

Digital Cable Technology Primer

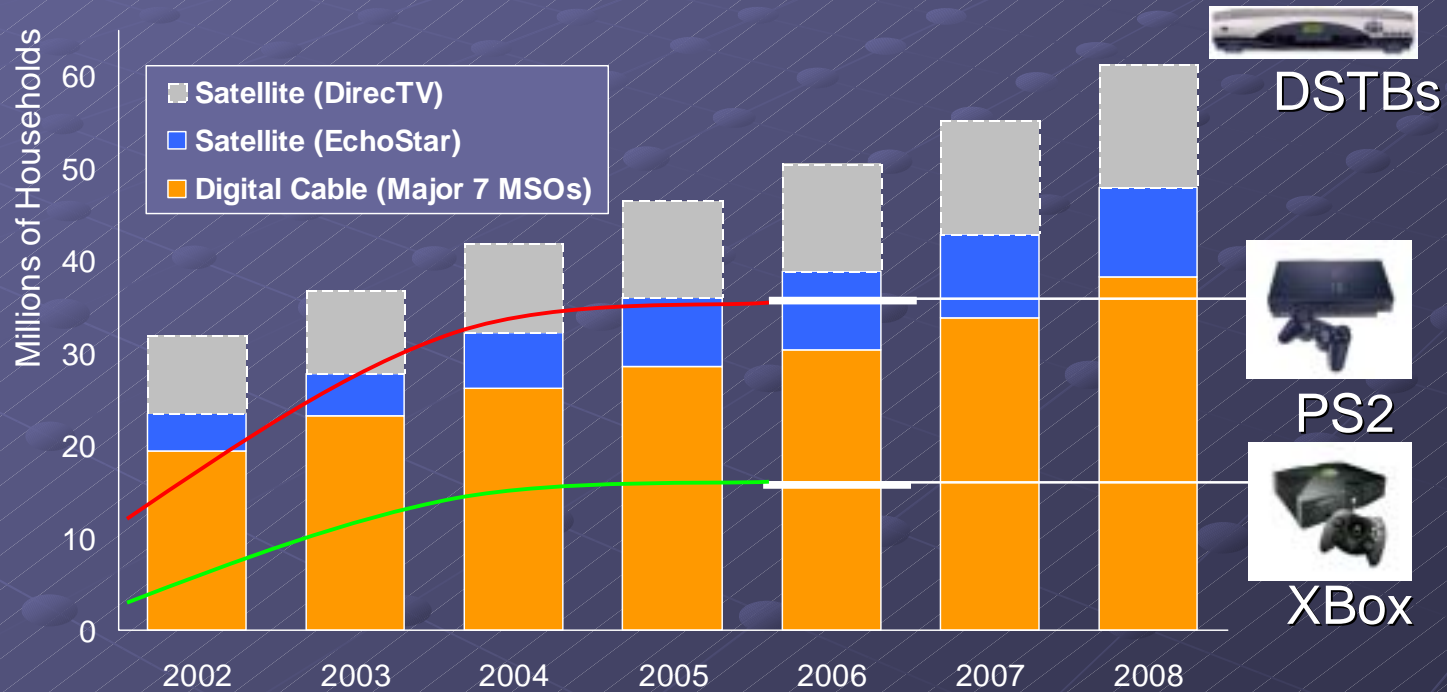
Courant Institute of Mathematics, NYU
Computer Science Department
Internet Programming, Spring 2004

Presented by
Paul Finster

March 2, 2004

What's the big deal anyway?

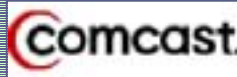





Digital Set-top Box Deployment Projections





Source: Morgan Stanley

Digital STBs Deployed (millions)

● Top Cable MSOs

- 8M 
- 4.7M 
- 2.3M 
- 1.5M 
- 3M 
- 3M 

● DBS Operators

- 10M 
- 9M 

• Satellite is winning the digital race today!

• But, cable operators have long-term advantages:

Voice, VOD, ITV, HDTV, DVR

Source: Bear Sterns

Agenda (1 of 2)

● Introduction

- A History of Cable TV
- Cable Service Offerings Overview

● Cable Infrastructure

- HFC networks – transition from analog to digital
- Set-top-boxes – why a cable box anyway?
- Network layers

● Cable Services

- Video – Analog to Digital and beyond
- Data – Broadband and VoIP
- Middleware – Proprietary and Open Standards

Agenda (2 of 2)

● Applications

- EPGs – resident applications
- Digital Video Recorders (DVRs/PVRs)
- VOD
- Interactive Portals
- Self-service provisioning is a money maker
- Games

● What's next?

- Digital Terrestrial: free HDTV?
- TV over DSL: welcome telcos?
- Consumer Electronic Revolution?
 - HD & DVR, OpenCable and CableCards

Timeline (1 of 2)

- 1950 – 70 cable systems serving 14k subscribers; 15 analog channel capacity
- 1960 – 800 cable systems serving 850k subscribers; 1st Pay TV devices tested
- 1972 – Gerald Levine launches pay-network HBO; HBO shows the Muhammad Ali vs. Joe Frazier
- 1973 – 1st satellite video test
- 1976 – Fiber optics 1st use in major trunks
- 1977 – Warner Cable shows 1st 2-way interaction system (QUBE)
- 1978 – Launch of CNN, ESPN, BET, Showtime, MSG, MTV
- 1979 – TRW proposes new hybrid technology lifting number of channels to 60-80
- 1980 – 15M cable households; \$15M invested in cable infrastructure
- 1980 – Addressable converters allow selected channels to STB
- 1981 – New channels introduced: Weather, Discovery, HSN, Disney, Playboy, Lifetime, A&E, AMC
- 1986 – 2M satellite users, mostly c-band
- 1986 – HBO scrambles signal to all users; General Instruments Video Cipher released (& hacked)
- 1987 – HFC technology 1st introduced (AM based)
- 1988 – CableLabs R&D group formed
- 1989 – GI compresses video into 6 MHz spectrum – digital systems soon to be released
- 1990 – 74 premium cable channels now available

Timeline (2 of 2)

- 1992 – DBS services: DirecTV (acquires PrimeStar) and EchoStar
- 1993 – Bell Atlantic buys John Malone's TCI (largest cable operator); 500 channel universe first described
- 1993 – DBS operators select MPEG-1 as digital video standard
- 1994 – Cable operators select MPEG-2 as digital video standard
- 1994 – Cable modem service begins
- 1995 – 64M cable households; 139 cable services; new broadband services launched including @Home, Roadrunner, others
- 1995 – Net2Phone is founded (VoIP)
- 1997 – \$5B spent to upgrade to digital networks; DOCSIS 1.0 spec released
- 1998 – Paul Allen buys Charter Communications (6th largest cable MSO); HDTV service begins; TCI buys TVGuide/Prevue
- 1998 – WorldGate launches 2-way internet TV
- 1999 – AT&T/TCI in \$48B merger; HDTV begins via Scientific Atlanta's set-top boxes
- 1999 – FireWire standard adopted by CableLabs; PacketCable launched for VoIP solutions; Diva Systems launches VOD offering
- 2000 – Cable available to 97% of American homes
- 2001 – DOCSIS 2.0 spec released
- 2003 – Comcast buys AT&T Broadband
- 2004 – 13 million cable modem subscribers in North America (only 20% penetration)

