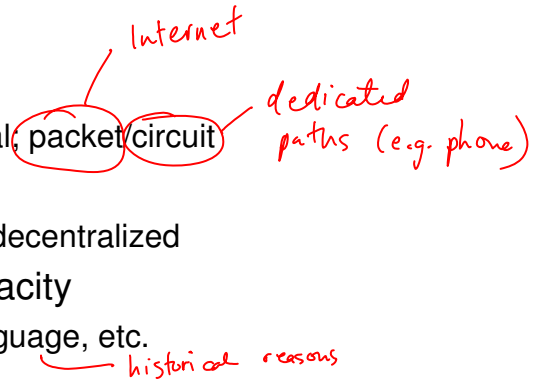
Connectivity

Week 9 – March 20, 22

The 4C Framework

- Information and Communications Technology (ICT) can be thought of as the 4Cs
  - Computers
    - Devices
  - Connectivity
    - Analog/digital; packet/circuit
  - Content
    - Centralized/decentralized
  - (human) Capacity
    - Literacy, language, etc.



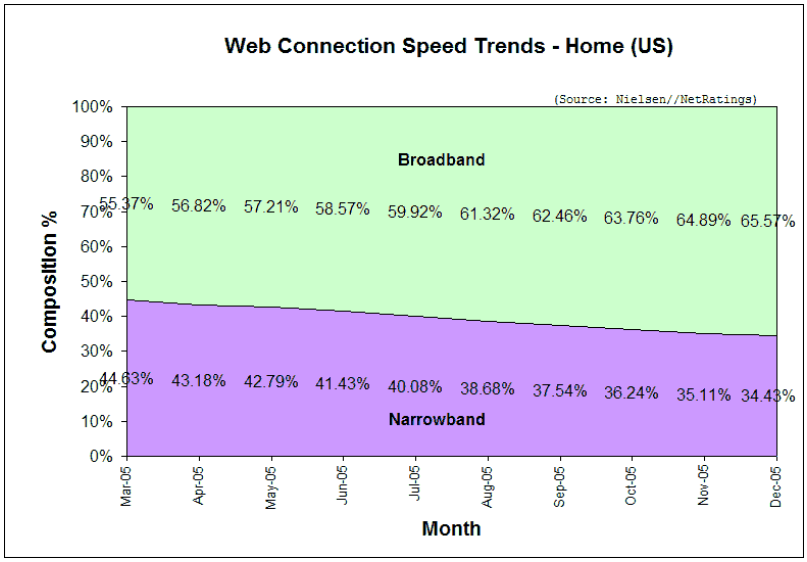
Some Questions about Connectivity

- Is it fast enough?
- Is it cheap enough?
- If not, is that a big deal?
- Are there distribution issues?
- What is the role of government and policy?

available enough ?

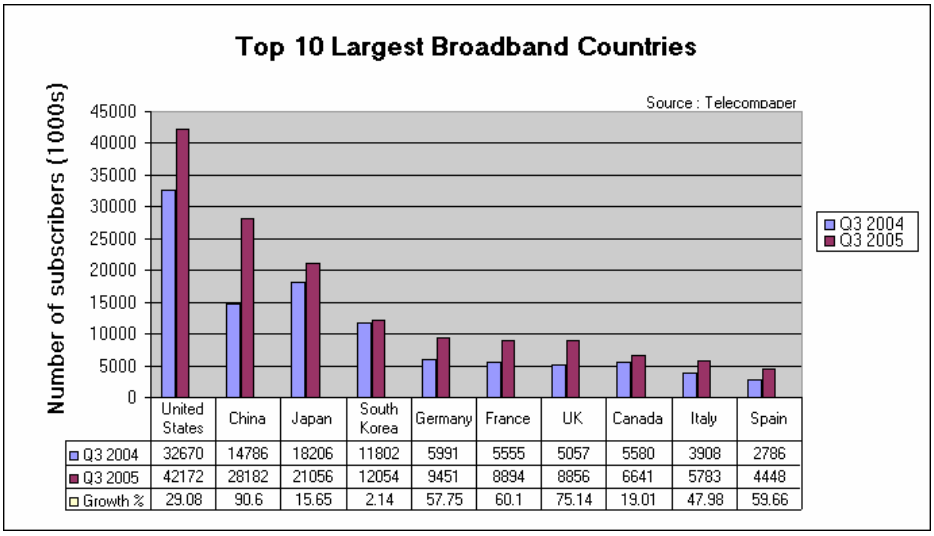
"Broadband"

US Broadband Penetration



- Why is this misleading?

