DOCSIS® 3.0
A CPE's Perspective

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Agenda

Progression of DOCSIS Technology
DOCSIS 3.0 Overview
Bonding Environment
Cable Modem in a DOCSIS 3.0 Environment
End-User Considerations

Progression of DOCSIS Technology

Progression of DOCSIS Technology

DOCSIS 1.0

- Telco Return
- 2-Way Technology
- Class of Service
- BPI

DOCSIS 1.1

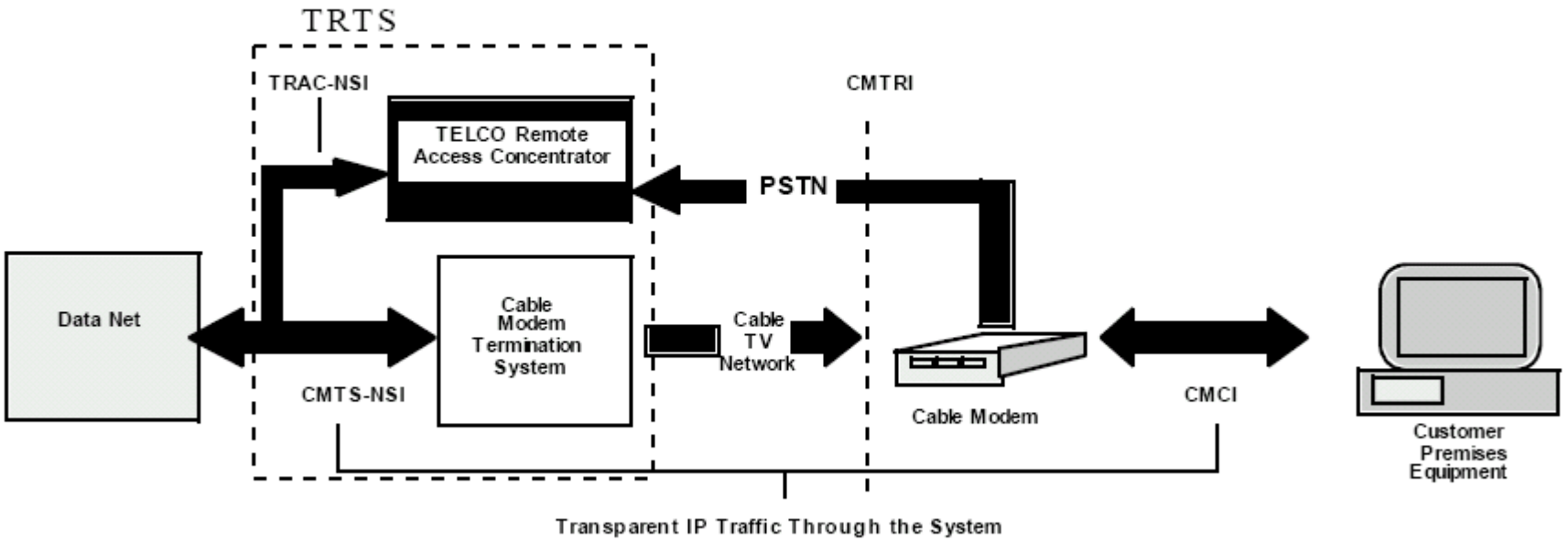
- Quality of Service - Service Flows and Classifiers
- BPI+

DOCSIS 2.0

- ATDMA - SCDMA

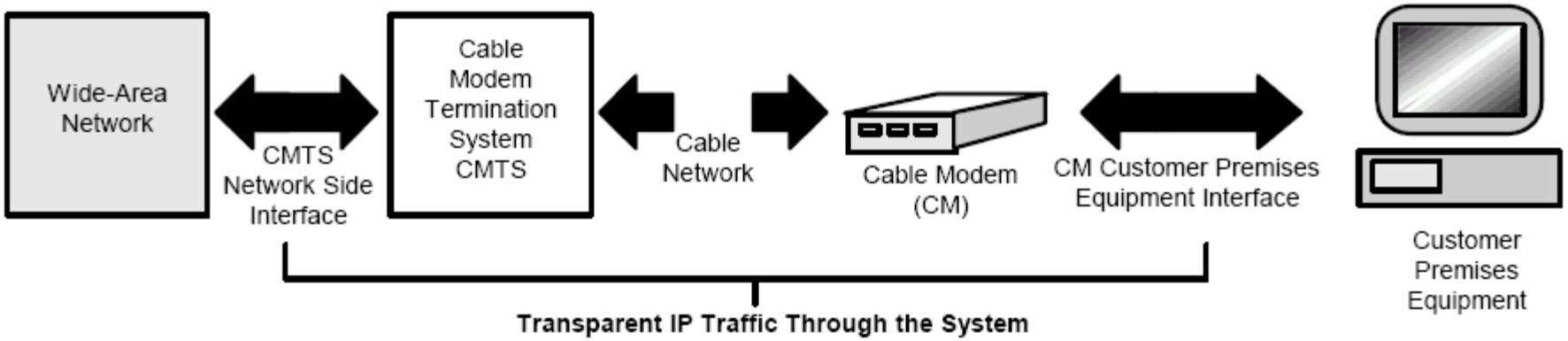
Progression of DOCSIS Technology continued..

DOCSIS 1.0 – Telco Return



Progression of DOCSIS Technology continued..

DOCSIS 1.0 – 2- Way



Progression of DOCSIS Technology continued..

DOCSIS 1.0 - Downstream

Modulation Type: 64-QAM or 256-QAM
Maximum Data Rate: 27 Mbps at 64-QAM, 38 Mbps at 256-QAM
Bandwidth: 6 MHz channel
Frequency Range: 88 - 860 MHz
Transport Protocol: MPEG-2
Carrier to noise ratio (Es/No) of:
23.5 dB for 64-QAM
30 dB for 256-QAM

Progression of DOCSIS Technology continued..

DOCSIS 1.0 – Upstream

- Upstream Time Sharing (TDMA)
- Variable RF bandwidth and modulation.
  - 200 kHz, 400 kHz, 800 kHz, 1600 kHz, and 3200 kHz
  - QPSK (Quadrature Phase Shift Key) or 16 QAM (Quadrature Amplitude Modulation)
- Frequency Range
  - 5 to 42 MHz (Edge to Edge)
- RF Performance requirements
  - CNR -- Not less than 25 dB
- 320 Kbps (QPSK 200 kHz) to 10.24 Mbps (16QAM 3200 kHz)

Progression of DOCSIS Technology continued..

