How to increase system bandwidth

Jesus Barrios
Staff Solutions Architect
Agenda

Introduction
- Challenges and trends for today networks

HFC/Access Network
- The Network Access flexibility
- Evolving the Network Access for allocating more services

Video Processing
- Video Encoding
- Switch Digital Video

High Speed Data
- DOCSIS evolution
- Spectral Eficiencies
Introduction

Challenges and trends for today networks
Bandwidth Growth – How Long?

FROM DIGITIZATION TO CLOUDIFICATION

1990 decade  Letter to Email

2000 decade  Music, Pictures online

2010 decade  Streaming Video, Multiscreen

2020 decade  Immersive Video Holographic/ M2M / Cloud

FROM DIGITIZATION TO CLOUDIFICATION
Max BW Traffic Engineering Predictions... BW Continues to Grow (Nielson’s Law)

If we change nothing, HFC plants may run out of gas in mid-2020s

What will you do?
There are at least 2 potential paths...
Max BW Traffic Engineering Predictions…
BW Continues to Grow (Nielson’s Law)

What will you do?
There are at least 2 potential paths…

1. Abandon HFC/DOCSIS
Max BW Traffic Engineering Predictions...
BW Continues to Grow (Nielson’s Law)

What will you do?
There are at least 2 potential paths...

1. Abandon HFC/DOCSIS
2. Extend the Capacity & Life-span of the Existing HFC/DOCSIS Network
Dealing With The Exponential Broadband Bandwidth Growth

• Managing the spectrum to accommodate exponential HSD Growth & the migration to IP Video will be the biggest challenges in the decade... it can be done with many combinations of the following:

<table>
<thead>
<tr>
<th>Technique</th>
<th>Impacting on Subscriber</th>
<th>Challenge to MSO</th>
<th>Challenge to Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constrain subscriber bandwidth</td>
<td>5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Analog or SD reclamation</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Improved compression techniques (ex: H.264 &amp; HEVC)</td>
<td>1</td>
<td>3</td>
<td>2</td>
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<tr>
<td>Transfer spectrum between services (ex: MPEG VoD to DOCSIS)</td>
<td>3</td>
<td>2</td>
<td>1</td>
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<tr>
<td>Switched Digital Video</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Node-splits</td>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>IP Video</td>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>DOCSIS 3.1</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Selective Subscriber Shedding</td>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Extended Spectrum DOCSIS 3.1</td>
<td>2</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>HFC spectral expansions (ex: 1 GHz and beyond)</td>
<td>2</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Upstream split changes (ex: 85 MHz or 200 MHz)</td>
<td>2</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>RFoG FTTH</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>PON FTTH</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>
All Nodes easily managed by SDN, Cloud-based AGM

What’s an MSO to Do in the Future?
How Long before HFC Capacity runs out?
The Stuff that Keeps us up at Night...

Fundamental Questions for Cable Industry on HFC capacity:

• How Long before we exceed the capacity of HFC?
  – But this is not specifically the right question to ask, instead need to ask:

1. When will HFC to FTTH migration absolutely need to start?
  – Most Likely in earnest within the next 5-10 years; some 1G FTTH near term

2. How Long will it take to migrate all HFC subs to FTTH?
  – ARRIS expects at least 20-40 year window to migrate all HFC subs to FTTH
    • If 5% of subs go to FTTH each year (which is aggressive & expensive), then 20 years!

3. How can we facilitate an orderly transition to FTTH over an extended period?
  – Selective Subscriber Shedding Strategy can extend the Life of HFC for Decades
  – DOCSIS 3.1 is key enabler to make sure HFC Lasts thru this Transition!