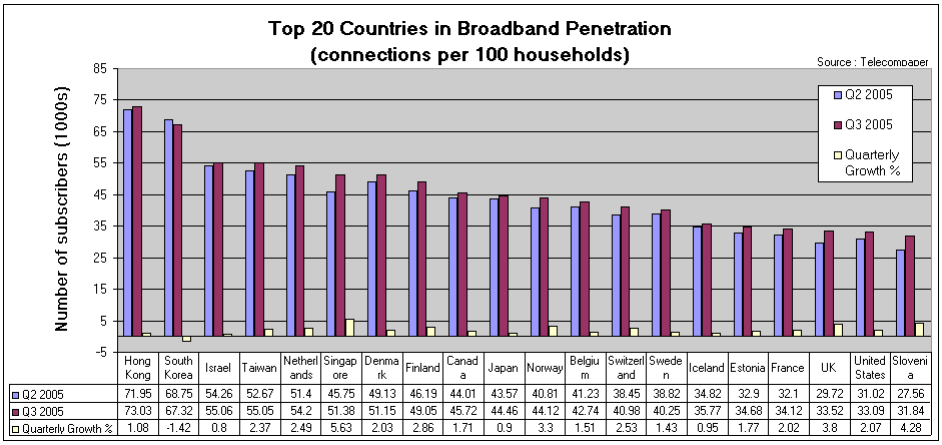
Global Broadband



	United States	China	Japan	South Korea	Germany	France	UK	Canada	Italy	Spain
Q3 2004	32670	14786	18206	11802	5991	5555	5057	5580	3908	2786
Q3 2005	42172	28182	21056	12054	9451	8894	8856	6641	5783	4448
Growth %	29.08	90.6	15.65	2.14	57.75	60.1	75.14	19.01	47.98	59.66

- Why could such information be misleading?

Truer Picture of Global Broadband



	Hong Kong	South Korea	Israel	Taiwan	Netherlands	Singapore	Denmark	Finland	Canada	Japan	Norway	Belgium	Switzerland	Sweden	Iceland	Estonia	France	UK	United States	Slovenia
Q2 2005	71.95	68.75	54.26	52.67	51.4	45.75	49.13	46.19	44.01	43.57	40.81	41.23	38.45	38.82	34.82	32.9	32.1	29.72	31.02	27.56
Q3 2005	73.03	67.32	55.06	55.05	54.2	51.38	51.15	49.05	45.72	44.46	44.12	42.74	40.98	40.25	35.77	34.68	34.12	33.52	33.09	31.84
Quarterly Growth %	1.08	-1.42	0.8	2.37	2.49	5.63	2.03	2.86	1.71	0.9	3.3	1.51	2.53	1.43	0.95	1.77	2.02	3.8	2.07	4.28

- Issues of speeds or price are not shown

In a Digital World, Everything's a Bit

- (retail) Bandwidth Providers often chase the so-termed "Triple Play"
  - Voice
    - Lots of $, still
  - Video
    - Very high subscription rates in the US, approaching 90%
    - Different designs are possible
      - Shared (e.g., broadcast)
      - Switched (e.g., Joost, YouTube, Pay-per-View)
  - Data
- Mobility is another HUGE market
- What about secure (low-bandwidth connections)?
  - Home alarms
  - Smart Homes ("Home of the Future")

low bandwidth; POTS = 64 kbps

Different Bits are Different

p$ = picodollars = 10^{-12}

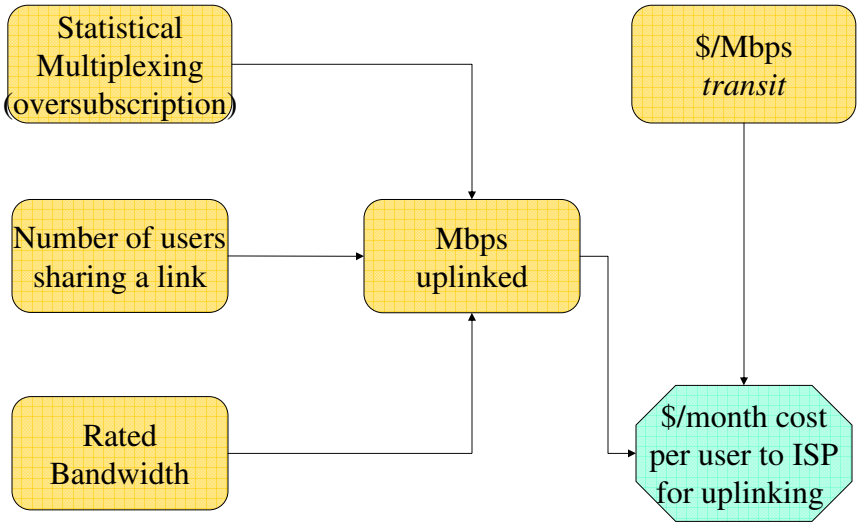
2002 or 2003 US Statistical Abstract Average Numbers except in *Italics*

- Voice
  - Fixed
    - 23 $/month, 1 month/*1923* min. → ~ 3,100 p$/bit
  - LD
    - *$0.10/minute* → 26,000 p$/bit
      - Incl. International charges (FCC numbers)
- Web (broadband user)
  - *35 $/month, 2 hours per day usage, 30 kbps average usage* → ~ 5,400 p$/bit
- TV (cable/satellite, excl. PPV)
  - 225 $/year/person, 2.58 persons/household, 850 hours/year watched → ~ 36 p$/bit
  - A good fraction of their revenues comes from advertising
  - *BUT, we don't know what demand will look from 5 years from now, or, say, under 100 Mbps conditions*

Components of Retail Connectivity

Hardware / Installation	Marketing / Advertising	O&M		Uplinking (transit fees)
		CRM	Technical	
• One-time capital costs are amortized over time • Cost depends on: - Interest rates - Churn - Re-usability of components	• One time costs • Depends on competition	• Also depends on competition	• Varies by technology	• Vary by location • Oversubscription ratios are an ISP choice • Speeds offered determine what applications can be run

What does it Cost to use up Bandwidth?