Source: <http://www.cablecenter.org/history/timeline/index.cfm>

Presented by Paul Finster

Today's Cable Service Offerings

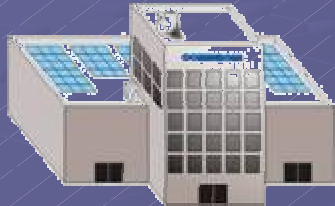


Video

- ◆ Video
- ◆ Premium Video
- ◆ Music

Voice

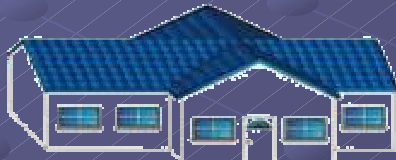
- ◆ VoIP
- ◆ Video Conferencing
- ◆ Lifeline



Commercial



Multi-Unit



Residential

HFC Cable Network

Data

- ◆ Cable Modem
- ◆ 128k → 45MB
- ◆ Managed
- ◆ "Always-on"



ITV Applications

- ◆ EPGs
- ◆ VOD
- ◆ DVR
- ◆ Games



Cable Infrastructure Overview

- Analog to Digital transition
 - Why we have set-top boxes
- Layers – the network from the ground up
 - Physical: Network
 - Transport: MPEG
 - Compression/Decompression
 - Session: Conditional Access
 - Services: Data, Voice, Applications

Cable Infrastructure

Analog to Digital Transition

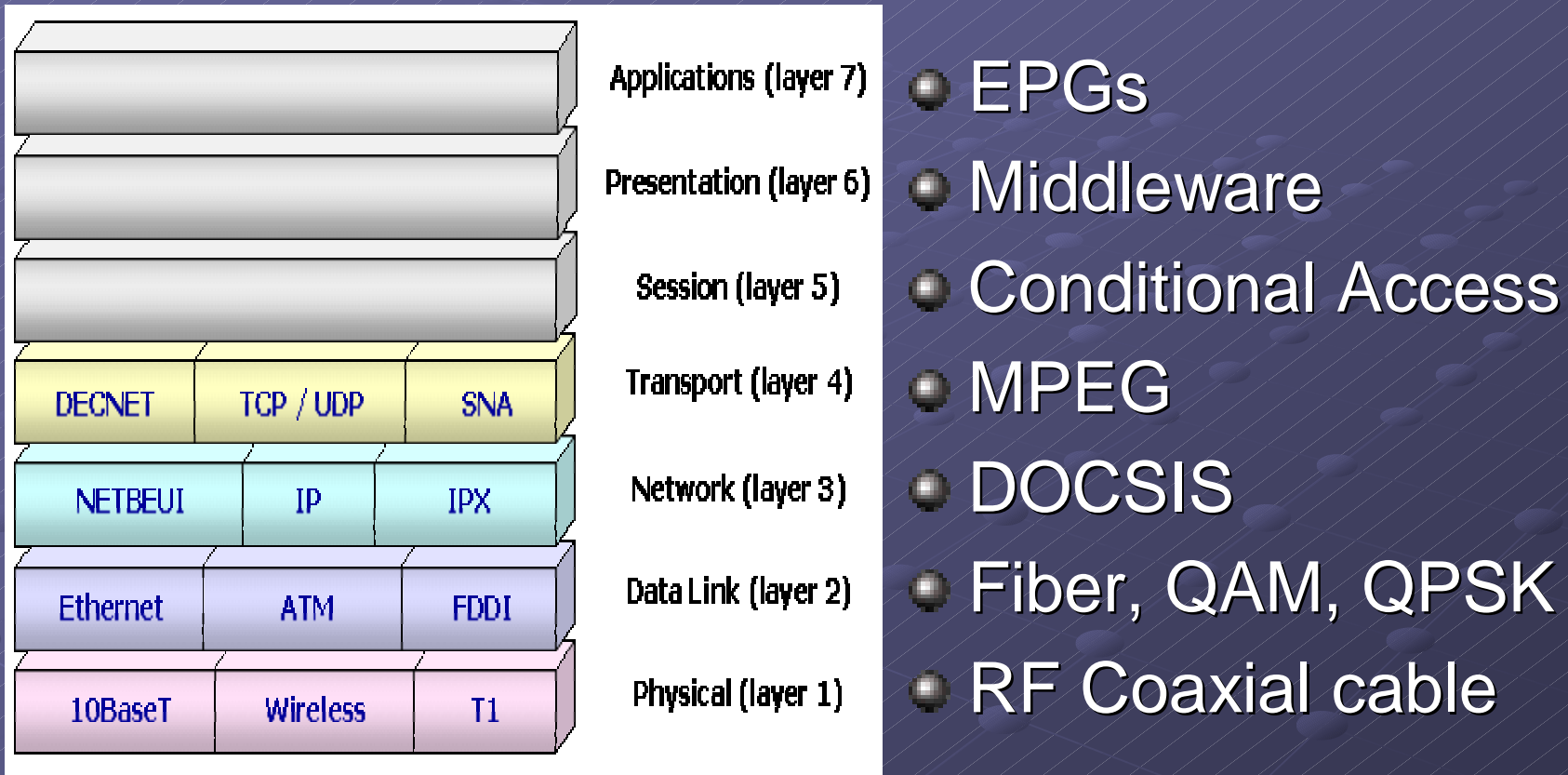
- Analog video transmission
 - Cable companies originally “pirated” over-the-air broadcasts for cable distribution
 - (sounds like today’s peer-to-peer issues!)
 - Added additional content as basis of charging for subscriber service
 - Up to 60 analog channels available
 - Birth of print version of TVGuide to find what was on TV
 - Needed system to scramble premium content → thus was born first version of conditional access
 - First analog cable box introduced with tuning and descrambling
 - First ability for Pay-per-View
 - Early pioneers: Jerrold, General Instruments, Scientific-Atlanta
- HFC (Hybrid Fiber-Coax) networks – transition from analog to digital
 - Analog coaxial cable
 - Limited by signal strength and reflections (noise)
 - New technologies allowed main trunk distribution of signals via fiber optics
 - New compression technologies allowed signal encoding (scrambling), compression and multiplexing (for data services)