4. Should MSOs use PON or DOCSIS technology for FTTH?
  – New Hybrid PON (HPON) technology allows the choice of either
HFC/Access Networks
Flexible Solutions Meets Future NEEDS

- **FTTLA and Amp/Node Conversion**
- Node Ethernet
- **Fiber Extensions of HFC Plant**
- Elimination of OBI with AgileMax™
- Node Splits
- Cascading Nodes and Fiber Deeper
- 1.2 GHz DOCSIS 3.1
- PON/DPOE
- PON offloads data from RFOG
- CTBH and Carrier ENET aggregation
- Standard Cascade HFC
- FTTLA and Amp/Node Conversion
- All IP FTTH
- All IP Migration for Fiber to the Home
- All IP Migration over DOCSIS
- Lower OPEX
- Higher Capacity
Progressive Segmentation with Optical Links

**Late 1990s**
- 1:4 Tx / Node ratio
- 2 - 6 fibers per node
- 2000 homes per node

**Mid 2000s**
- 1:1 Tx / Node ratio
- 2 - 6 fibers per node
- 500 homes per node

**Late 2000s**
- New Community
- Existing fibers approaching exhaustion
- Number of homes per node being reduced even further as needed
Architectures Today

Segmentable HFC

Extended Reach

Headend

FTTx

Fiber Deep (N+x)
## System Assumptions

<table>
<thead>
<tr>
<th></th>
<th>Total Homes Passed</th>
<th>Homes passed per node</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>300,000</td>
<td>500</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Drop-in Upgrade</th>
<th>Node Split</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starting Bandwidth</td>
<td>750 MHz</td>
<td>200 MHz digital per 500 HP</td>
</tr>
<tr>
<td>Upgraded Bandwidth</td>
<td>1000 MHz</td>
<td>400 MHz digital per 500 HP</td>
</tr>
<tr>
<td>Bandwidth increase</td>
<td>250 MHz</td>
<td>200 MHz</td>
</tr>
</tbody>
</table>
Node Segmentation More Cost Effective than Full Bandwidth Upgrades

<table>
<thead>
<tr>
<th></th>
<th>Bandwidth Upgrade</th>
<th>Node Split</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Cost per node</td>
<td>$15,500</td>
<td>$6,500</td>
</tr>
<tr>
<td>Cost per HP</td>
<td>$31</td>
<td>$13</td>
</tr>
<tr>
<td>Minimum Project Cost</td>
<td>$9,300,000</td>
<td>$6,500*</td>
</tr>
<tr>
<td>Added Bandwidth</td>
<td>250</td>
<td>200MHz</td>
</tr>
<tr>
<td>Added Bandwidth per HP</td>
<td>0.5</td>
<td>0.4MHz</td>
</tr>
<tr>
<td>Cost per added MHz</td>
<td>$62</td>
<td>$33</td>
</tr>
<tr>
<td>Boosts Downstream &amp; Upstream?</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

* Cost for targeted area Upgrade vs. Whole Network
Bandwidth Upgrade or Node Splits

• Compared to Bandwidth Upgrade –
  – Node splits cost ~ half as much per added MHz
  – Node splits can be done gradually & selectively
    • when & where needed, “pay-as-you-grow”
  – Node splits provide comparable added capacity per home
  – Node splits improve both Upstream & Downstream capacity

• But –
  – Bandwidth Upgrade plus SDV (in addition to Nodes Splits) gives the ultimate capacity upgrade
  – Bandwidth Upgrade must cover entire system to be effective
Segmentation Upgrade Solutions

Network with Existing Amplifier Cascades

Network with Amplifier to Node Upgrade
Potential Long-term Evolutionary Paths for MSOs

Node+3 Node+1 Node+0 FTTC FTTT FTTH

- **PON**
  - Remote PON OLT FTTH
  - Head-end PON OLT FTTH

- **DAA**
  - DAA HPON-FTTH
  - DAA HPON-FTTC/FTTT

- **I-CCAP**
  - I-CCAP HPON-FTTH
  - I-CCAP HPON-FTTC/FTTT

**Fiber Depth**
- ~1-10 Gbps
- ~1-10 Gbps
- ~1-10 Gbps
- ~1-25 Gbps
- ~1-25 Gbps
- ~1-25 Gbps
- ~1-200 Gbps
- ~1-200 Gbps
- ~1-200 Gbps
- ~1-400+ Gbps
- ~1-400+ Gbps
- ~1-400+ Gbps

