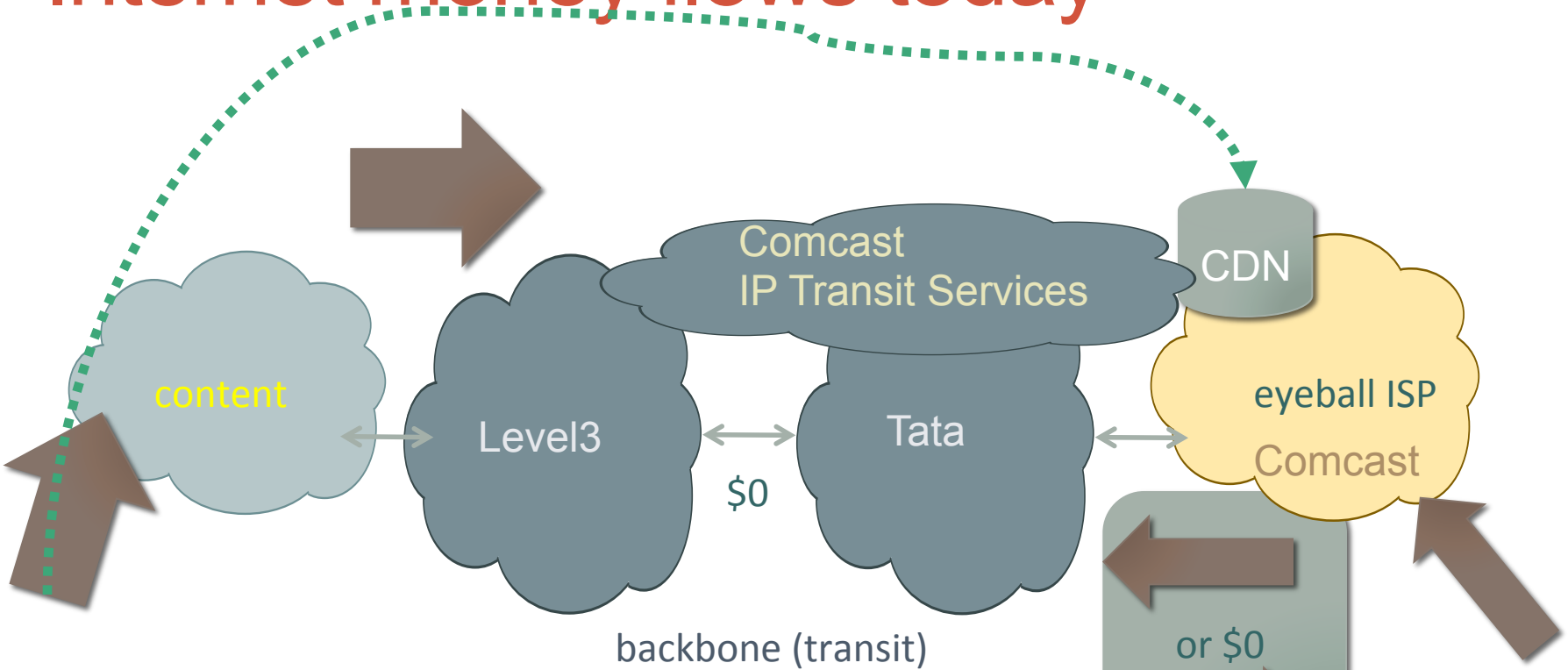
Hide Plan Details ^

INTERNET BACKBONE

Internet traffic flows today

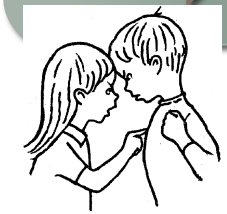