DOCSIS 1.0 - Capabilities

- Service capabilities defined using Class of Service Settings (CoS)
  - Shared Bandwidth – Best Effort
- Single SID capabilities
  - No mapping of traffic to a specific downstream/upstream flow
- RF Encryption using BPI (no authentication of CMs)
- Single Downstream 64QAM or 256QAM
- Single Upstream QPSK or 16QAM

Progression of DOCSIS Technology continued..

DOCSIS 1.1 – Capabilities

- Packet Classification, based on fields in the Ethernet, IP, and UDP/TCP headers, into a Service Flow
- Service Flow association with a DOCSIS Service Identifier
- QoS MIB's
- Fragmentation
- Concatenation
- Payload Header Suppression (for increased bandwidth efficiency, particularly in the case of relatively small Voice-over-IP [VoIP] packets)
- Priority Queuing (e.g. Weighted Fair Queuing) at the CMTS
- BPI+ (Base Line Privacy - Plus)
- Single Downstream 64QAM or 256QAM
- Single Upstream QPSK or 16QAM

Progression of DOCSIS Technology continued..

DOCSIS 2.0 - Upstream

Physical Layer change only
Single Downstream 64QAM or 256QAM
Single Upstream
QPSK, 16QAM, 32QAM (A-TDMA), 64QAM (A-TDMA), SCDMA
320 Kbps (QPSK 200 kHz) to 30 Mbps (64QAM 6400 kHz)

TDMA:
+8 to +54 dBmV (32QAM, 64QAM)
+8 to +55 dBmV (8QAM, 16QAM)
+8 to +58 dBmV (QPSK)
SCDMA
+8 to +53 dBmV (all modulations)
MER values (transmit EQ off):
MER >= 30 dB over 15 to 30 MHz carrier frequency
MER >= 27 dB over 10 MHz to 15 MHz and 30 MHz to 35 MHz carrier frequency
MER >= 23 dB over 5 MHz to 10 MHz and 35 MHz to 42 MHz carrier frequency
MER values (transmit EQ on):
TDMA/QPSK, MER >= 30 dB
S-CDMA and all TDMA modulations except QPSK, MER >= 35 dB

Progression of DOCSIS Technology continued..

DOCSIS 2.0 – Upstream ATDMA

ATDMA is the most logical progression from the DOCSIS 1.X TDMA. ATDMA offers the following technology enhancements:

- **EXTENDED EQUALIZER – 24-TAPS**
- **PER BURST EQUALIZATION (POST EQ.) – Though not officially part of the DOCSIS 2.0 Standard**
- **Ingress Noise Cancellation - though not officially part of DOCSIS 2.0 Standard**
- **Higher Modulation Rate or Symbol Rate – MAX Symbol Rate = 5120 ksym/s (BW = 6.4 MHz) – Throughput can doubled**
- **Higher QAM Constellations – ATDMA supports up to 64-QAM with any DOCSIS 2.0 Cable Modem**

Progression of DOCSIS Technology continued..

DOCSIS 2.0 – Upstream SCDMA

SCDMA by definition is a different animal than DOCSIS 1.X. Therefore, when SCDMA is operational, the scheduler must play Traffic COP (i.e. allowing SCDMA to transmit numerous contiguous MINI-SLOTS and then let TDMA or ATDMA operate.

SCDMA offers the following technology enhancements:

- **EXTENDED EQUALIZER – 24-TAPS**
- **Higher Modulation Rate or Symbol Rate – MAX Symbol Rate = 5120 ksym/s (BW = 6.4 MHz) – Throughput can be doubled**
- **Even Higher QAM Constellations – supports up to 64-QAM Un-coded & *128-QAM Trellis-Coded Modulation (TCM)* - Up to 30.72 Mbit/s**