**Possible End-Games For 2040+**
- FTTC
- FTTT
- FTTH

**Head-end**
- PON OLT FTTH
- Remote PON OLT FTTH

**Remote**
- PON OLT FTTH
- Remote PON OLT FTTH

**Possible End-Games**
- FTTC
- FTTT
- FTTH
A Network Evolution Example

Architecture

Fiber Depth

Node+3  Node+2  Node+1  Node+0  FTTC  FTTT  FTTH

Head-end PON OLT FTTH

Normal DAA HFC

DAA HPON-FTTH

DAA HPON-FTTC/FTT

I-CCAP HPON-FTTH

I-CCAP HPON-FTTC/FTT

I-CCAP HFC

~1-10 Gbps

~1-10 Gbps

~1-100 Gbps

~1-200 Gbps

~1-400+ Gbps

~1-400+ Gbps

~1-400+ Gbps

~1-400+ Gbps

2015-2025

2017-2025

2020-2030

2020-2030

2025-2035

2025-2035

2030-2045

2030-2045

2030-2045

2030-2045

27 July 2016
HFC Flexible Evolution Path

HFC CHP Optical Tx/Rx

Node

PROFIT

CAPACITY

Services

Enterprise

Small Business

IPTV

Gigabit Data

High Speed Data

VoIP

Video on Demand

Analog/Digital Video

ARRIS Optical Wavelength Plan
HFC Flexible Evolution Path
HFC Flexible Evolution Path

HFC CHP Optical Tx/Rx + RFoG + ePON

Opti Max Node

CORWave 4λ

CORWave 4λ

EPON OLT

Max / Denux

Max / Denux

PROFIT

HFC

RFoG

ePON

CAPACITY

HFC

RFoG

ePON

10G ePON

10G ePON

Optical Ethernet

Services

Small Business

IPTV

Gigabit Data

High Speed Data

VoIP

Video on Demand

Analog/Digital Video

ARRIS Optical Wavelength Plan

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HFC Flexible Evolution Path

HFC CHP Optical Tx/Rx + RFoG + ePON
HFC Flexible Evolution Path

HFC CHP Optical Tx/Rx + RFoG + ePON + 10Gig ePON

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Video Processing
SDV
Switched Digital Video

- Broadcast no longer scales with available programming

- SDV reclaims bandwidth and allows channel lineup expansion

- No impact to subscriber
- Additional channel change time < 100msec
SDV Drivers

- Additional spectrum required for
  - DTV transition
  - HD growth and 3D HD
  - HD and 3D HD VOD
  - Time-shifted TV, Network DVR
  - DOCSIS 3.0 and IPTV expansions, MultiScreen TV

- SDV is the lowest cost, fastest, least intrusive way of reclaiming spectrum

- Only SDV provides infinite bandwidth. Analog reclaim, 1GHz plant upgrade, high-end rate-shaping, MPEG4 migration, only offer expensive short term alternatives to cope with spectrum needs

- SDV is the gateway to Personalized TV
  - Switched Unicast
  - Addressable Advertising
SDV Business Case – ROI From New Services

- Additional HDs
  - Required to compete against other providers and avoid customer churn
  - Additional $10 to $20 a month per subscriber for ‘extended’ HD packages

- Linear 3D HD
  - No clear business model yet, but lots of press covering availability and offerings

- Additional VOD, Time-shift TV, HD VOD, 3D HD
  - Decrease over the top video traffic (save on CMTS upgrades)
  - Additional revenue, $4 to $8 per movie watched

- Network DVR
  - Save on expensive STBs with dual tuners and DVR and charge little monthly premium
  - Additional advertising revenue from being able to target Ads