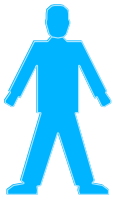
Internet money flows today



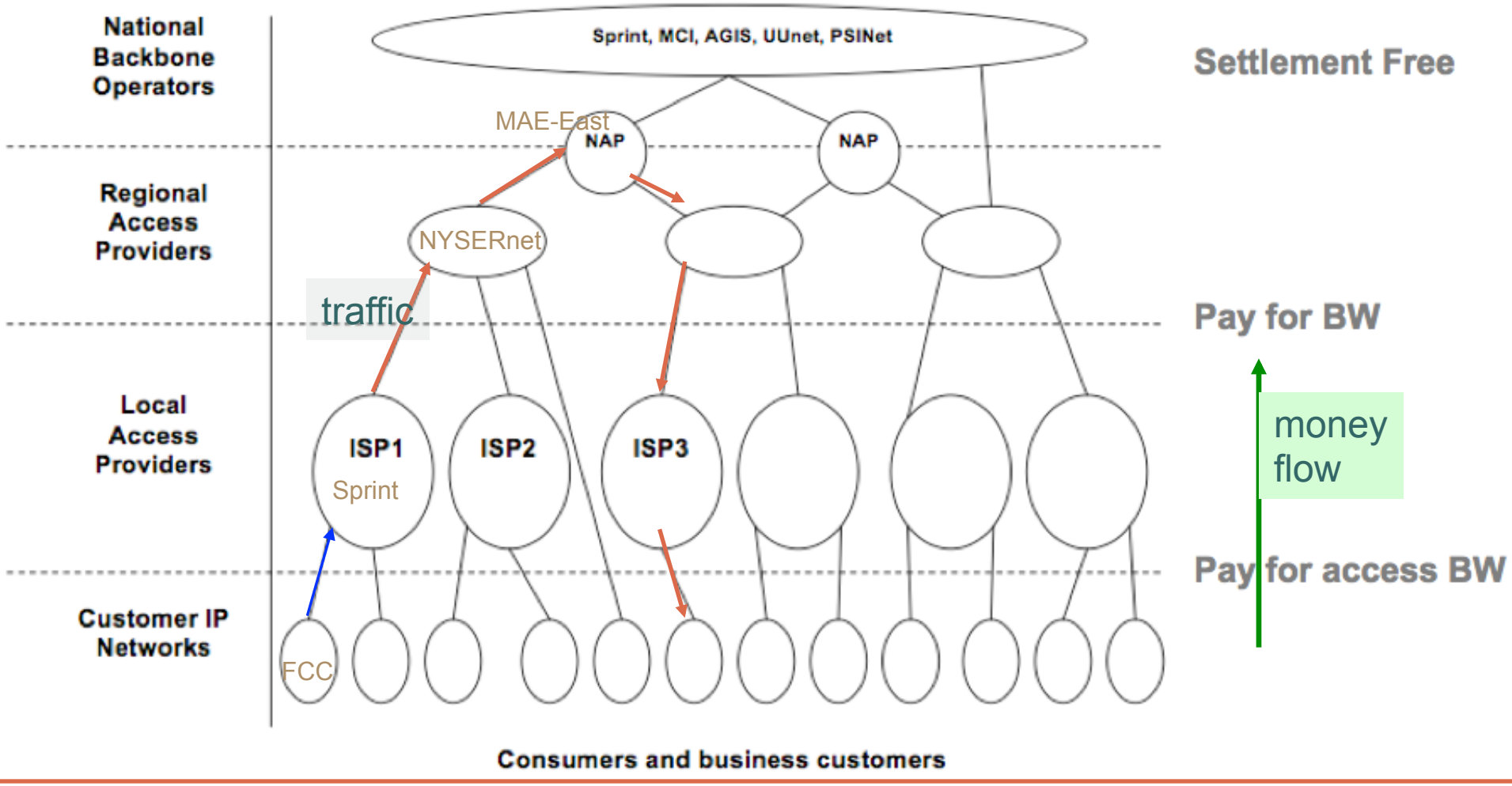
server farm

"bill & keep"