Cable – Analog TV

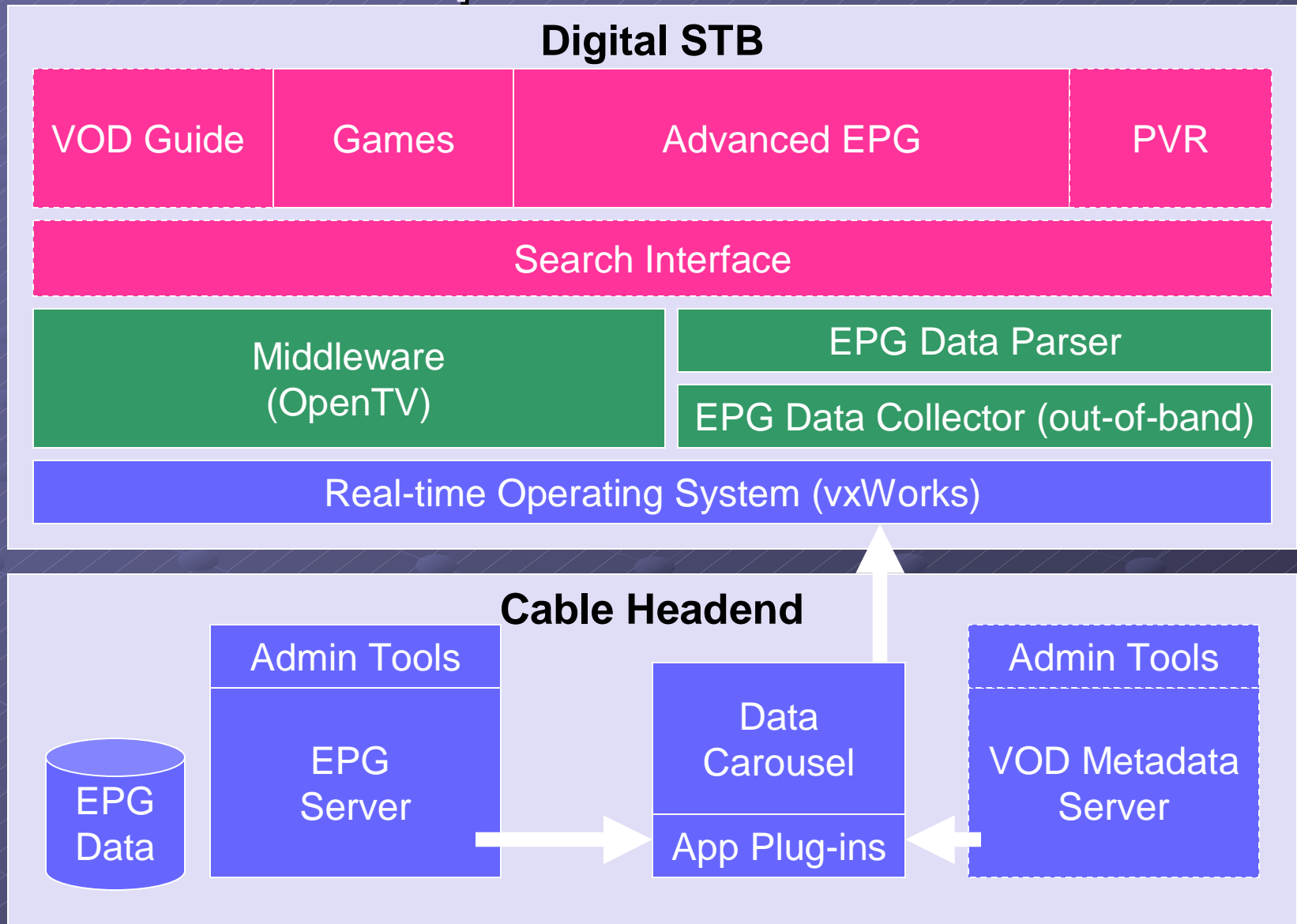
NTSC vs. PAL

- **NTSC (National Television Standards Committee)** – Used in U.S., Canada and Korea
 - Video format has 525 lines per frame (480 video image) and a refresh rate of 29.97 interlaced frames of video a second
 - Extra lines are used for sync, vertical retrace, and other VBI data such as captioning and EPG data.
 - VBI (Vertical Blanking Interval) is part of a television transmission signal that is blanked, or left clear of viewable content, to allow time for the television's electron gun to move from the bottom to the top of the screen as it scans images
 - NTSC interlaces its scan lines, drawing odd-numbered scan lines in odd-numbered fields and even-numbered scan lines in even-numbered fields, which gives a nearly flicker-free image at approximately 59.94 hertz (nominally 60 Hz / 1.001) refresh frequency, which is close to the nominal 60 Hz alternating current power used in the United States
 - Video professionals and television engineers do not hold NTSC video in high regard calling it “Never the same color”
- **PAL (Phase Alternating Line)** – Used World-wide
 - Color encoding used in broadcast television systems
 - Video format that has 625 lines per frame and a refresh rate of 25 frames per second, interlaced

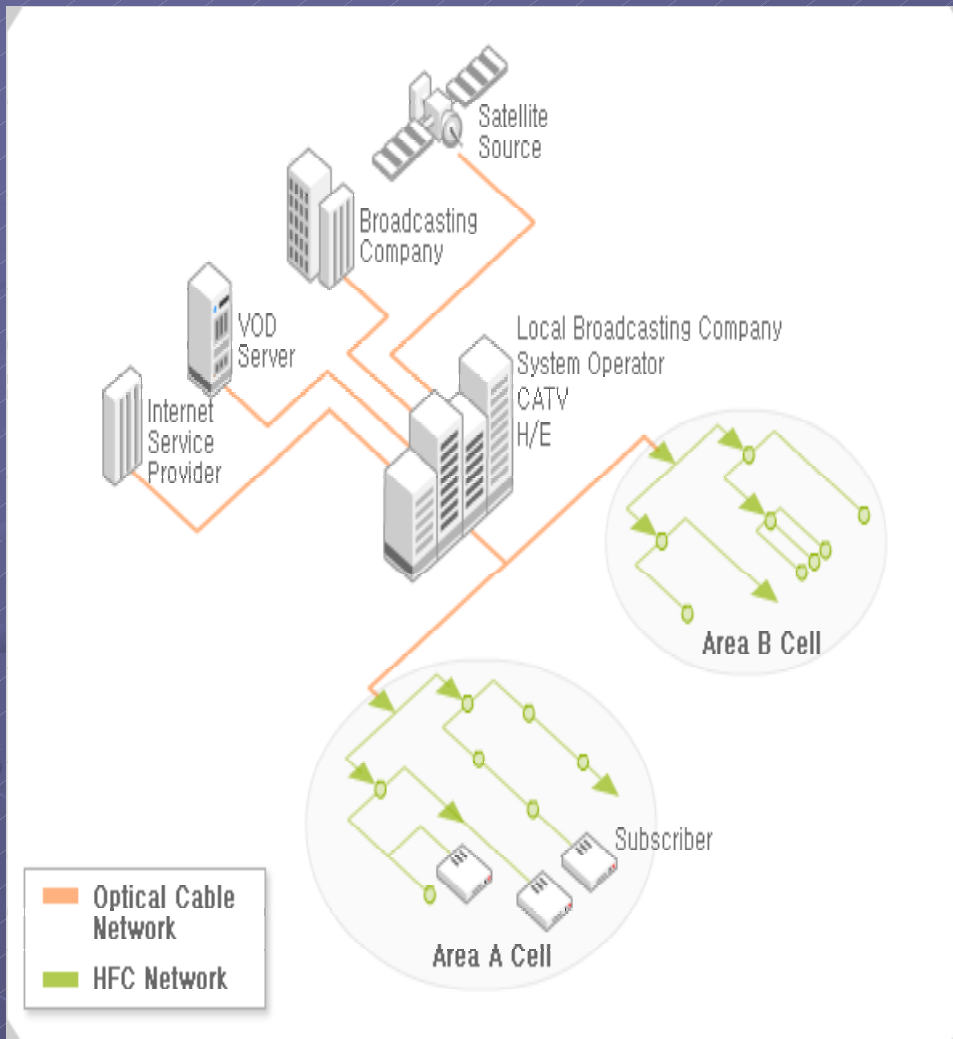
Cable Infrastructure Software/Hardware Stack