Primer on Communications…

History of Telecommunications

- Ancient History
  - Marathon
    - Ran 40 km in 490 BC to deliver a message of victory (and then died)
  - Smoke, fire, optical, and acoustic signals
    - Water signals also allow the message to be stored (linked to fire/smoke signals)

Use of electricity gave rise to "instantaneousness"

History of Telecommunications

1800s:

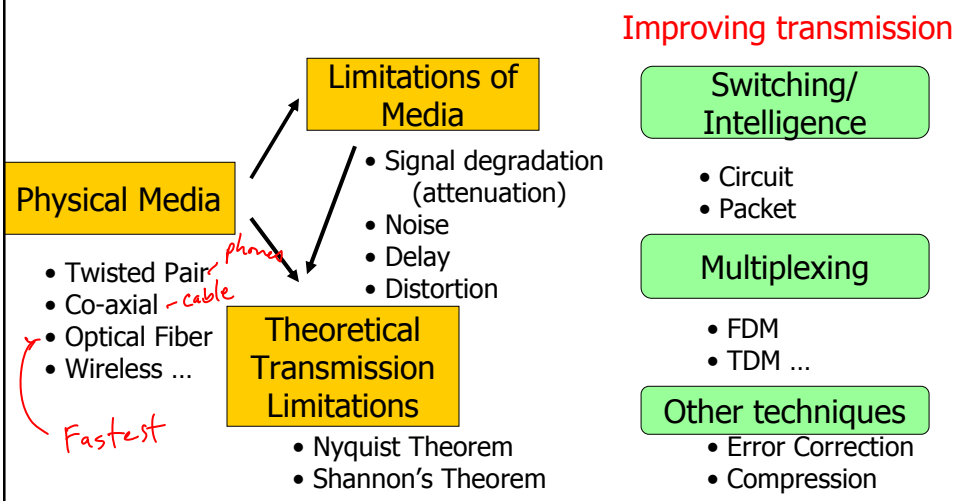
- Telegraph
  - Patented by Samuel Morse
  - Idea came to him in 1832 on during a visit to Italy
  - Patented in 1838
  - First line opened in 1844 between Washington High Court and Baltimore
    - "What Hath God Wrought?"
  - Improvements
    - Two way communications, single battery, etc.
  - TransAtlantic line continuously operating from 1866
- Pony Express came about in 1860
- Transcontinental railroad completed in 1869

History of Telecommunications (cont.)

- Telephone
  - Bell patented the telephone on February 14, 1876, beating Elisa Gray by 2 hours!
  - Bell recognized the commercial potential of his device
    - Tried to sell the patent to Western Telegraph for $100,000, who refused
      - "What shall we do with a toy like that?"
    - Few years later, they offered Bell $25,000,000 (he refused)
    - Established Bell Telephone Company
      - Delivered and installed 50,000 telephones within the first three years
      - Became the world's largest telephone company: AT&T
  - Almon Strowger, an undertaker, invented the exchange in 1889 — because of PRIVACY

Transmission of data

Digital world deals with bits



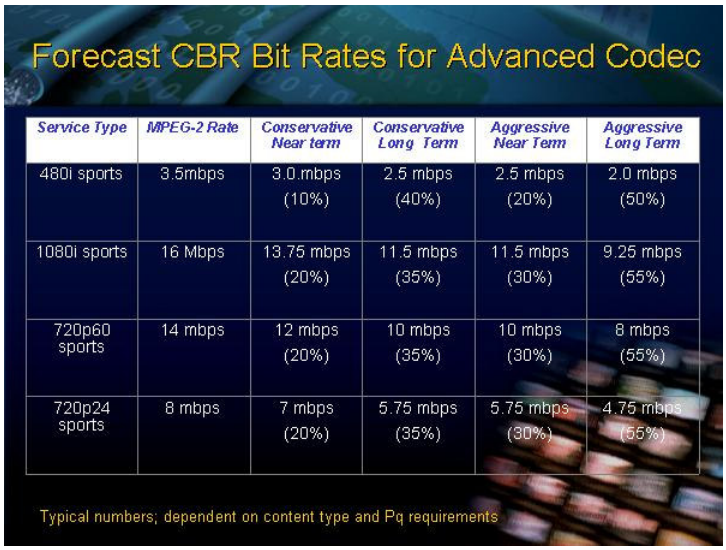
Encoding and Information

- Sampling – How often you "take in" data
  - Nyquist Sampling Theorem: Minimum rate of 2x the highest frequency needed
    - E.g., CDs sample at 44.1 kHz
- Claude Shannon's seminal work in 1948 led to Information theory
  - Statistical properties of message, averaged out over the whole message--without regard to content
  - Tells us channel capacity (signal to noise ratio)
    - 2^x = M (x = number of bits, M = of messages)
    - Thus, log(2) M = x (now, x is a measure of "entropy")

Shannon's Information Theorem

- Relates error-free transmission capacity C, given a bandwidth W (hertz) and signal to noise ratio (S/N)
- C = W log2 * (1 + S/N)
- Only provides theoretical limits to transmission capabilities
  - Does not tell us how to encode