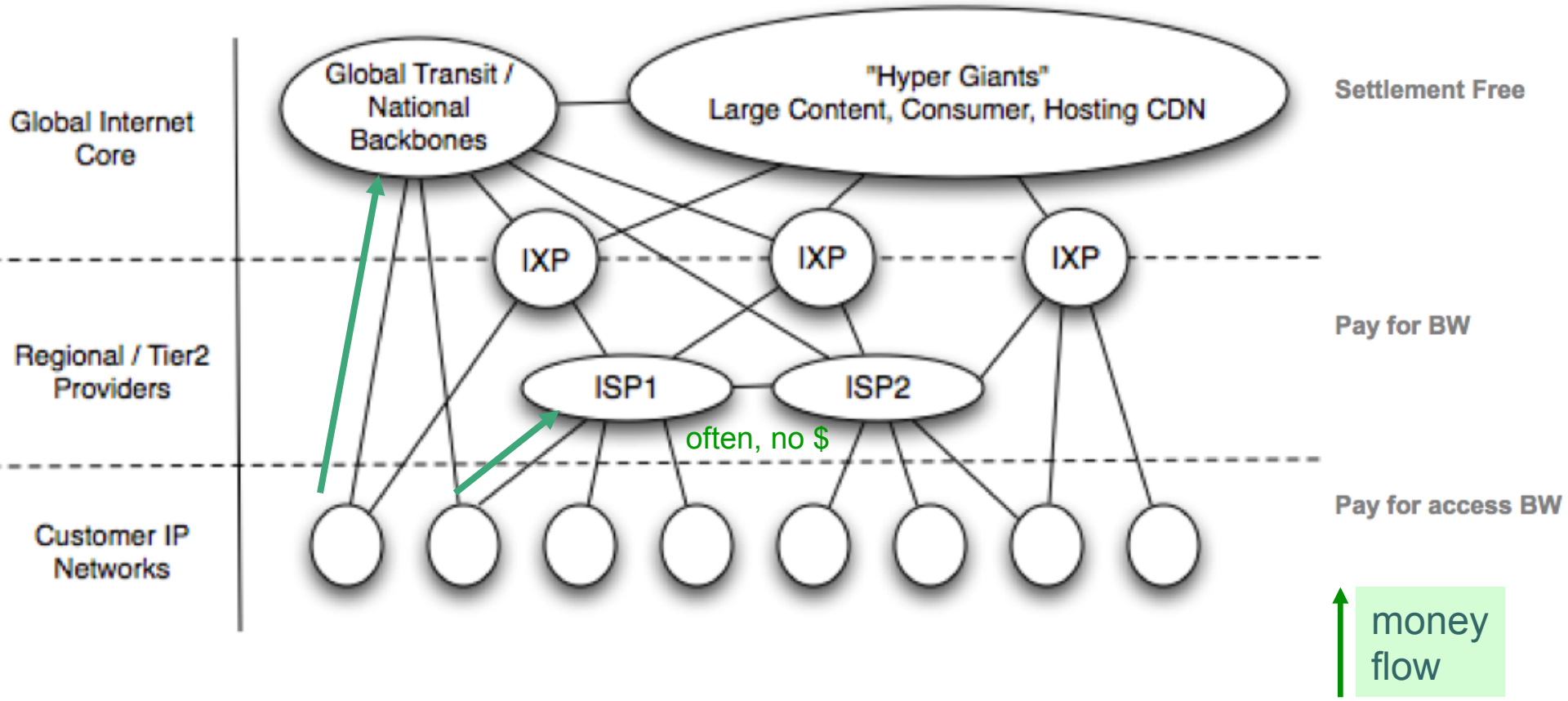


The "classic" Internet – ca. 1995



Craig Labovitz, "Internet Traffic and Content Consolidation", IETF March 2010.

A denser Internet



Craig Labovitz, "4", IETF March 2010.