DOCSIS 3.0 Overview

DOCSIS 3.0 Overview

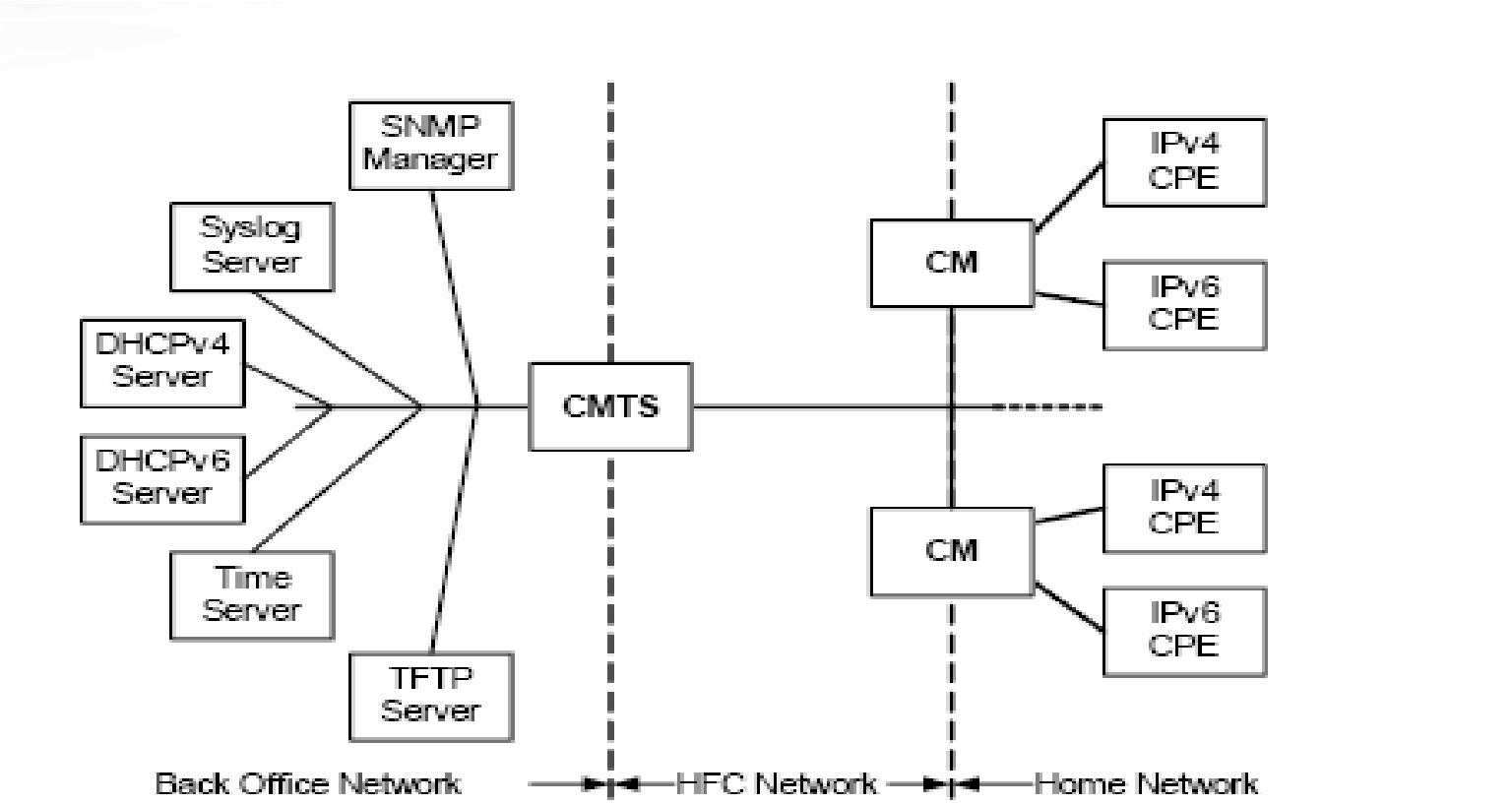
IPv6

Multicast

Security

Channel Bonding

DOCSIS with IPv4/IPv6



DOCSIS 3.0 introduces built-in support for the Internet Protocol version 6. DOCSIS 3.0 CMs can be provisioned with an IPv4 management address, an IPv6 management address, or both. Further, DOCSIS 3.0 CMs can provide transparent IPv6 connectivity to devices behind the cable modem (CPEs), with full support for Quality of Service and filtering.

DOCSIS 3.0 Security

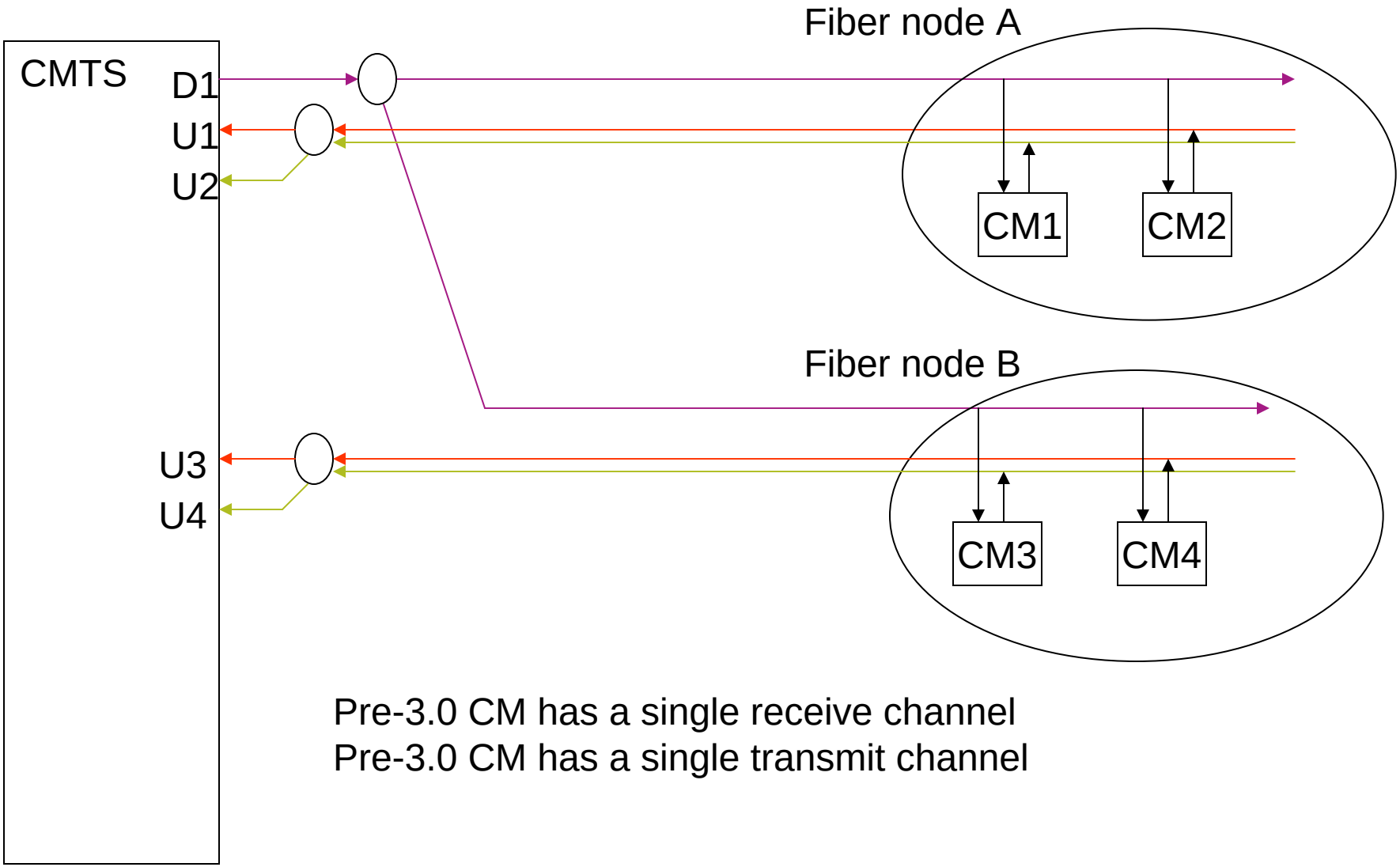
Advanced Encryption Standard (AES)

- DOCSIS 3.0 adds new traffic encryption algorithm (128-bit AES with 128-bit keys).
- The key management protocol (Baseline Privacy Key Management, or “BPKM”) still provides secure distribution of keying data from CMTS to CMs.