IPTV Bit Rates



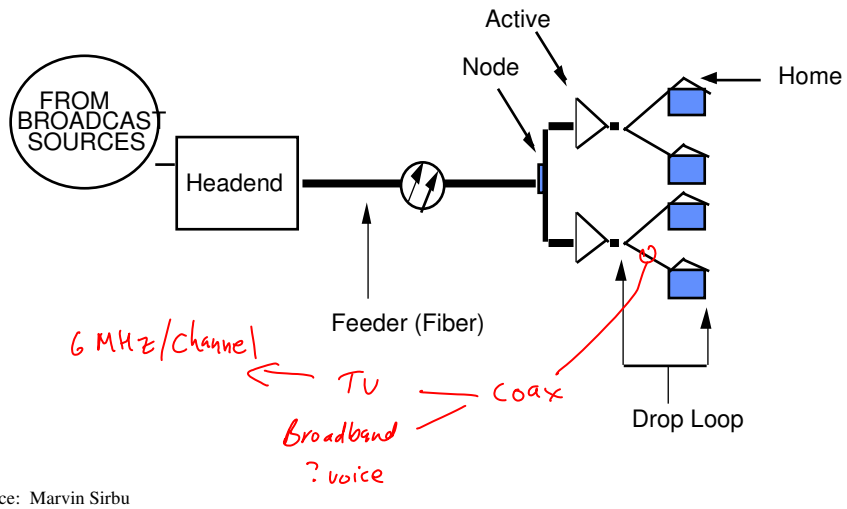
Service Type	MPEG-2 Rate	Conservative Near term	Conservative Long Term	Aggressive Near Term	Aggressive Long Term
480i sports	3.5mbps	3.0 mbps (10%)	2.5 mbps (40%)	2.5 mbps (20%)	2.0 mbps (50%)
1080i sports	16 Mbps	13.75 mbps (20%)	11.5 mbps (35%)	11.5 mbps (30%)	9.25 mbps (55%)
720p60 sports	14 mbps	12 mbps (20%)	10 mbps (35%)	10 mbps (30%)	8 mbps (55%)
720p24 sports	8 mbps	7 mbps (20%)	5.75 mbps (35%)	5.75 mbps (30%)	4.75 mbps (55%)

Source: http://www.dslprime.com/pix/cbrrates.jpg

Broadband Access…The "Last Mile"

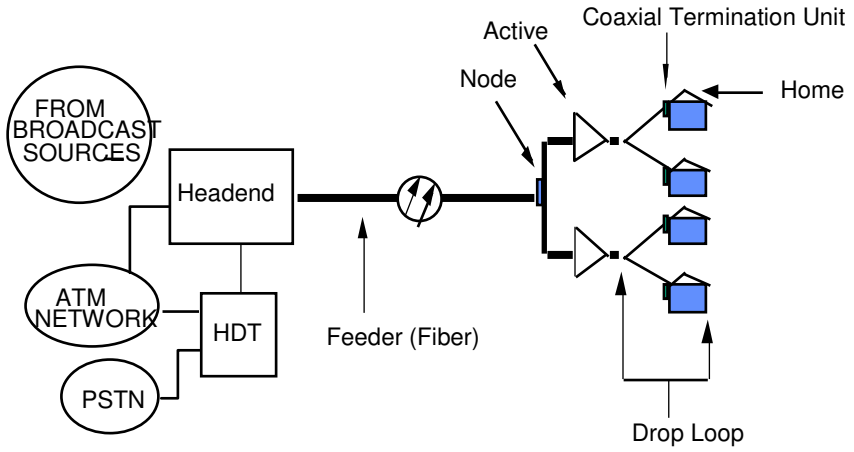
- Different technologies are available
  - Cable
  - DSL
  - Fiber
  - Wireless
    - Fixed
    - Mobile
    - Satellite
  - Powerline
- They differ in
  - Reach
  - Speeds
  - Costs
  - Regulation (?)

Cable: Hybrid Fiber Coax (HFC)