Set-top Architecture

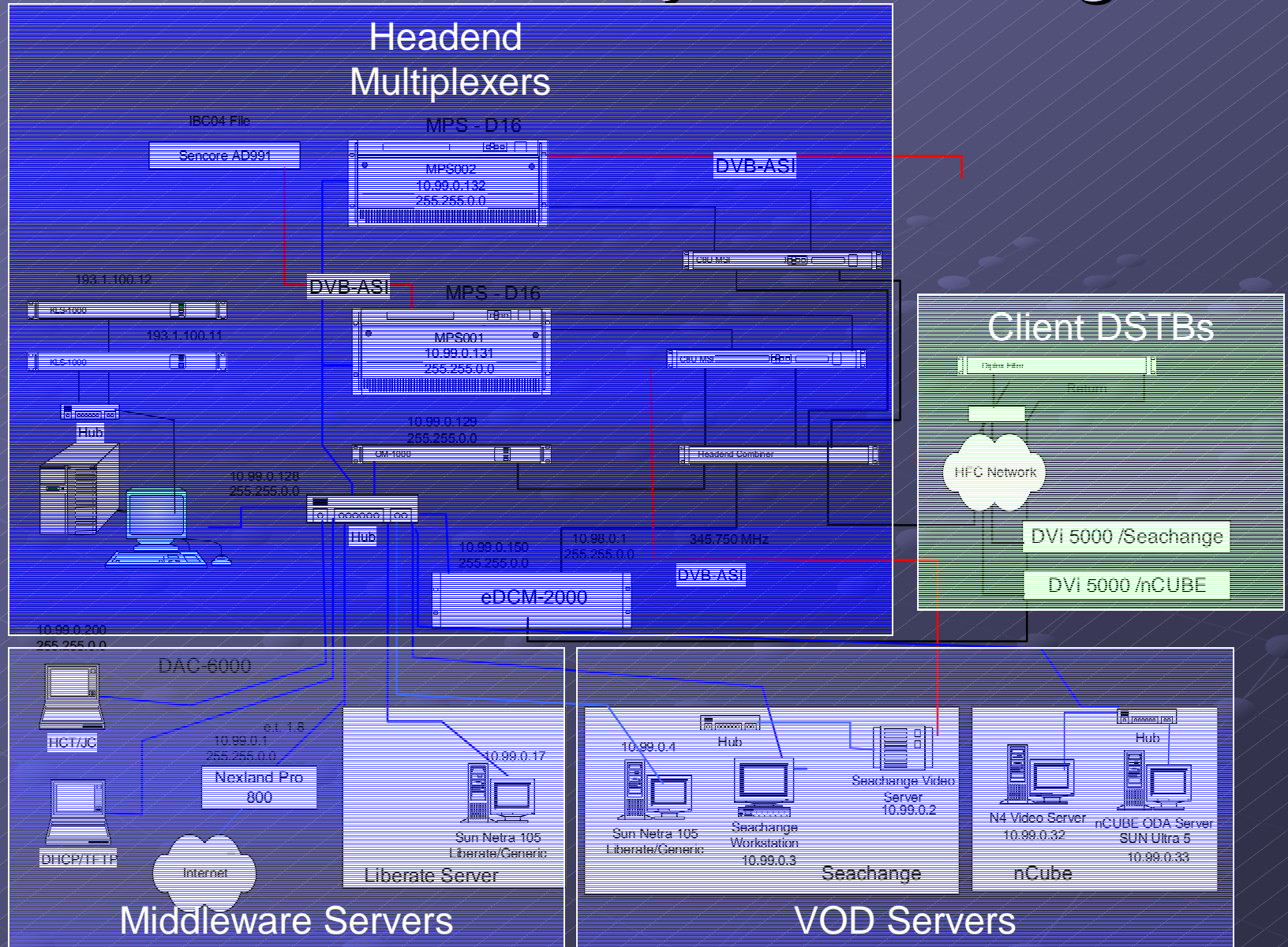


Typical MSO network



- Mix of Internet and Coax networks
- Coordination of streams managed at Headend (CATV H/E)

Typical Headend System Diagram



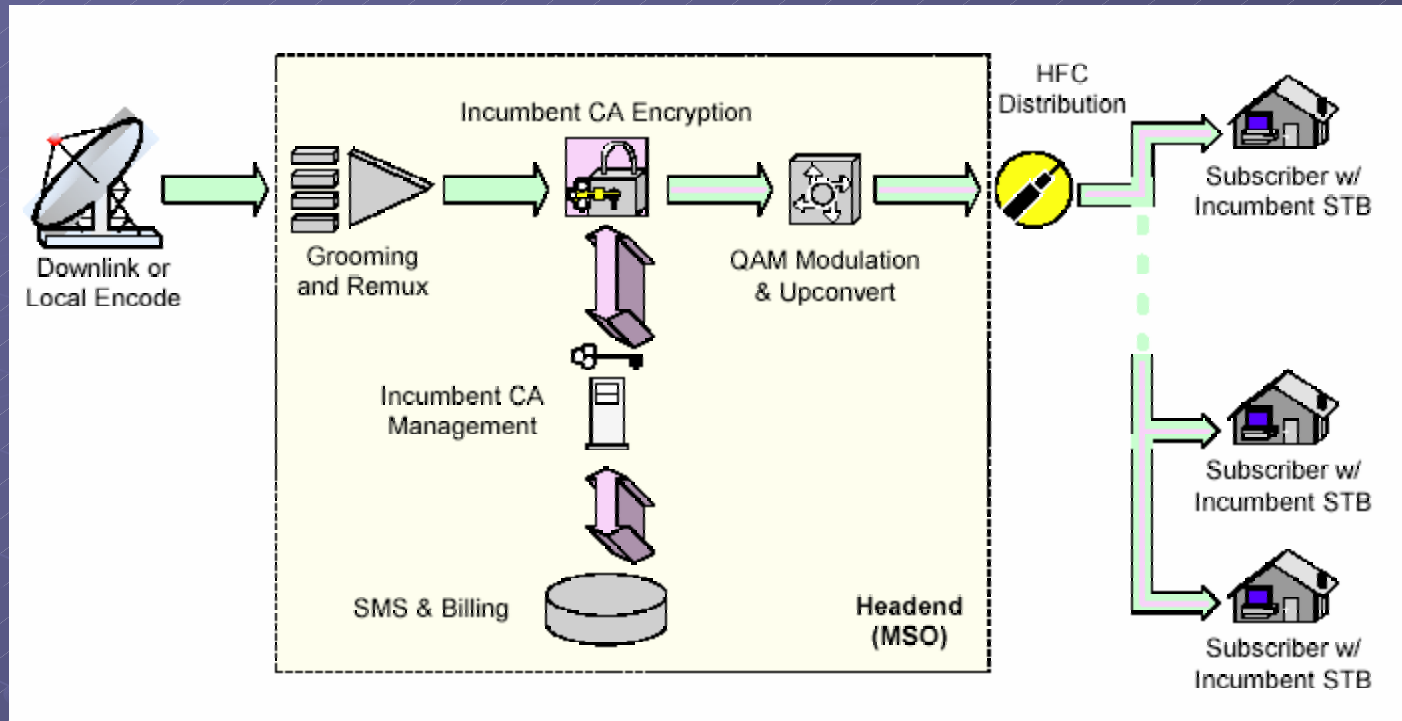
Cable Infrastructure

Conditional Access

- U.S. “dualopoly” is born and rooted in Conditional Access (CA)
- 50% Motorola (General Instruments)
 - Proprietary conditional access
 - DigiCipher 1® used in PrimeStar
 - DigiCipher 2® (DCII) – developed in 1997
 - Both incompatible with DVB due to System Information (SI) differences
- 50% Scientific Atlanta (S-A)
 - Proprietary conditional access
 - PowerKEY®
- New competitors
 - Sony Passage – allows multiple CAs to co-exist on one network by multiplexing MPEG “packets”
 - NDS, NagraVision, Viaccess, others