Role of the IXPs (inter-exchange points)

- IXP
  - As NAPs congested, IXPs emerged (including overseas)
  - IXPs → private peering and secondary peering
  - IXPs
    - reduced tromboning
    - provided cost reductions
    - improved performance and
    - occurred mostly without regulatory oversight
- About 85 IXPs in US

More precisely…

- Tier 1 = those ISPs that run no-default routing tables on their backbones
  - operations in more than one country
  - own and operate their own physical networks
  - revenue-neutral peering agreements with other tier 1
  - may only be tier-1 regionally
  - not a clearly-defined club
- Tier-2 ISPs buy connectivity (upstream transit) from one or more Tier-1 ISPs
- *Transit providers* = wholesale whole Internet
- *On-net peering* = access to own customers

Tier-1 providers

Provider	AS	Degree
AT&T	7018	2337
Level 3 (with Global Crossing)	3356 / 3349 / 1	3971
Verizon Business (was UUNET)	701 / 702 / 703	1544
NTT Communications (was Verio)	2914	1047
Cogent	174	4212
XO	2828	1082
Zayo (was AboveNet)	6461	1236
Centurylink (was Qwest & Savvis)	209 / 3561	1531
Sprint	1239	734
Telecom Italia Sparkle (Seabone)	6762	308
TeliaSonera International Carrier	1299	812
Deutsche Telekom AG (DTAG)	3320	518
NTT Communications	2914	1047

Wikipedia

Network Interconnections *example*

Cox Communications - interconnection data from peeringdb.com

Company Information	
Company Name	Cox Communications
Also Known As	
Company Website	http://www.cox.com/peering
Primary ASN	22773
IRR Record	AS22773
Network Type	Cable/DSL/ISP
Approx Prefixes	
Traffic Levels	100+ Gbps
Traffic Ratios	Mostly Inbound
Geographic Scope	North America
Looking Glass URL	
Route Server URL	
Notes	Public: Req's minimum traffic exchange of 100Mbs Private: Req's minimum traffic exchange of 250Mbs
Protocols Supported	Unicast IPv4 ☑ Multicast ☐ IPv6 ☑
Date Last Updated	2010-07-30 11:18:29 UTC
Peering Policy Information	
Peering Policy URL	http://www.cox.com/peering
General Policy	Selective
Multiple Locations	Preferred
Ratio Requirement	No
Contract Requirement	Required