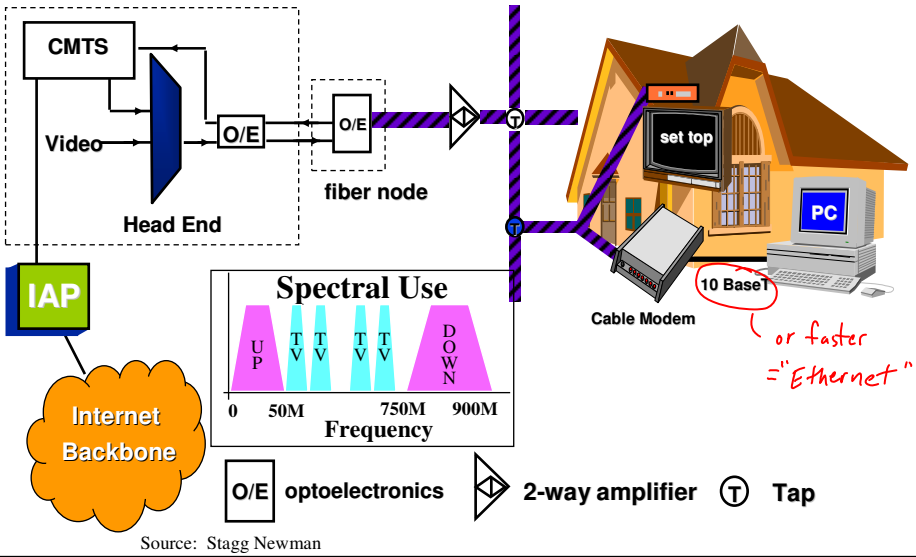
Source: Marvin Sirbu

Advanced Hybrid Fiber Coax



Source: Marvin Sirbu

CABLE MODEMS



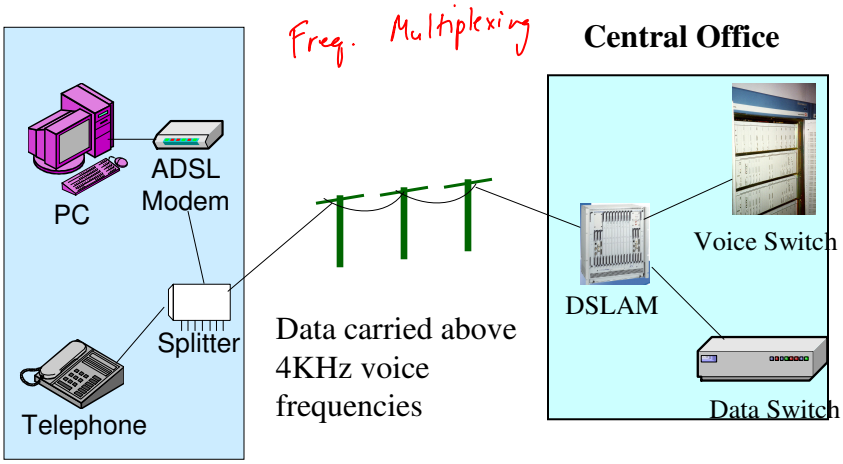
Source: Stagg Newman

DSL from Central Office

Subscriber Premises

Freq. Multiplexing

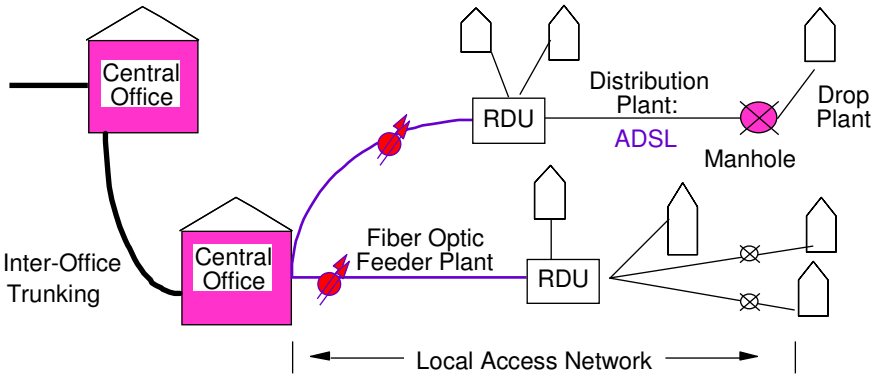
Central Office



This simplification ignores the use of remote terminals and digital loop carrier (DLC)

Source: Marvin Sirbu

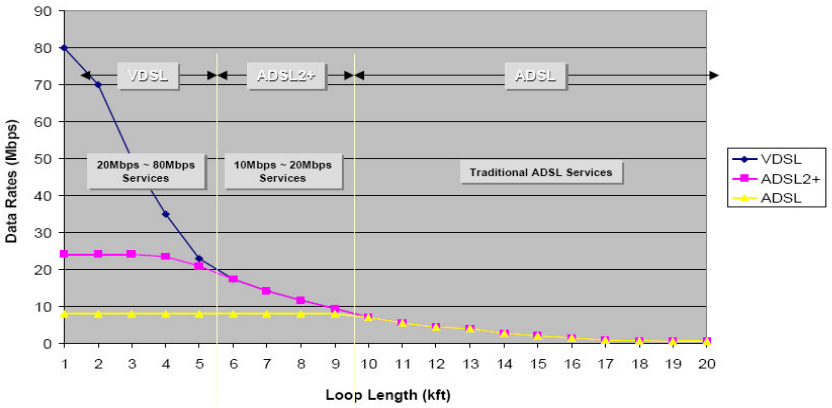
Fiber to the Neighborhood



- Can go all the way to the home (FTTH)
- Fiber can easily provide Gigabit speeds

Source: Marvin Sirbu

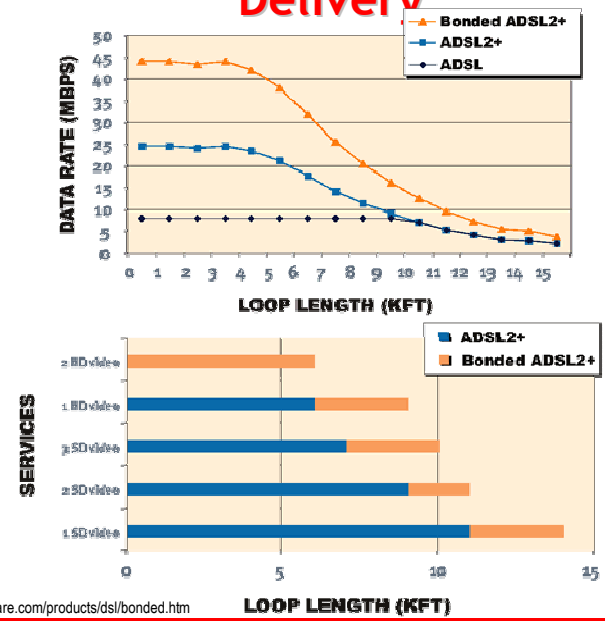
VDSL vs ADSL



-140dBm/Hz. 26AWG

Source: http://www.comsoc.org/comsig/Slides/Oct2003_DSL_BernardDebbasch.pdf, Oct 2003