Cable Infrastructure Conditional Access



- Most in-bound video for cable systems comes from satellite networks!
- Custom channel lineups mean video channels are re-sorted
- Content often comes pre-encrypted with S-A and Motorola CA
- Additional encryption can be added for PPV content, etc

Source: <http://www.sonypassage.com>

Cable Services - Video

- Analog
 - ~6 MHz wide spectrum per analog channel
 - First 60 or so channels on most digital cable systems are still analog (for backwards compatibility and cable-ready TVs)
 - Significance of VBI
- Digital
 - Coding, Compression and Transmission
 - MPEG Packetization
- TV Formats
 - NTSC
 - PAL
 - MPEG
- Data Services
 - DOCSIS
 - Cable Network Infrastructure

History of Analog Video Data

● Vertical Blanking Interval (VBI)

- Time needed for CRT to re-trace to upper-left of screen after drawing one video frame!
- Time clock
- Closed Captioning (introduced in 1982 by Norpak)
- TeleText in Europe

● Definition

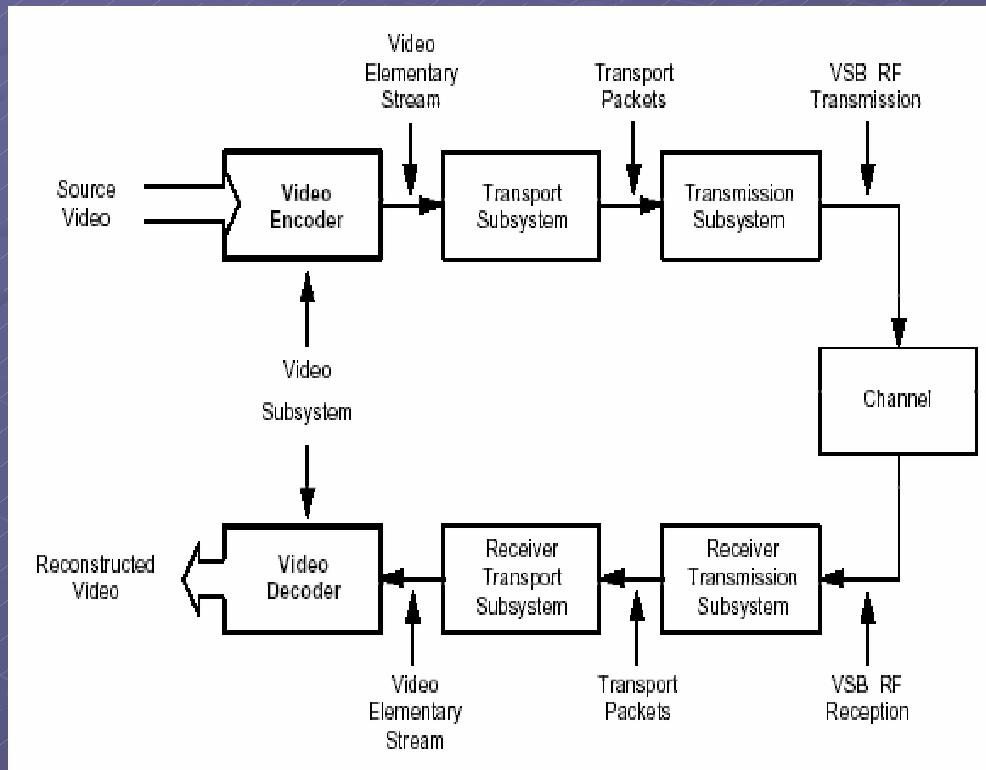
- The VBI is represented by the black stripe at the top and bottom of a TV picture. Physically, it constitutes 21 lines of a total 525 lines transmitted per second to the set in the analog National Television Standards Committee (NTSC) TV signal. The VBI is embedded inside two rectangular fields comprised of 262.5 lines each. Each line is made of 427 pixels that form the color video images on the screen through a process called "interlaced scanning" (an electron beam zig-zags up and down the screen depositing the pixels). The first 9 lines of the VBI are used for timing information of the shows. Lines 10-20 are, for the most part, unused. Line 21, however, is used for closed captioning, teletext, and now to send HTML data and interpreted with special software on a set-top box, software-ready digital TV, or TV tuner card on a computer.

● Uses:

- Bloomberg TV terminals send out news headlines and stock prices through the VBI
- Cable networks broadcast TV schedule information for patented Gemstar-TVGuide EPGs
- Early developers of ITV platforms such as Intel, WebTV, Wink Communications, and WorldGate explored new types of broadcasting over the VBI in the mid and late-90's and continue today
- ATVEF, used to trigger HTML content for enhanced TV

Source: <http://www.itvt.com/etvwhitepaper-3.html>

Basic Digital Video Block Diagram



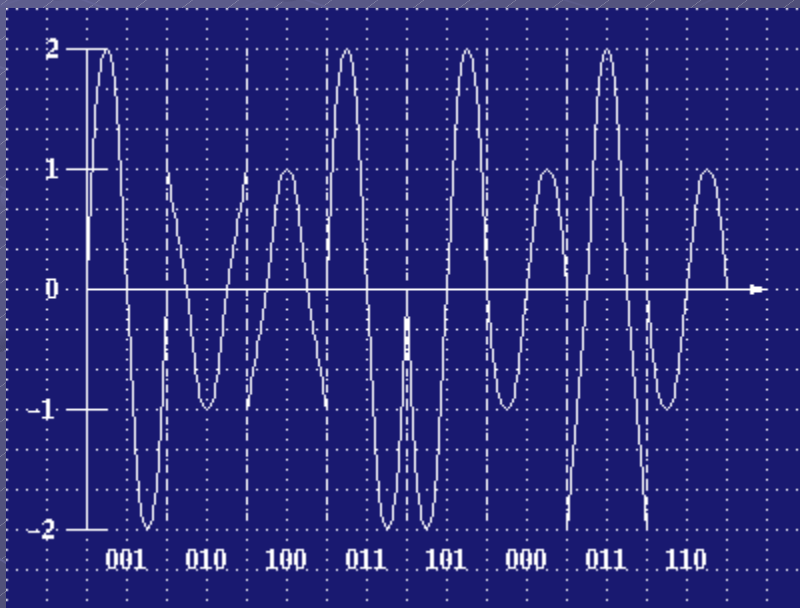
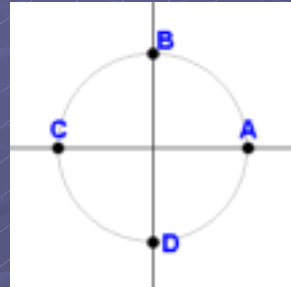
- Analog Video source
- Encoded into MPEG packets and stream
- Multiplexed with other Video streams
- Modulated on QAM or QPSK
- Broadcast via RF (HFC) network
- Received by Digital STB
- Channel tuned by Digital STB
- Decode elemental MPEG Stream
- "Tune" channel from MPEG stream
- Re-construct from MPEG packets
- Produce analog (baseband) & digital (Firewire), and PCM/Dolby/optical audio outputs
- This is why Digital tuning takes so long!