Early Authentication and Encryption (EAE)

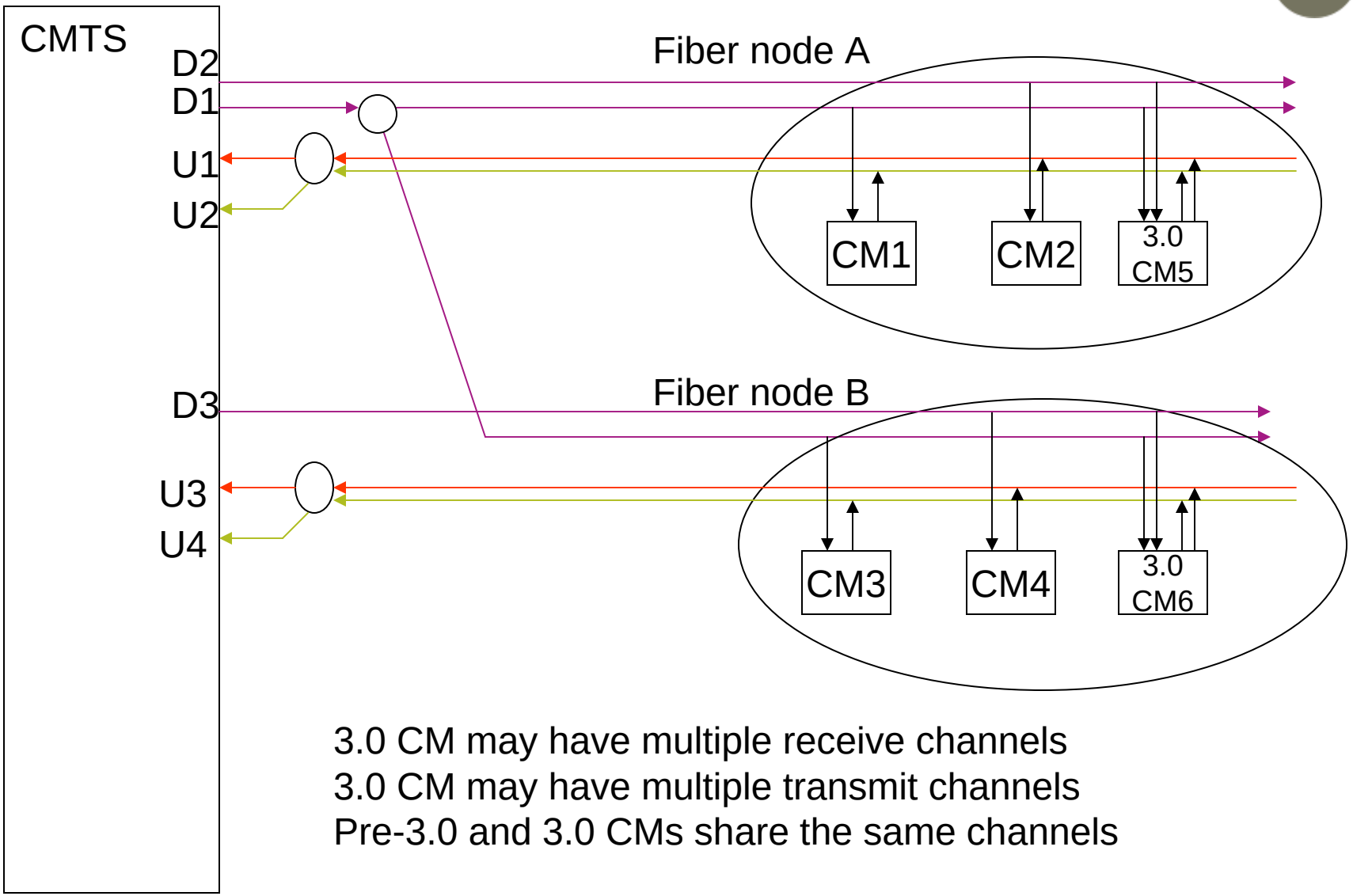
- BPI+ initialization takes place after downstream and upstream acquisition has completed but before the Provisioning process (DHCP, ToD, TFTP, Registration) has initiated.

CM Single Channels



Pre-3.0 CM has a single receive channel
Pre-3.0 CM has a single transmit channel

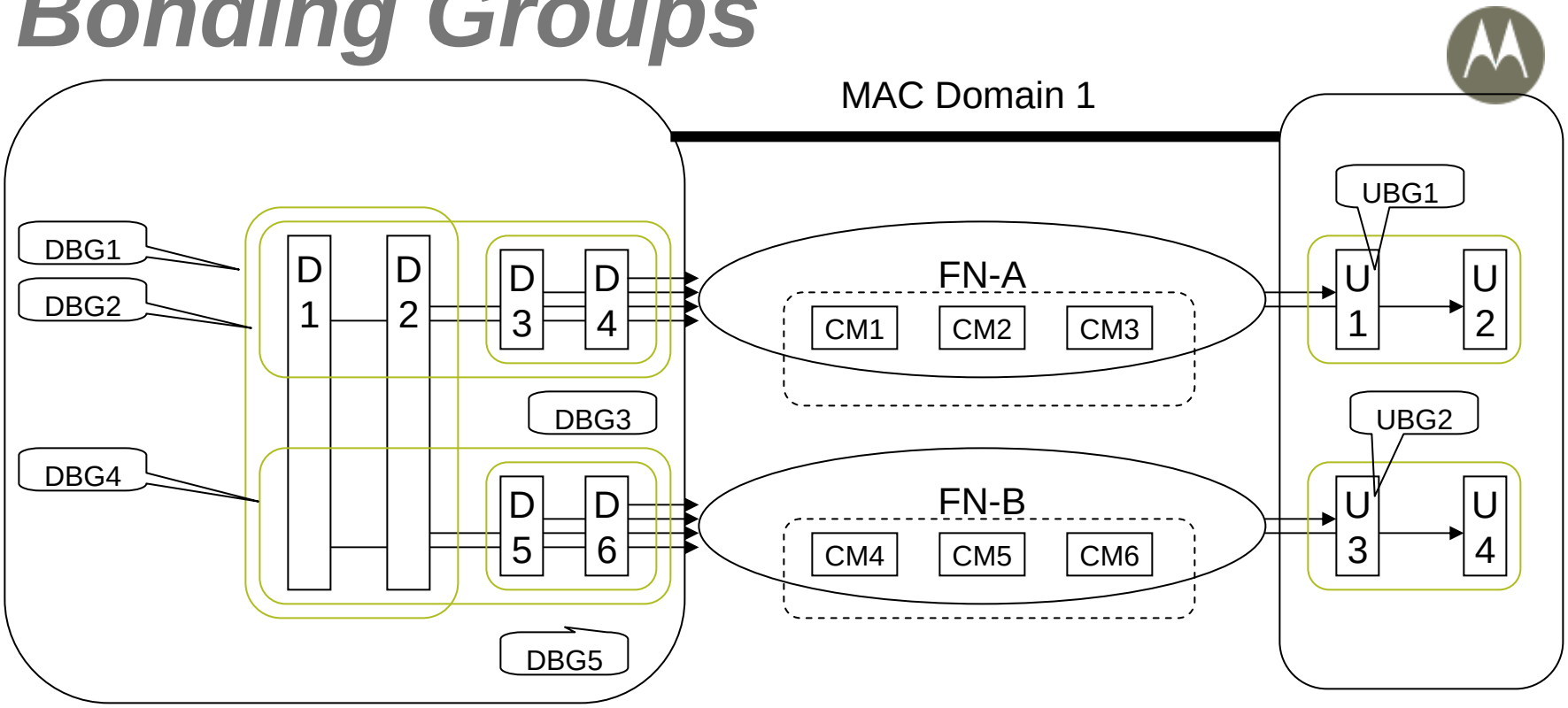
3.0 CM Multiple Channels



3.0 CM may have multiple receive channels
3.0 CM may have multiple transmit channels
Pre-3.0 and 3.0 CMs share the same channels