Distance vs Bit Rate and Video Delivery



Source: http://www.aware.com/products/dsl/bonded.htm

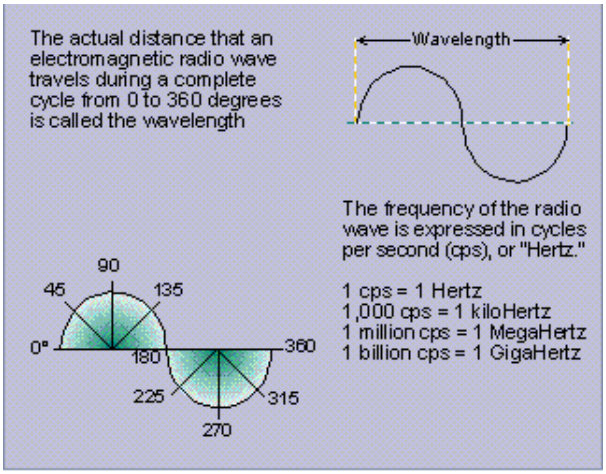
Wireless is Gaining Ground

- Landlines have stagnated or diminished in the US
- In much of the world, mobiles are 5-10x landlines
  - E.g., Africa has about 10% mobile phone penetration
  - Why? less infrastructure cost
- There is a generational gap as well….
- Telephony is more established
- Data varies in service
  - Mobile
  - Portable / nomadic
  - Fixed

History of Wireless and Radio

- 1894 Marconi sends signal 2 miles
  - Preceded by Bose and Tesla
- 1910 First song transmitted from Metropolitan Opera in New York
- 1917 AM transmission of speech
- 1920 First public radio broadcast in Germany
- 1928 FM transmission of speech (higher quality)

Wireless and other Waves



$c = \lambda * f$

where

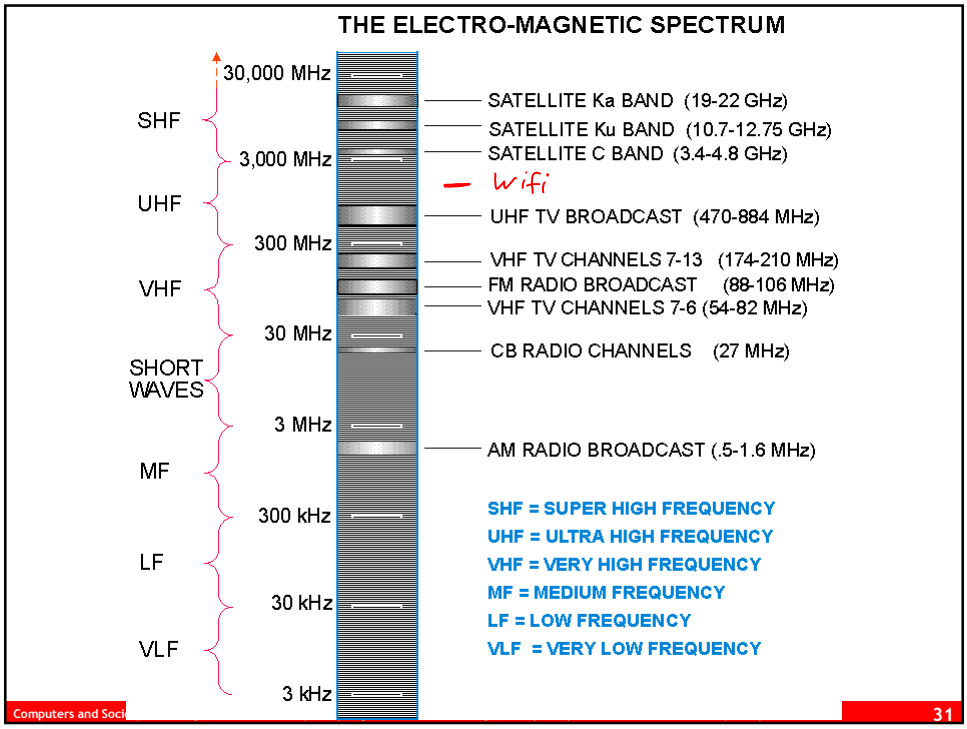
c = speed of wave (light)

λ = wavelength

f = frequency

Spectrum

Region	Wavelength (Angstroms)	Wavelength (centimeters)	Frequency (Hz)	Energy (eV)
Radio	$> 10^9$	> 10	$< 3 \times 10^9$	$< 10^{-5}$
Microwave	$10^9 - 10^6$	10 - 0.01	$3 \times 10^9 - 3 \times 10^{12}$	10^{-5} - 0.01
Infrared	10^6 - 7000	0.01 - 7×10^{-5}	$3 \times 10^{12} - 4.3 \times 10^{14}$	0.01 - 2
Visible	7000 - 4000	$7 \times 10^{-5} - 4 \times 10^{-5}$	$4.3 \times 10^{14} - 7.5 \times 10^{14}$	2 - 3
Ultraviolet	4000 - 10	$4 \times 10^{-5} - 10^{-7}$	$7.5 \times 10^{14} - 3 \times 10^{17}$	$3 - 10^3$
X-Rays	10 - 0.1	$10^{-7} - 10^{-9}$	$3 \times 10^{17} - 3 \times 10^{19}$	$10^3 - 10^5$
Gamma Rays	< 0.1	$< 10^{-9}$	$> 3 \times 10^{19}$	$> 10^5$



Special Properties of Spectrum

- Heavily controlled
  - Military uses
  - Licensed use

Wifi Spectrum = FREE!