Cable Services - Digital

- Digital data signals are transmitted over radio frequency (RF) carrier signals on a cable system
 - For two-way communication
 - "downstream" direction is from the cable network to the customer
 - "upstream" direction is from the customer to the cable network
 - Digital data must be encoded into RF waveforms
 - Technology derived from early modem work on Telephone systems
 - Cable networks run between the 750 MHz/860 MHz range
- QAM – higher numbers require more sensitive equipment
 - 16 – 16 symbols (or phases)
 - 64 – 64 symbols
 - 256 – 256 symbols
- QPSK (Quadrature-Phase-Shift-Keying) transport
 - Benefits: Lower noise
 - Primarily used for satellite (KU and L-band modulation)

QAM Explained

Bit value	Amplitude	Phase shift
000	1	None
001	2	None
010	1	1/4
011	2	1/4
100	1	1/2
101	2	1/2
110	1	3/4
111	2	3/4



● QAM (Quadrature-Amplitude-Modulation) transport

- Quadrature → 4 symbol (phase) states (A,B,C,D)
- Represent bit values as a combination of amplitude modulation and phase shift keying

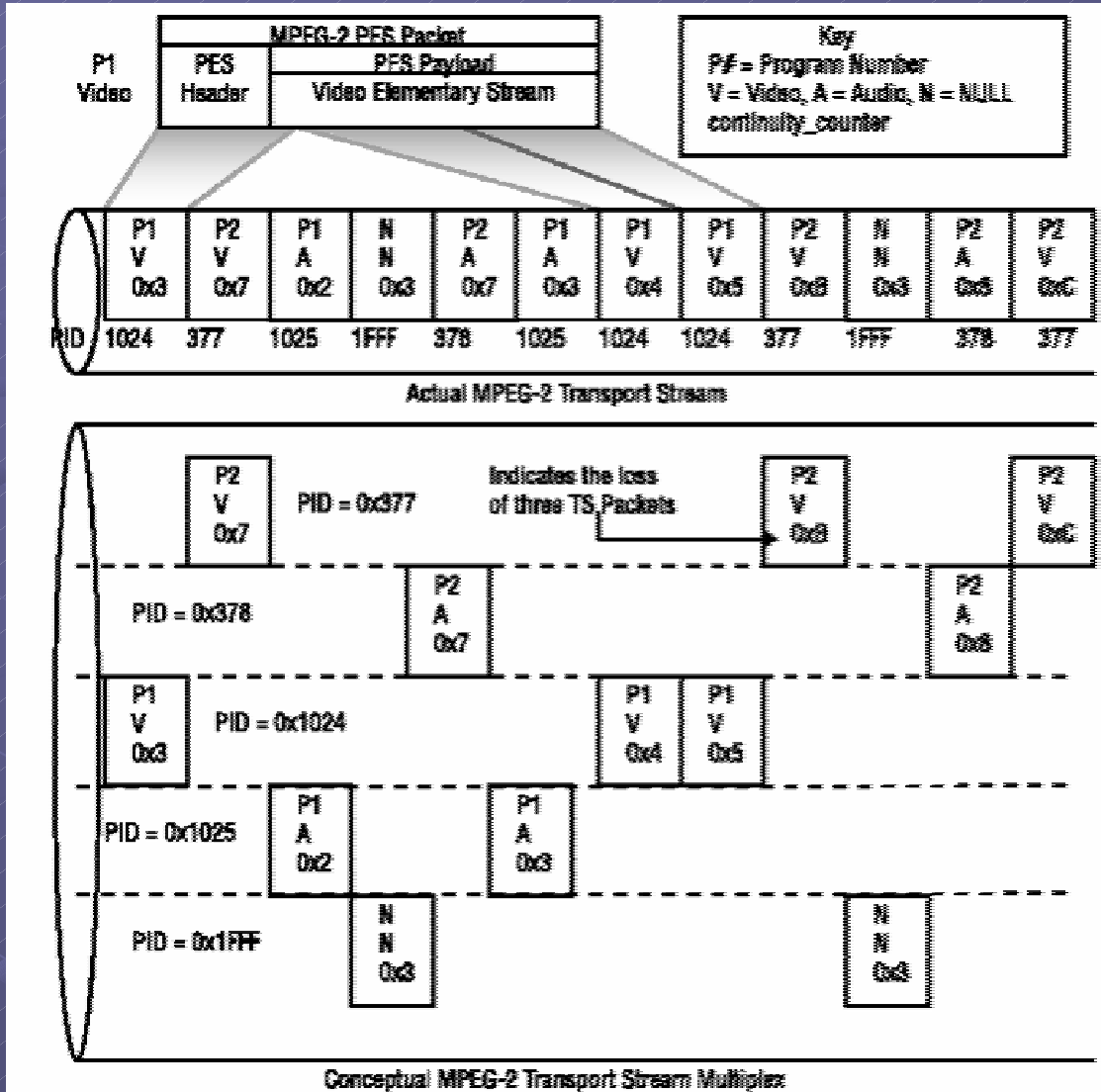
■ Example:

- 001010100011101000011110
- 001-010-100-011-101-000-011-110
- 2A NS, 1A $\frac{1}{4}$, 1A $\frac{1}{2}$, 2A $\frac{1}{4}$, 2A $\frac{1}{2}$, 1A NS, 2A $\frac{1}{4}$, 1A $\frac{3}{4}$

MPEG Basics

- MPEG (Moving Picture Experts Group)
 - MPEG-1
 - Includes popular audio compression format (MP3)
 - MPEG-2
 - Broadcast quality Video and Audio
 - Used on DVDs and digital cable/satellite networks
 - MPEG-4
 - Includes 3-D content, digital rights management (DRM)!
 - Lossy data compression
 - I-frames (Intra- baseline image)
 - P-Frames (Predicted → difference images)
 - Licensed to industry by MPEGLA

MPEG Packets



-MPEG is a packet structure protocol

-Reference video frames are encoded/compressed

-Predictive (or difference) frames are encoded/compressed

-Multiple Audio tracks are multiplexed with Video frames

-Multiple video channels can be encapsulated within a single MPEG stream

-MPEG Streams are modulated onto an RF frequency using traditional radio codecs (QAM-cable, QPSK-satellite)

Cable – Digital TV Formats

SDTV vs. HDTV vs. DVD

● SDTV

- 704 × 480 pixels with NTSC
- 2-3 Mbps average

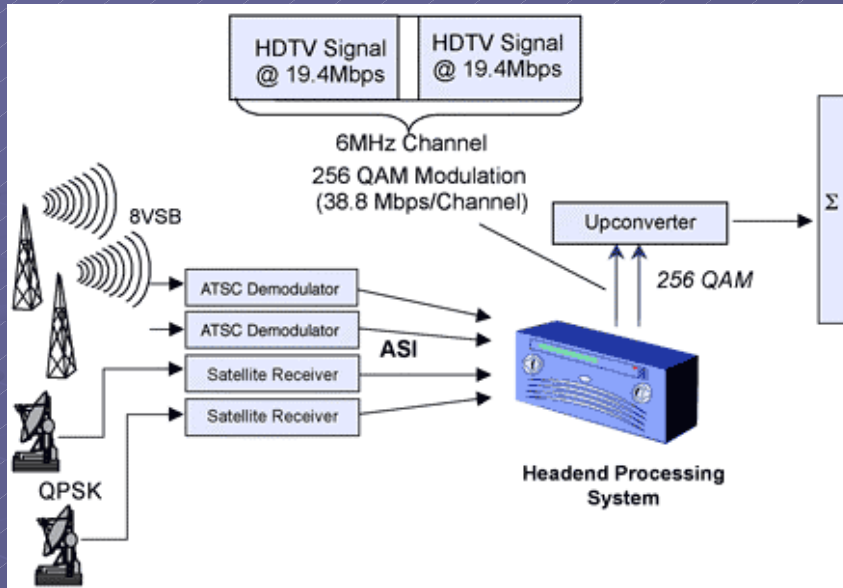
● HDTV

- 1280 × 720 pixels in progressive scan mode (abbreviated 720p) or 1920 × 1080 pixels in interlace mode (1080i).
- 11-18 Mbps depending upon content
 - Sports requires more due to movement
 - Needs 6 analog channels to support!
- ATSC terrestrial broadcasts with 8-VSB modulated signals