Bonding Environment

Bonding Groups



A downstream bonding group (DBG) is a set of channels on which the CMTS distributes a sequence of packets to a set of CMs.

An upstream bonding group (UBG) is the set of channels on which the CMTS schedules a sequence of upstream segments on a SID cluster.

A cable modem service group (CM-SG) refers to the complete set of downstream and upstream channels within a single CMTS that a single CM can receive and transmit on.

MDD message introduced - MAC Domain Descriptor Message

Channel Bonding

Downstream Channel Bonding

In order to provide peak downstream data rates in excess of 100Mbps to customers, while maintaining interoperability with legacy CMs, DOCSIS 3.0 introduces a mechanism by which the CMTS dynamically distributes downstream packets over a set of downstream channels for delivery to a single CM.

The term "downstream channel bonding" means the distribution of packets from the same service flow over different downstream channels.

Determining the Downstream Bandwidth

	DOCSIS (256QAM)	Euro-DOCSIS (256QAM)
RAW BW	42,884,296	55,616,000
After FEC & MPEG*	37,778,501	49,890,823
3 – Channel BG*	113,335,502	149,672,468
4 – Channel BG*	151,114,004	199,563,291
5% DOCSIS OH	35,889,575	47,396,281
3 – Channel BG	107,668,725	142,188,843
4 – Channel BG	143,558,300	189,585,124

*** Does not includes DOCSIS MAC messages overhead**

Channel Bonding

Downstream Channel Bonding cont ..

- Each packet is tagged with a sequence number so that proper data sequencing is not lost if there are differences in latency between the channels in the set.

- The CM, in turn, has multiple receivers and is tuned to receive all of the channels in the set. The CM re-sequences the downstream data stream to restore the original packet sequence before forwarding the packets to its CPE port(s).

Channel Bonding

Downstream Channel Bonding cont ..

- Primary Capable Channel
  - Carries SYNC messages and the UCD and MAP messages for at least one associated upstream.
  - Can be utilized by any DOCSIS modem for registration purposes.
  - A DOCSIS 3.0 modem must choose a primary capable downstream for timing purposes.

Channel Bonding

Downstream Channel Bonding cont ..

Non-Primary Capable Channel

Also called “secondary” channels. SYNC messages are not present. MAPs, UCDs, and MDDs are.

CMs can not register on Non-primary channels.

A downstream channel that is a member of a bonding group that does not have upstreams bound to it.

Channel Bonding

Upstream Channel Bonding

The Cable Operators have stated an objective of 100Mbps upstream throughput from a single user or group of users. Given the current impracticality of using very high orders of modulation (e.g., 1024-QAM) and wider channels in the upstream, the only way to achieve the desired throughput using cable is to allow a user to transmit on multiple upstream channels simultaneously.

Smaller bandwidth upstream channels can be bonded together to create a larger bandwidth pipe.

Channel Bonding

Upstream Channel Bonding cont ..

The actual bonding process is controlled by the CMTS as part of the scheduling process via grants. The CM makes a request for bandwidth for a given service flow on one of the service flow's associated upstream channels. The CMTS then chooses whether to grant the request on one or more of the channels associated with that service flow. The CMTS is responsible for allocating the bandwidth across the individual upstream channels.

This mechanism for upstream channel bonding requires that the upstream channels be synchronized to a master clock source. No other requirements are placed on the physical layer parameters of any of the channels within the Upstream Bonding Group. The individual channels can be any mix of modulation types, symbol rates.

Channel Bonding

DOCSIS 3.0 – Downstream RF Requirements

Table 6–22 - Electrical Input to CM[45]

Parameter	Value
Center Frequency of DOCSIS channel	111 to 867 MHz ±30 kHz, CM MAY tune 111 to 999 MHZ ± 30 KHz
Level Range (one DOCSIS channel)	-15 dBmV to +15 dBmV
Modulation Type	64-QAM and 256-QAM
Symbol Rate (nominal)	5.056941 Msym/s (64-QAM) and 5.360537 Msym/s (256-QAM)
Bandwidth	6 MHz (alpha = 0.18 Square Root Raised Cosine shaping for 64-QAM and alpha = 0.12 Square Root Raised Cosine shaping for 256-QAM)
Total Input Power (40 MHz and above)	< 33 dBmV
Maximum average power of carrier input to CM, within any 6 MHz channel from 54 MHz up to 1002 MHz	X = average power of lowest power demodulated QAM channel Channels demodulated within the CM: ≤ Min (X + 10 dB, +15 dBmV). Non-demodulated 6 MHz bands within the CM a) ≤ Min (X + 10 dB, +20 dBmV), for zero, one, or two 6 MHz bands. b) ≤ Min (X + 10 dB, +15 dBmV), for all other 6 MHz bands besides the two possible allocated exceptions[46]
Input (load) Impedance	75 ohms
Input Return Loss	> 6 dB (across the selected upstream frequency range 5-42 MHz or 5-85 MHz).