- Source of licensing fees
- Is a public good; everywhere yet not limitless
- *Should it be a property (auctioned off?) or a shared resource?*
- Many forms are appropriate for point to multipoint (including broadcast)
- Encoding is key for capacity *in practice* – bits per hertz
  - Theory is bounded by Shannon's Theorem

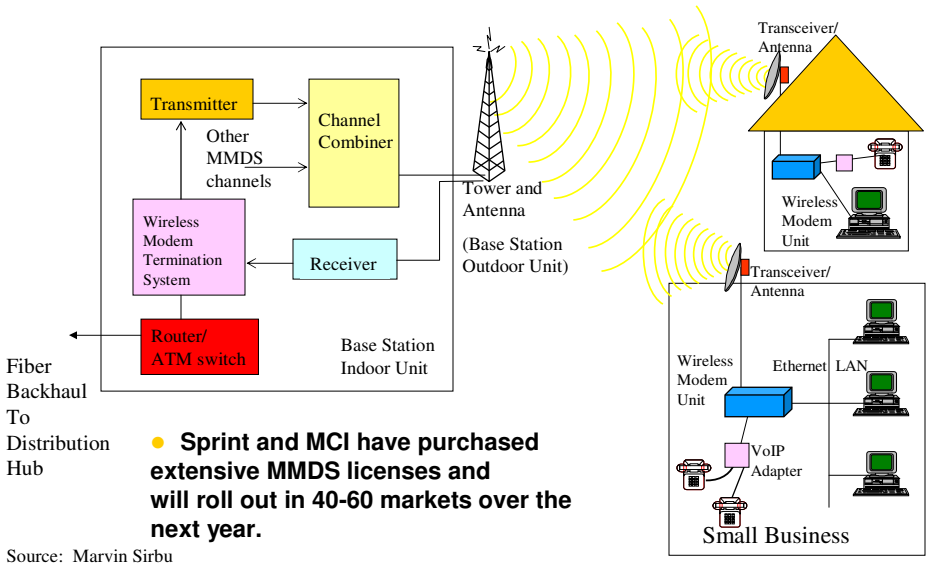
Challenges with Wireless…

- What prevents us from more wireless broadband?
  - Spectrum
  - Reach
    - Related to power levels
    - Line of Sight
  - Costs
  - Evolving standards and technologies
    - WiFi
      - Mesh, MIMO, etc.
    - WiMax
      - Fixed and Mobile
    - 3G, 4G, etc.

Fixed Wireless Access- Inherently Shared

- Base station
  - Point to Multipoint
- Receivers
  - Rooftop
  - Indoors
  - Mobile/Portable
- Shared bandwidth depends on technology
  - 25-40 Mbps downstream (might be)
  - 15-25 Mbps upstream
  - Spectrum matters
    - Unlicensed (UNI – 5 GHz)
    - Licensed (e.g., MMDS - 2.5 GHz)

MMDS Fixed Wireless Architecture: Base Station and CPE



- **Sprint and MCI have purchased extensive MMDS licenses and will roll out in 40-60 markets over the next year.**

Source: Marvin Sirbu

Customer Fixed Wireless Units

Source: Sprint (Hybrid Networks) (antenna/transceiver only)

- Typically, requires clear Line of Sight (LOS)
  - Except in small radius
  - This requires costly site visit to install antenna, run wiring to computer
- Newer alternatives emerging (non-LOS)

Base Station Equipment

Source: Sprint (Hybrid Networks-Phoenix)

- A single tower can cover up to 20 mile radius
  - Depends on terrain
- As subscribers increase, may need additional base stations/cells for frequency reuse

Wireless ISPs

- There are several thousand Wireless ISPs (WISPs) in the U.S.
  - Easy because of light touch regulation
    - Spectrum
    - Antennae
- Majority of WISPs use souped up wireless LAN technology
  - Normal WLAN coverage ~ few hundred feet
  - With directional antennas, coverage can reach several miles

Wireless Mesh Networks

- Popular for many city networks
  - Philadelphia, San Francisco, etc.
- Major advantage
  - Issues of backhaul
- Challenge
  - Shared throughput
- Business model questions
  - Free vs. subsidized vs. at cost
- Q: Can one share connectivity?
  - Open Access Points (mesh or non-mesh)?

Antennas for Long Range WLANs

13.5dBi Yagi
18 in. Long, 3 in. Dia.
Distances over
6.5 Miles @ 2 Mbps and
2 Miles @11 MB

21dBi Solid Dish
24 in. Parabolic Dish
For Distances up to
25+ Miles @ 2 Mbps
11.5 Miles @ 11 MB

Note: Distances include identical antennas on each site, 50 feet of Low Loss Cable (6.7dB/100 ft) and 10dB fade margin

Source: Cisco

Could I use WiFi for a "Last Mile" Technology?