● DVD

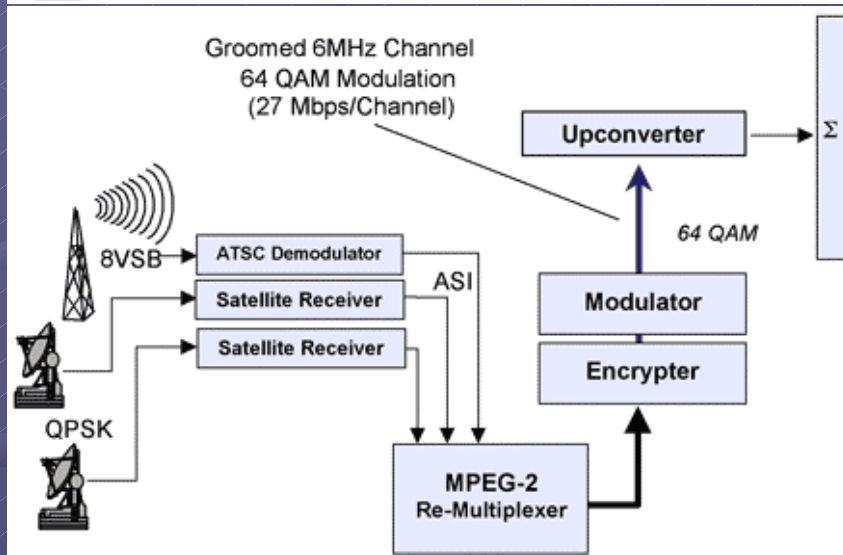
- Video discs require a DVD-drive with a MPEG-2 decoder
- Commercial DVD movies are encoded using a combination of MPEG-2 compressed video and Dolby Digital audio plus other audio tracks (Spanish, PCM, etc)
- 3-10 Mbps
- CSS (Content Scrambling System) provides encryption; reverse engineered
- MacroVision protects against copying to a VCR
- Regional lockouts
- Blue-Ray Disks for HD DVD recording coming soon

How will cable broadcast HDTV?



Option 1

- 2 HDTV channels on 256 QAM modulator



Option 2

- Re-multiplex, re-sample MPEG onto single 64 QAM modulator

Source: <http://www.cedmagazine.com/ced/2001/1001/10h.htm>

Cable Services – Data

DOCSIS 1.0, 1.1, 2.0...

● DOCSIS 1.0

- 100's users share a 6-Mhz channel; requires CMTS at headend
- Downstream: up to 40Mbps (QAM 64 or 256)
- Upstream: 3.2 MHz wide, 10Mbps (QAM 16 and QPSK)
- TDMA encoding
- DES encryption (optional)

● DOCSIS 1.1

- Real-time services, QoS, VoIP, interactive gaming, tier-based services (managed bandwidth)
- Downstream/Upstream: same as 1.0

● DOCSIS 2.0

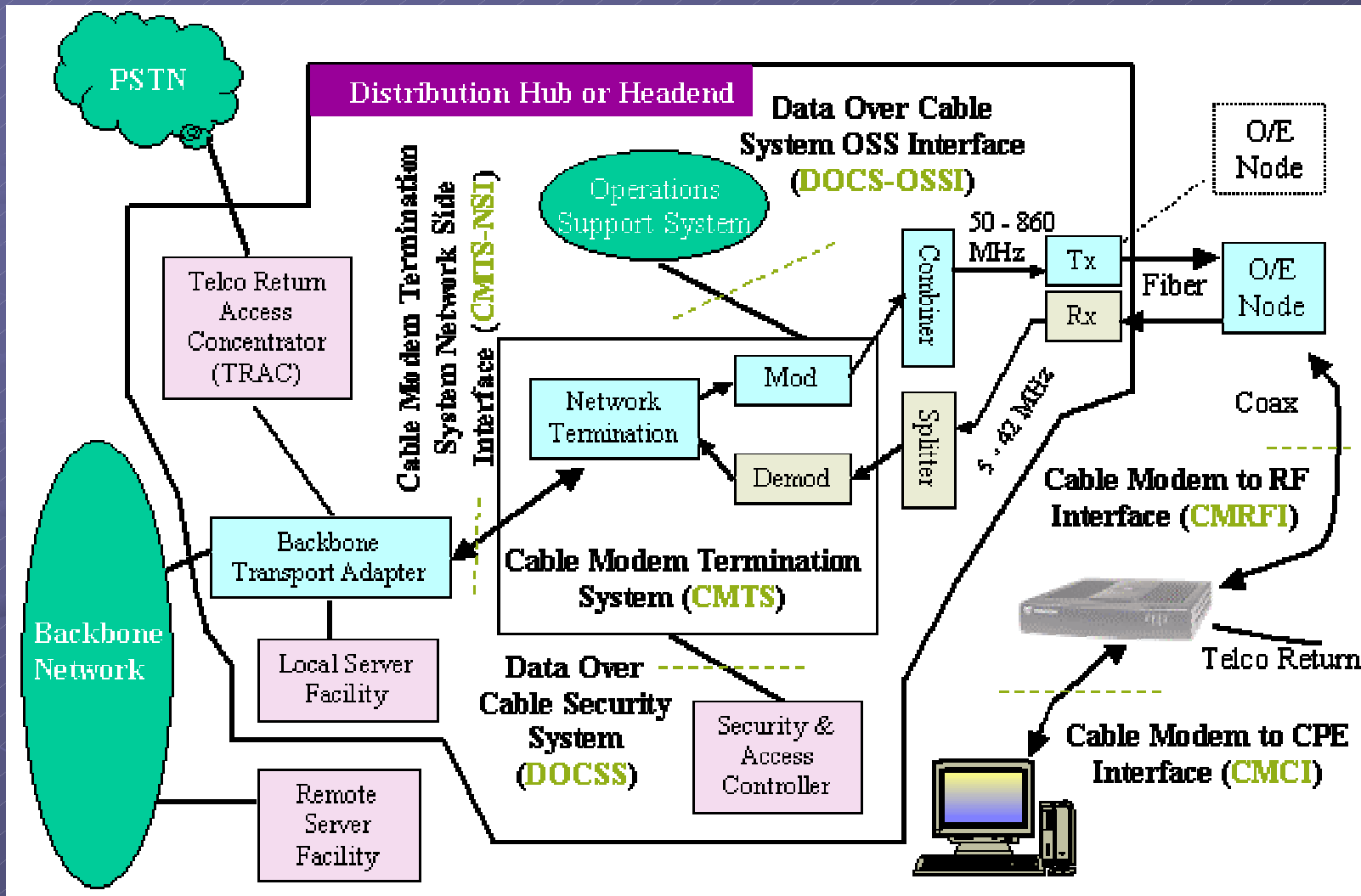
- Authenticated modems using digital certificates, secure modem patch downloads, Multicast data, technology includes both TDMA and CDMA, noise reduction strategies is focus
- Upstream: 6.4 MHz wide, 30Mbps
- Why more bandwidth?
 - Peer-to-peer services
 - Digital photography
 - Music downloads