Channel Bonding

DOCSIS 3.0 – Upstream RF Requirements

Table 6–21 - Electrical Output from CM[40]

Parameter	Value
Frequency	5 to 42 MHz edge to edge The following option MAY be provided: Mode Selection Option: Mode 1: 5 to 42 MHz edge to edge Mode 2: 5 to 85 MHz edge to edge
Level range per channel (Multiple Transmit Channel mode disabled, or only Multiple Transmit Channel mode enabled with one channel in the TCS)	TDMA: P_{min} to +57 dBmV (32-QAM, 64-QAM) P_{min} to +58 dBmV (8-QAM, 16-QAM) P_{min} to +61 dBmV (QPSK) S-CDMA: P_{min} to +56 dBmV (all modulations) where P_{min} = +17 dBmV, 1280 kHz modulation rate P_{min} = +20 dBmV, 2560 kHz modulation rate P_{min} = +23 dBmV, 5120 kHz modulation rate

Channel Bonding

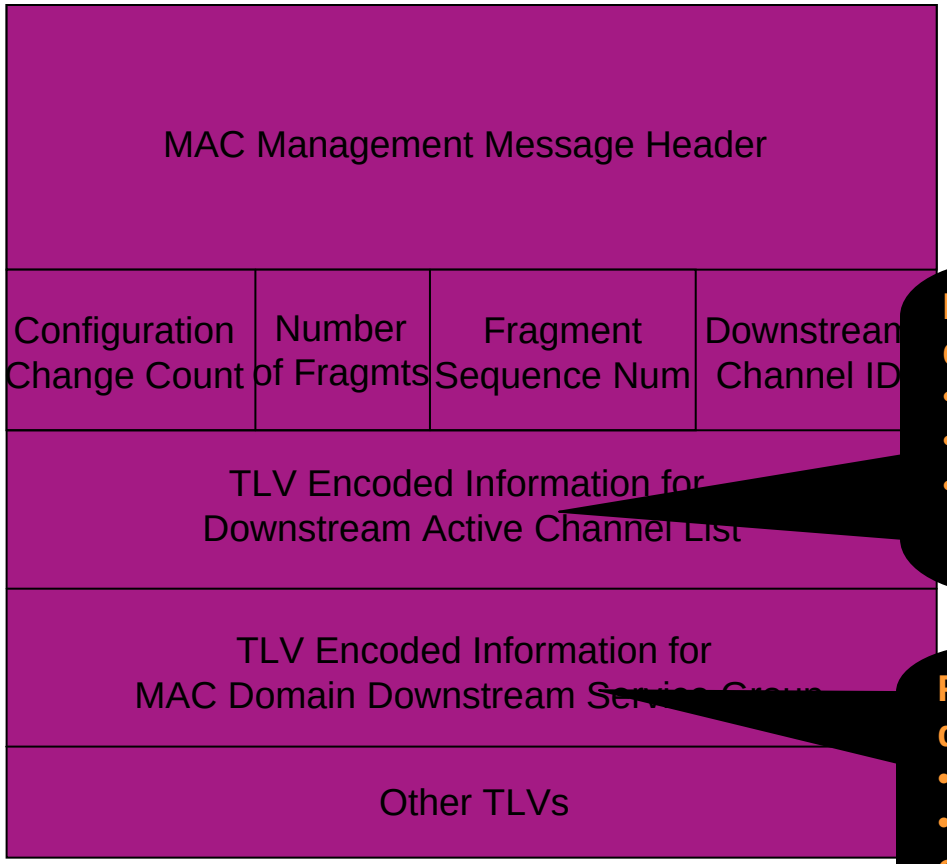
DOCSIS 3.0 – Upstream RF Requirements cont..

Parameter	Value
Level range per channel (two channels in the TCS)	TDMA: P_{min} to +54 dBmV (32-QAM, 64-QAM) P_{min} to +55 dBmV (8-QAM, 16-QAM) P_{min} to +58 dBmV (QPSK) S-CDMA: P_{min} to +53 dBmV (all modulations) where P_{min} = +17 dBmV, 1280 kHz modulation rate P_{min} = +20 dBmV, 2560 kHz modulation rate P_{min} = +23 dBmV, 5120 kHz modulation rate
Level range per channel (three or four channels in the TCS)	TDMA: P_{min} to +51 dBmV (32-QAM, 64-QAM) P_{min} to +52 dBmV (8-QAM, 16-QAM) P_{min} to +55 dBmV (QPSK) S-CDMA: P_{min} to +53 dBmV (all modulations) where P_{min} = +17 dBmV, 1280 kHz modulation rate P_{min} = +20 dBmV, 2560 kHz modulation rate P_{min} = +23 dBmV, 5120 kHz modulation rate
Modulation Type	QPSK, 8-QAM, 16-QAM, 32-QAM, 64-QAM, and 128-QAM

Channel Bonding

MAC Domain Descriptor Message (MDD)

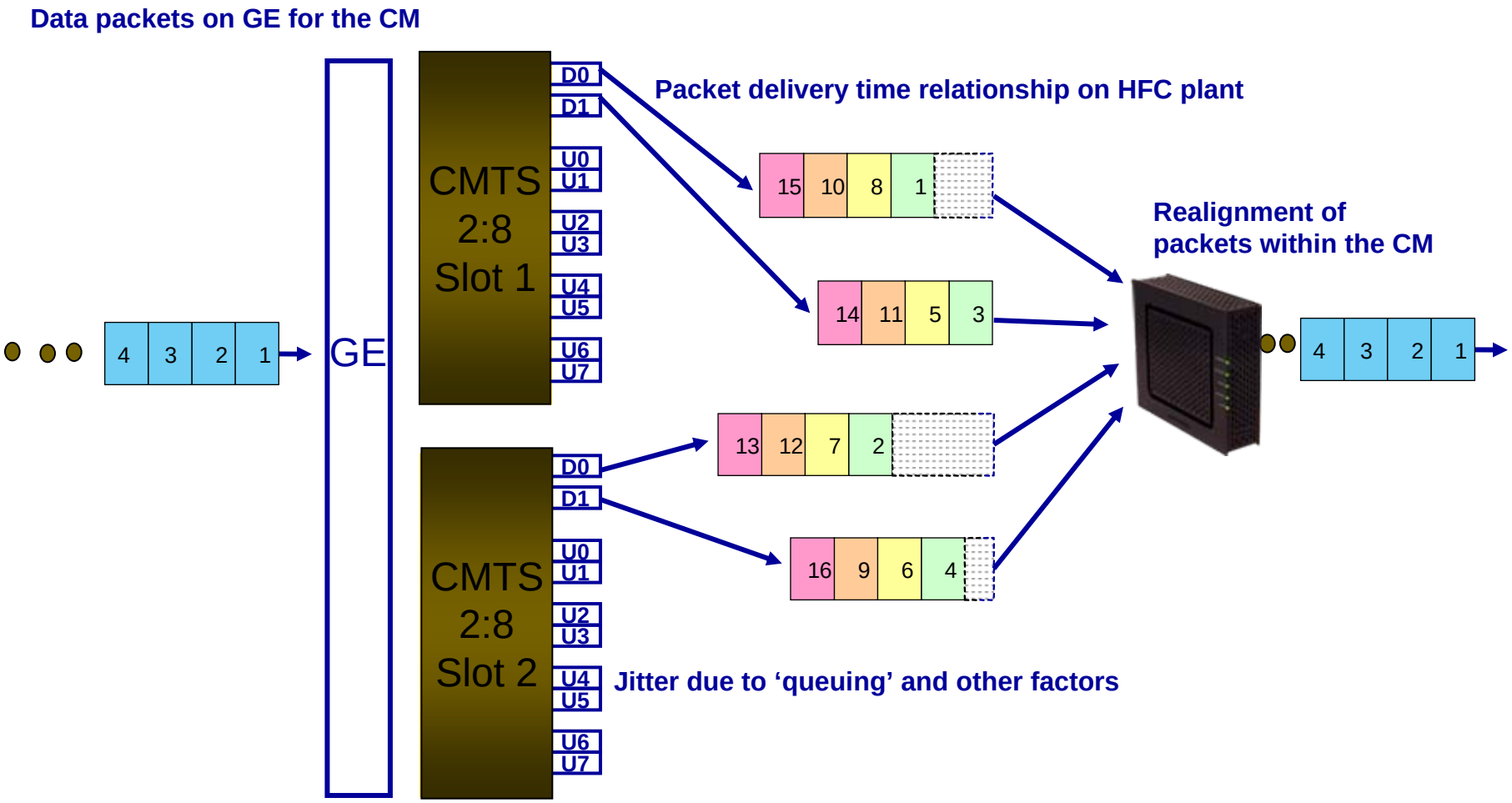
Message advertises topology initialization parameters
Sent periodically on every downstream channel in the MAC domain.