- What's the speed?
- What's the reach?
- What's the cost?
- What else do I need?
  - Backhaul = uplinking
  - Management
  - Access Control

How Could we "Secure" WiFi?

- Access control vs. Encryption
  - WEP
  - WPA
  - Access Control – MAC Layer
- Choose to run networks as open
  - Why or why not?
  - Default settings are "non-secure" – why? / easier
- Calif. is enacting legislation to limit open access points
- People have been arrested/charge for "stealing WiFi"

Topics for discussion

- Community networks
- Municipal Networks (public)
- Sharing networks
  - Fon, Free
  - Would these be legal in the US?

Violates terms of service

Techno-Economic Model of Connectivity

- Based on Tongia (2003)

Hardware	Common equipment; CPE	Is there physical media available? Cost of capital?
Operating Costs	CRM; Billing; Maintenance	"cheap labor" in developing countries
One-time Costs	Regulatory fees (e.g., spectrum); Marketing; Promotional equipment (e.g., CPE); Line conditioning / Testing; Installation	Installation can be a bottleneck
Uplinking Costs	Connecting to global network	*Enormous* variance across nations; depends on rated speeds / oversubscription

Regulatory and Policy Add-ons

{Differences beyond lack of competition}

- Above and beyond techno-economic minimum costs

- ISP licensing fees
- Spectrum
- Rights of Way charges
- Import Duties
- User Taxes and Surcharges
- Uplinking and interconnection restrictions
- Limits on applications and services
- Limits on sharing connectivity

(In no particular order)

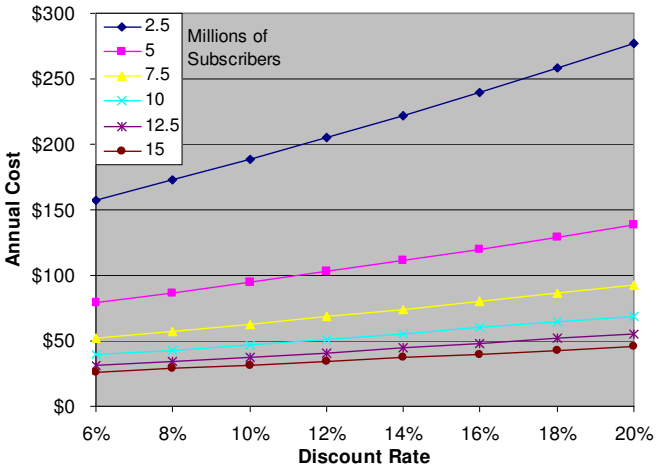
- Lack of clarity / consistency on "affiliate transactions"
- Low density of target users
- Design without scalability or upgrading possibilities
- Proprietary or National-only standards
- High costs of regulatory compliance
- Higher failure rates and/or maintenance
- High costs of capital

Quantification of Add-on Costs

- Generalization is nigh impossible
  - Case to case variation
    - Location
    - Carrier
    - Country
    - Technology
  - Data unavailability
- Larger components often include
  - Licensing
  - Technology and design choice
    - Legacy systems
  - Other infrastructure (power, security, etc.) [is it an add-on?]

Egypt's 3rd Mobile License (incl. 3G)

- Recently went to Etisalat for $2.9B + 6% revenue share
- Technology estimated at only ~$1B



Source: Tongia (2006)

Where does Policy come in?

- US regulator is the Federal Communications Commission (FCC)

  Charge from Congress:

  "Ensure that the American people have available, at reasonable costs and without discrimination, rapid, efficient, Nation- and world-wide communication services; whether by radio, television, wire, satellite, or cable"

  – FCC Website

- History
  - Succeed Federal Radio Commission in 1934
  - Federal Radio Commission (based on Radio Act of 1927) superceded Radio Act of 1912
    - That one was made in response to the *Titanic* – all ships must have open and monitored radio channels

FCC Jurisdiction

- All non-governmental use of radio
- All international communications originating or terminating in the US
- All interstate telecommunications (whether wired or wireless)
- What about Cable TV?
- Regulations initially separated Information Service from Telecommunications Services
  - Different regulations

Do we need "Old Style" Regulation?

- Could new technologies make "ownership" of spectrum obsolete?
  - UltraWideBand
    - Really lower power
  - Cognitive Radios
    - Can adapt their transmissions as per ambient conditions
      - Change band, power level, modulation, etc.
- Reality: Most existing spectrum is empty or underused!

Issues in Telecommunications

- Standards
  - Backwards compatibility
- Metrics
  - How to measure size, number of users, etc?
    - Important because of inter-player payments
- Digital Communications
  - Broadcast industries
    - TV
    - Radio
- Mobile communications
  - Rush for "3G"
- "Convergence"

Issues in Telecommunications:

- Internet (more later)
- Security
  - Encryption
  - Privacy
- Policy
  - Convergence
  - Open Access
- Market Power
  - Not easy to define – at what Layer?
- Globalization
  - "Winner Takes All"

Broadband Policy Issues

- Unanswered questions
  - Is there a “natural monopoly” in broadband?
    - Very low marginal costs in telecom
  - How can one support competition over broadband infrastructure?
  - Who should build broadband networks?
    - Public/Private
    - Market/Regulated
  - How do we define and pay for “Universal Service?
- Thinking of layers or boundaries becomes important
  - Wholesale vs. retail
  - Physical vs. logical
  - Content vs. carriage