● euroDOCSIS – 8 MHz instead of 6Mhz

sources

- <http://www.cablemodem.com>
- http://www.scte.org.uk/member/events/docsis2_0_terayon_presentation_scte250903.pdf

Cable – Data Network



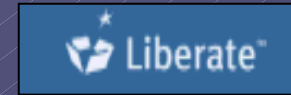
Source: http://www.nextgendc.com/?/seminar_docsis_qos.htm

Cable Service – Voice

Voice-over-IP (VoIP)

- Phone service using TCP/IP
 - Requires quality of service (QoS) → need DOCSIS 1.1+
 - Less than 400ms delay required; else talker overlaps and echos
 - Minimal packet loss allowed
 - Bandwidth on-demand
 - Compression of TCP/IP overhead expensive
 - Requires interconnection to PSTN (Public Switched Telephone Network)
 - Switching to other phone carriers via gateways
 - Billing
 - Network Address Translation (NAT) services needed to find PSTN networks for 10 digit numbers
 - Class 5 services: Call forwarding, Caller ID, etc
 - E911 service requires powered cable edge devices
 - Communications Assistance for Law Enforcement Act (CALEA) of 1994 allows for lawful access for wiretapping
- Successes
 - Vonage (New Jersey)
 - Net2Phone

Cable Services - Middleware



● Liberate

- Standard – browser-based with enhanced JavaScript objects
 - Highlights, scrolling text within <TD>, access to EPG data, boot-strap drivers for gotoURL, popup volume, popup channel change, etc
 - Deployed in UK, Philips AOLTV
- Compact – Java-based
 - Micro-Java engine
 - Deployed at Insight, Shaw

● OpenTV



- Runtime Engine – C, C++ code
 - Majority of STB deployments world-wide
 - Deployed on UK's BSkyB, TPS France, EchoStar Dish, Foxtel Australia
- Device Mosaic (Spyglass) – embedded browser
 - Deployed at CableVision
- Wink – low-bandwidth
 - Deployed Charter, DirecTV

Cable Services - Middleware

- Microsoft TV

- Foundation



- WorldGate & ICTV

- Server-side MPEG frames
- Minimal backchannel needed for remote clicks
- Thin-client ready



- NDS

- CA deployed on DirecTV, CableVision
- MediaHighway (Canal+ acquisition) is Java-based



- Open Standards

- MHP (Multimedia Home Platform)
 - International Java-based standard supports JVM and HTML browser profiles
 - Deployed in Europe
 - Adopted for digital terrestrial and satellite broadcasts (Berlin, Finland, etc)
- OCAP (Open Cable Application Protocol)
 - American CableLabs standard supports unbound/bound applications on U.S. cable systems; includes a subset of MHP (adopted by DASE working group)
 - Not deployed yet; in testing



Cable Services - Applications

- EPGs – resident applications

- Monopoly created by Gemstar-TVGuide

- VCRPlus codes
- VBI EPGs
- Built into Motorola DSTBs

- TVGuide Interactive

- 4-8MB RAM

- Resident applications

- S-A
 - SARA - PowerTV
 - Pioneer
- Motorola
 - VxWorks
 - Native API

- The future of EPGs

- PSIP will replace VBI in digital transmissions
- However, VBI will remain for backward compatibility for some time



Gemstar Highlights

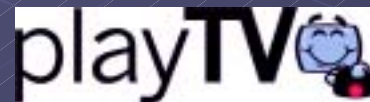
- 1997 - Gemstar acquires StarSight after patent infringement battle
- 1998 - Gemstar sues TVGuide (United Video)
 - Then eventually acquires TVGuide
- Oct 2000 - Motorola licenses Gemstar patents for \$200M (10 year deal)
 - Past infringement and future use in DCT2000 and DSR products
- Gemstar exclusively licensed SuperGuide patents for cable industry
- Gemstar licenses patents to Microsoft (WebTV, MSNTV, UltimateTV)
- Gemstar 12-year agreement with Time Warner
- Gemstar decides to buy Diva (May 2002)
 - Gemstar backs out of deal (Sept 2002)
 - Diva wins \$39M in lawsuit for failed takeover
 - Diva patent auction early August 2003

Gemstar Highlights

- SuperGuide vs. EchoStar, Pioneer and S-A (vs. Gemstar)
 - SuperGuide started suit; Gemstar forced to follow
 - ITC Court
 - Stop import of products
 - Declares patent misuse
 - +\$40M spent on losing case
 - EchoStar files counter claim of anti-trust behavior
- Justice department (DOJ) begins investigation on Anti-trust case
 - Determines fast-start “gun jumping” with merger with TVGuide (print)
 - \$5.6M fine and injunction
- StarSight (Gemstar) sues TiVo (2000)
 - Suit followed by counter-suit
 - TiVo licenses one or more patents from Gemstar
- 2004
 - Settles with Pioneer
 - EchoStar EPG lawsuit re-opened by higher court
 - Licenses TVGuide code base to Comcast

Cable Services - Applications

- Digital Video Recorders (DVRs)
 - TiVo & Replay
 - Motorola & S-A
- Interactive Portals – news, weather, sports
 - Digeo
 - MetaTV
 - SourceMedia
- VOD – on-demand digital MPEG streams from servers at headend
 - nCube
 - Concurrent
 - SeaChange
- Self-service provisioning
 - PPV, Order premium packages, pay bill
- Games
 - PlayTV
 - others



What's Next?

- Digital Terrestrial
 - Free HDTV?
 - Maybe: checkout TitanTV.com for HDTV programming
 - Yikes! Need \$500-1,000 Tuner
 - 6 channels of CBS: possible!
 - Data services?
- TV over DSL?
 - Telcos like SBC and other carriers in discussions with DirectTV and EchoStar
 - Broadband delivered TV already active in Canada and Germany
- Consumer Electronic Revolution?
 - HDTV & DVRs
 - New HDTV TVs shipping – yet confusion in the marketplace for standards: 720p, 1080i, etc
 - New networked devices connect to home PC content (mp3, mpeg, etc)
 - OpenCable and CableCards
 - CableLabs and cable companies are promoting a PC-Card standard conditional access (CA) that will allow CE TVs and DSTBs direct access to premium encrypted content delivered over the cable networks
 - Portable CA will allow end-users to buy their own cable equipment
 - Portable CA will allow cable companies to keep DSTB expenses off your cable bill and their balance sheet
 - Will the new PlayStation3 (PSX) or Xbox include the CableCard?
 - Many TVs (like Panasonic) and DSTBs (like TiVo) will!

Trends

- HDTV requires new STB
 - Motorola, S-A, Pace, Sony
 - Cable moves to sell these STBs at retail; this is a first
- Cable losing subs to satellite
 - Cable less subs than year before
 - CableVision launches new satellite DBS solution in late 2003 called VOOM
 - Focused on DOCSIS cable modems for new revenue
 - Remember only 20% penetration so far
 - Double the speed of Telcos DSL
 - Forced to start VOD now to battle satellites
 - HDTV programming

Thank You!

Digital Cable Technology Primer

March 2, 2004

Prepared by Paul Finster

paul@10011.com

<http://10011.com>