For each channel being defined in the MAC Domain:
- **Downstream channel ID**
- **Frequency**
- **Modulation and annex (ex: 256QAM/Annex B)**

For each channel being defined in the MAC Domain:
- **MD-DS-SG ID**
- **ID of other DS that are part of this MD-DS-SG**

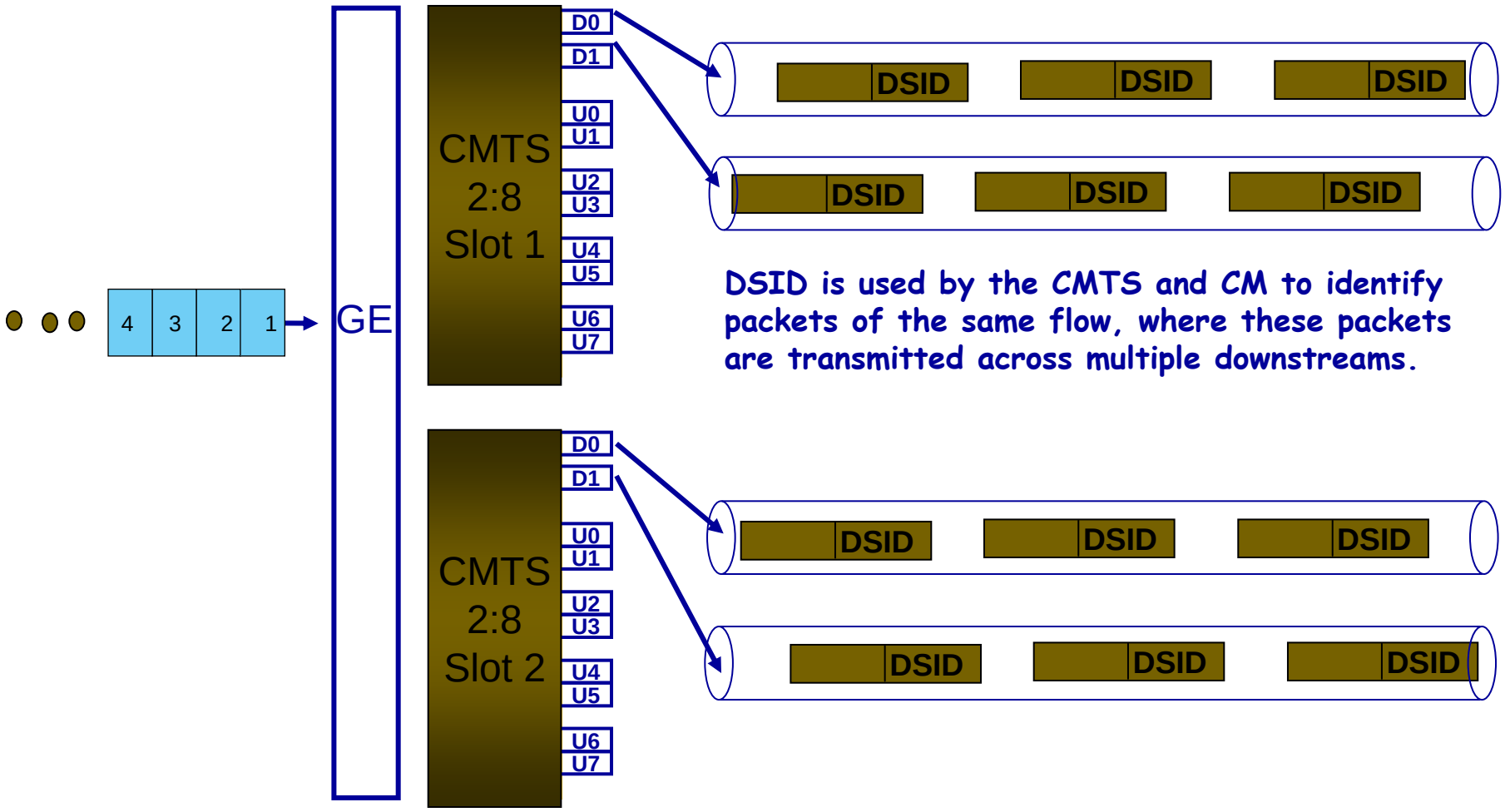
Channel Bonding Packet Transmission



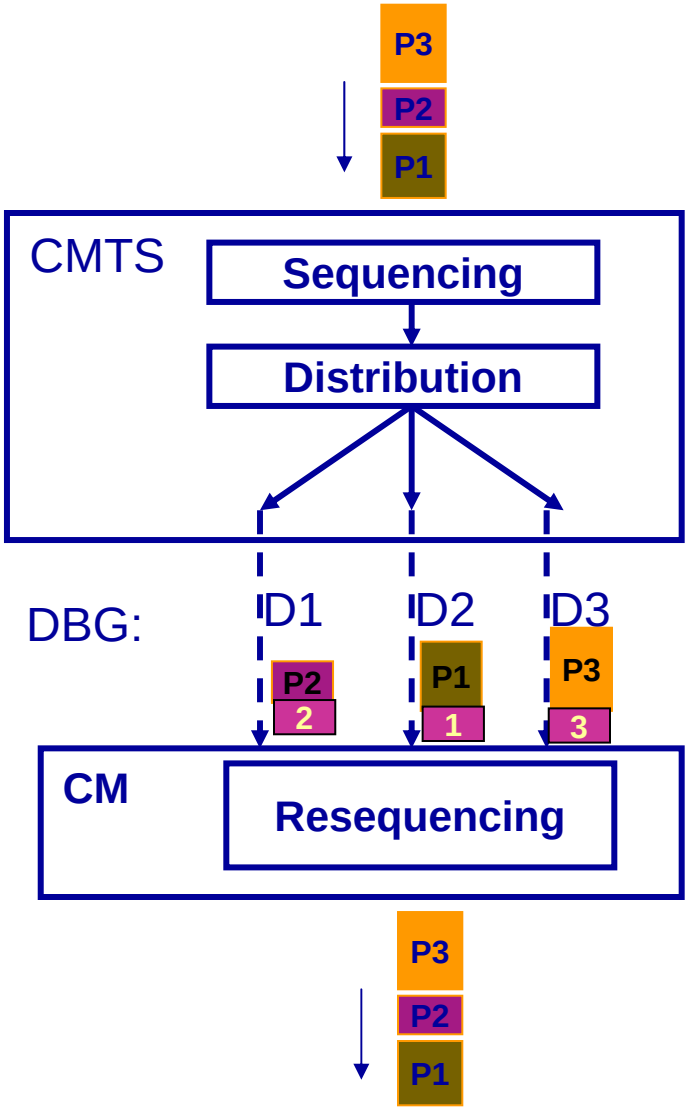
DSID

- **DSID is a 20-bit value in a DOCSIS extended header that identifies a stream of packets distributed to the same cable modem or group of cable modems**
- **DSID is unique per MAC Domain**
- **DSID can represent:**
  - One or more Service Flows to a single CM
  - All Service Flows to a CM
  - A IP Multicast Session to multiple CMs
- **Sequence Number may or may not be present**
  - Bonded HSD – *present*
  - Bonded or Non-Bonded Voice – *not present*
  - Non-Bonded Multicast – *not present*