- PPV events (Fights, Concerts, etc.) tuner with DVR
  - $50 to $150 per subscriber per event

- Sport subscription packages - All season NBA, NHL, MLB (up to 40 channels)
  - Up to $250/$300 per subscriber per season

- Ethnic packages - For example 4 channels of Italian TV
  - $10 per subscriber per month

- Other niche content
  - Additional packages at $5-$10 per subscriber per month
  - Educational Channels - Get schools to get a cable subscription

- High Speed Data
  - $20-$30 a month per subscriber for premium HSD service
  - Target small business customers

- Video to IP devices
  - Additional revenue per subscriber signing on to service
  - Additional eye balls, increasing advertising revenue
Video Compression
Common video formats

- **Film**: Progressive, 24 x 2 Fps.
- **Analog TV NTSC** – **North America**
  - Interlaced, 30(29.97) Fps (60 fps).
  - 480 active horizontal lines.
- **Analog TV PAL** – **Europe**
  - Interlaced, 25 Fps (50 fps)
  - 576 horizontal lines
- **Digital Video**
  - SD (similar to analog)
  - High Definition TV (HD)
    - 1080i or 1080p is common for other HD channels
# Digital TV resolutions

<table>
<thead>
<tr>
<th>Short name</th>
<th>Used in</th>
<th>Active Resolution</th>
<th>Aspect ratio</th>
<th>Common frames refresh</th>
</tr>
</thead>
<tbody>
<tr>
<td>SD 480i</td>
<td>DTV NTSC</td>
<td>704 × 480</td>
<td>4:3</td>
<td>interlaced 29.97 FPS (59.94 fields/sec)</td>
</tr>
<tr>
<td>SD 576i</td>
<td>DTV PAL</td>
<td>720 × 576</td>
<td>4:3</td>
<td>interlaced 25 FPS (50 fields/sec)</td>
</tr>
<tr>
<td>HD 720p</td>
<td>HDTV</td>
<td>1280 × 720</td>
<td>16:9</td>
<td>progressive 59.94 FPS</td>
</tr>
<tr>
<td>HD 1080i</td>
<td>HDTV</td>
<td>1920 × 1080</td>
<td>16:9</td>
<td>interlaced 29.97 FPS (59.94 fields/sec)</td>
</tr>
<tr>
<td>HD 1080p</td>
<td>HDTV</td>
<td>1920 × 1080</td>
<td>16:9</td>
<td>progressive 59.94 FPS</td>
</tr>
</tbody>
</table>
Video compression process

For SD NTSC: Required bit rate:
720 X 526 X 30 X 3 X 8 = 272678400b/s
Compression is needed!

Video compression relies on:
1. The eye's inability to resolve high frequency color changes.
2. The fact that there's a lot of redundancy within each frame (Intra) and between frames (Inter).
### Example average bit rates. Actual bit rates will vary from encoder to encoder and sequence to sequence.

<table>
<thead>
<tr>
<th></th>
<th>MPEG2</th>
<th>H.264</th>
<th>HEVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>480i30</td>
<td>3.7 Mbps</td>
<td>2 Mbps</td>
<td>1 Mbps</td>
</tr>
<tr>
<td>720p30</td>
<td>6 Mbps</td>
<td>3 Mbps</td>
<td>1.5 Mbps</td>
</tr>
<tr>
<td>720p60 (or 1080i60)</td>
<td>12 Mbps</td>
<td>6 Mbps</td>
<td>3 Mbps</td>
</tr>
<tr>
<td>1080p60</td>
<td>20 Mbps</td>
<td>10 Mbps</td>
<td>5 Mbps</td>
</tr>
<tr>
<td>4Kx2Kp60</td>
<td>80 Mbps</td>
<td>40 Mbps</td>
<td>20 Mbps</td>
</tr>
<tr>
<td>8Kx4Kp60</td>
<td>320 Mbps</td>
<td>160 Mbps</td>
<td>40-80 Mbps</td>
</tr>
<tr>
<td>8Kx4Kp120</td>
<td>640 Mbps</td>
<td>320 Mbps</td>
<td>80-160 Mbps</td>
</tr>
</tbody>
</table>