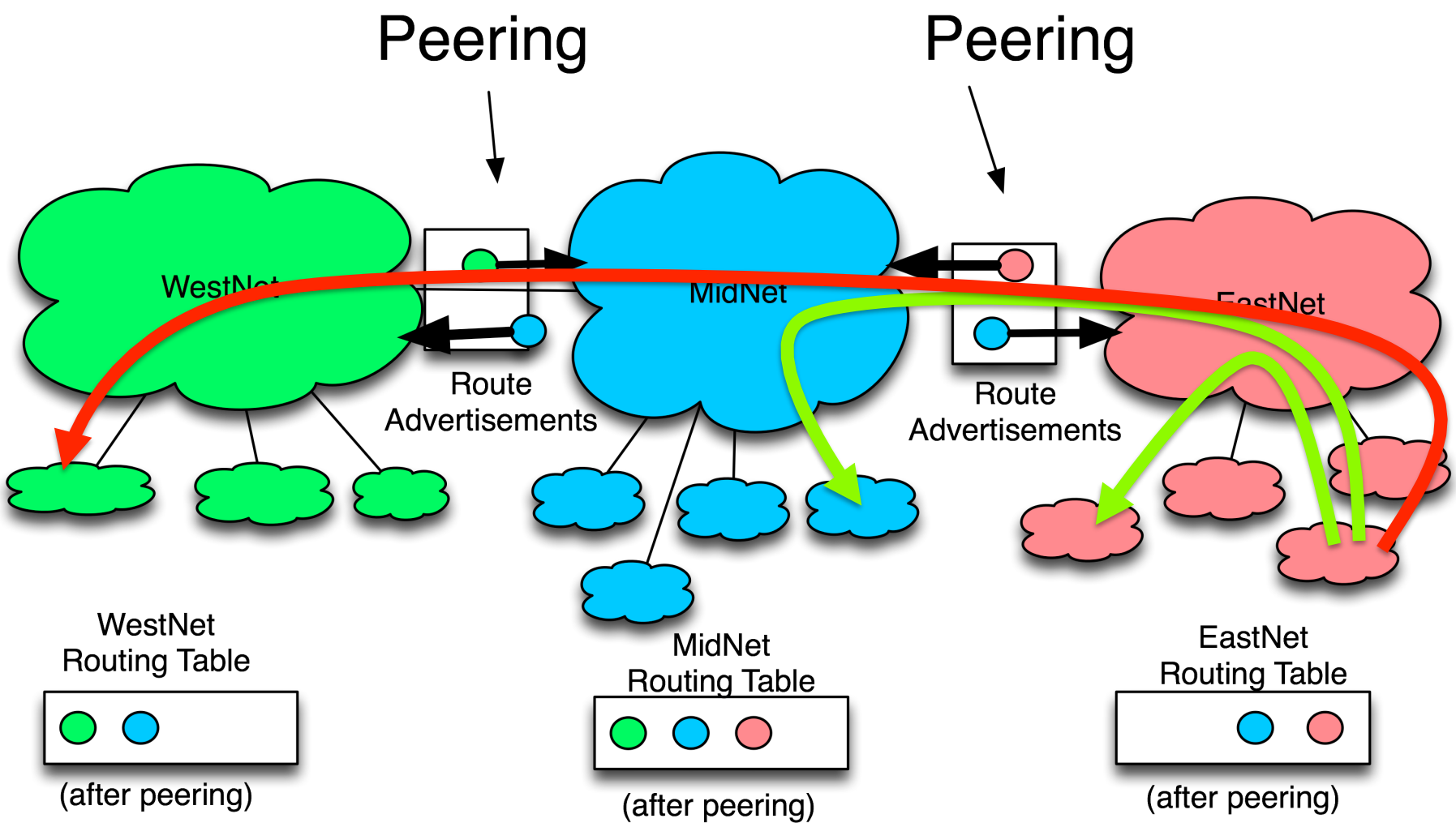
Public Peering Exchange Points

Exchange Point Name	ASN	IP Address	Mbit/sec
Equinix Ashburn	22773	206.223.115.42	10000
Equinix Ashburn	22773	2001:504:0:2::2:2773:1/64	10000
Equinix Chicago	22773	2001:504:0:4:0:2:2773:1/64	10000
Equinix Chicago	22773	206.223.119.42	10000
Equinix Dallas	22773	206.223.118.42	10000
Equinix Dallas	22773	2001:504:0:5:0:2:2773:1/64	10000
Equinix Los Angeles	22773	206.223.123.42	10000
Equinix Los Angeles	22773	2001:504:0:3::2:2773:1/64	10000
Equinix New York (was: PAIX)	22773	198.32.118.65	10000
Equinix New York (was: PAIX)	22773	2001:504:f::61/64	10000
Equinix Palo Alto (was: PAIX)	22773	198.32.176.144	10000
Equinix Palo Alto (was: PAIX)	22773	2001:504:d::90/64	10000

1 2 of 2 Next > Last >>

Private Peering Facilities

Facility Name	ASN	City	Country	SONET	Ethr	ATM
Equinix Ashburn (DC1-DC5)	22773	Ashburn	US	☐	☑	☐
Equinix Atlanta (AT1-3)	22773	Atlanta	US	☐	☑	☐
Equinix Chicago (CH1/CH2)	22773	Chicago	US	☐	☑	☐
Equinix Dallas (DA1)	22773	Dallas	US	☐	☑	☐
Equinix Los Angeles (LA1)	22773	Los Angeles	US	☐	☑	☐
Equinix New York (111 8th)	22773	New York	US	☐	☑	☐
Equinix Palo Alto (SV8)	22773	Palo Alto	US	☐	☑	☐


Peering
Peering
WestNet
MidNet
EastNet
Route
Advertisements
Route
Advertisements
WestNet
Routing Table
(after peering)
MidNet
Routing Table
(after peering)
EastNet
Routing Table
(after peering)