**Streaming Video**

**UHD TV**
High Speed Data
# The History of DOCSIS

<table>
<thead>
<tr>
<th>DOCSIS 1.0</th>
<th>March 1997</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Beginning of Data Over Cable System Interface Specification (DOCSIS)</td>
<td></td>
</tr>
<tr>
<td>• Defined support for High-speed Data over HFC</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DOCSIS 1.1</th>
<th>April 1999</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Adds state of the art QoS techniques for priority services (e.g. VoIP)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DOCSIS 2.0</th>
<th>December 2001</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Increased upstream modulation format for more b/s/Hz</td>
<td></td>
</tr>
<tr>
<td>• Added a new PHY for the upstream SCDMA</td>
<td></td>
</tr>
<tr>
<td>• Defined a state of the art advanced MAC (even to this day)</td>
<td></td>
</tr>
<tr>
<td>• Enabled two (2) dimensional upstream bandwidth allocation and/or simultaneous transmission within the same channel for QoS and QoE.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DOCSIS 3.0</th>
<th>August 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Added IPv6 &amp; Multicast QoS</td>
<td></td>
</tr>
<tr>
<td>• Expanded 2D upstream scheduling now across multiple channels</td>
<td></td>
</tr>
<tr>
<td>• Increases data capacity with channel bonding similar to other technologies</td>
<td></td>
</tr>
<tr>
<td>• Kept PHY Layer Modulation Formats &amp; Old FEC (DOCSIS 3.0 Speed Limit)</td>
<td></td>
</tr>
</tbody>
</table>

It’s Time to Modernize the PHY Layer & Spectrum Plan ~ DOCSIS 3.1

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**DOCSIS 3.0 Technology**
- Places Limits on b/s/Hz over Existing HFC

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DOCSIS 3.1 in a Nutshell

- **Define New Cable Spectrum Band Plan**
  - Downstream may extend to 54 - 1218 MHz or up to 1.7 GHz (D3.0 defines 54 - 1 GHz)
  - Upstream may extend to 5 - 204 MHz (D3.0 defines 5-85 MHz)

- **Modernizes DOCSIS to Increase Spectral Capacity**
  - Adds Downstream Orthogonal Frequency-Division Multiplexing (OFDM)
  - Adds Upstream Orthogonal Frequency-Division Multiple Access (OFDMA)
  - Adds New Error Correction technology
    - Low-density parity-check (LDPC) codes (inner FEC) and Bose-Chaudhuri-Hocquenghem (BCH) codes (outer FEC)
    - Enables More Spectrum capacity compared to legacy DOCSIS in similar SNR/MER
  - Adds Multiple Modulation Profiles (MMP)
    - Allowing Groups of customers to operate at highest capacity
  - Expands Modulation Formats to enable more spectrum capacity
    - Downstream up to 16384 QAM and Upstream up to 4096 QAM

- **Maintains Backward Compatibility (as opposed to Coexistence)**
  - Enables “1” DOCSIS MAC and channel bonding across Legacy PHYs and New PHYs to enable “1” network
  - DOCSIS 3.1 CMTS/CCAP and Cable Modems may operate in Legacy Mode, Mixed Mode, or D3.1 Only mode
  - Avoids the Spectrum Tax (does not allocate dedicated spectrum just for old PHYs and just for new PHYs)

- **Data Rate Capacity Increases**
  - The Maximum Data Capacity is Unbounded and depends on spectrum allocation
  - May enable ~10 Gbps downstream capacity (spectrum and CNR dependent)
  - May enable ~1.5+ Gbps upstream capacity (spectrum and CNR dependent)
Key DOCSIS 3.1 Technologies – OFDM, OFDMA

• OFDM –
  – Orthogonal Freq Division Multiplexing
  – Widely adopted; large pool of expertise
  – Enables extra wide channels:
    • **24 – 192 MHz** DS, 6.4 – 96 MHz US

• OFDM is Very Robust – Adapts to plant conditions
  – Operate in Roll-off regions!!!
  – E.g. operate OFDM channel to 800 or 900+ MHz on a 750 MHz plant
Modernized RF Data Technology “DOCSIS 3.1”

- Adds modern and efficient error correction technology
  - Pushes us ever closer to Shannon’s Limit
  - Outer FEC: Bose-Chaudhuri-Hocquenghem (BCH)
  - Inner FEC: Low-density parity-check (LDPC)
  - Allows higher order modulation format in same SNR
  - One (1) mod format order increase against J.83 B (Downstream)
  - Two (2) order increase against J.83 A (Down) and A-TDMA (Up)

- Expands Modulation Formats
  - Downstream 4096 QAM (12 bits per symbol) up to 16384 QAM
  - Upstream Recommendation 4096 QAM

DOCSIS 3.1 Will Increase Spectrum Capacity (b/s/Hz)

Note: The dB values for each modulation format DOCSIS 3.1 Specification Value and an ARRIS Noise Margin Number in CNR at the RF connector of the DOCSIS 3.1 Modem

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# Bandwidth Capacity Potential of DOCSIS (with New D3.1 Technologies)

## Downstream (DS) PHY Capacity

<table>
<thead>
<tr>
<th>DS Range (MHz)</th>
<th>D3.0 in 2012</th>
<th>Next D3.0 Phase</th>
<th>D3.1 DS Day 1</th>
<th>D3.1 DS Gen 2 – Full Spectrum</th>
</tr>
</thead>
<tbody>
<tr>
<td>54 - 1002</td>
<td>108 - 1002</td>
<td>108 - 1218</td>
<td>258 - 1218</td>
<td></td>
</tr>
<tr>
<td>DS QAM Level</td>
<td>256-QAM</td>
<td>4096-QAM (up to 16384-QAM if possible)</td>
<td></td>
<td></td>
</tr>
<tr>
<td># DS Channels</td>
<td>8</td>
<td>24 - 32</td>
<td>24-32 + 2x192</td>
<td>6x192 5x192</td>
</tr>
<tr>
<td>CPE DS Capacity</td>
<td>300 Mbps</td>
<td>~1 Gbps</td>
<td>~5 Gbps</td>
<td>10+ Gbps 9+ Gbps</td>
</tr>
</tbody>
</table>

## Upstream (US) PHY Capacity

<table>
<thead>
<tr>
<th>US Range (MHz)</th>
<th>D3.1 US Day 1 – 8x6.4 + 2x96</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 - 42</td>
<td>5 - 42 12 - 204</td>
</tr>
<tr>
<td>US QAM Level</td>
<td>To 64-QAM 1024-QAM to 4096-QAM</td>
</tr>
<tr>
<td># US Channels</td>
<td>4 8 4x6.4, 1x37 8x6.4, 1x70 8x6.4, 2x96</td>
</tr>
<tr>
<td>CPE US Capacity</td>
<td>~100 Mbps ~200 Mbps ~250 Mbps ~600 Mbps</td>
</tr>
</tbody>
</table>
DOCSIS 3.1 Summaries

• DOCSIS 3.1 Tool Box to Maximize Capacity b/s/Hz:
  – Modern FEC
  – Higher Order Modulation
  – Multiple Modulation Profiles
  – Backward Compatibility (to avoid the “spectrum tax”)

• DOCSIS 3.1 Will Increase Spectrum Capacity (b/s/Hz)

• Coax to the Home will Compete with Fiber to the Home!!!!
Thank You

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