Downstream Service Identifier (DSID)



Sequence Number



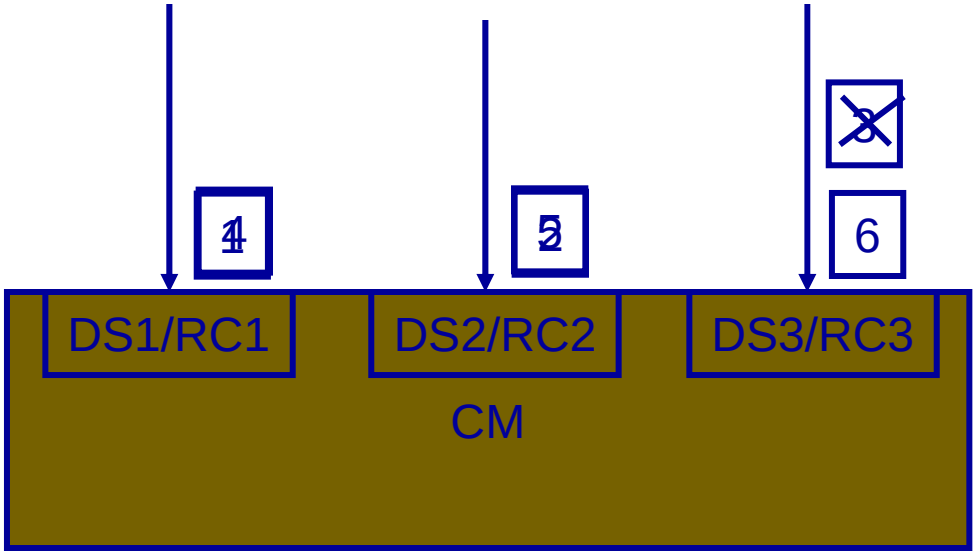
- The CMTS marks HSD bonded packets with a packet *"sequence number"*
- The CMTS distributes a stream of downstream packets to a set of channels; "Bonding Group" (BG)
- Bonded packets may arrive at the CM out of sequence order

- The CM "resequences" bonded packets and transmits them in packet sequence order.

Sequence Number

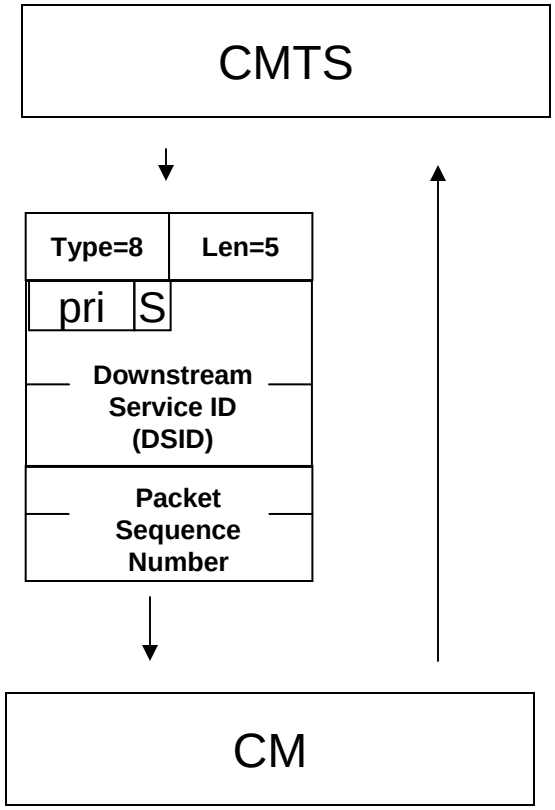
- **Bonded packets will be given a sequence number (in the extended header) by the scheduler**
  - **There are exception to this rule – voice packets**
- **Within any *single* downstream the packets will be transmitted in order**
- **Due to queuing delays for each DS channels, packets may arrive *out of order* at the CM**
- **CM must be able to collect and re-order packets**
- **Limit on how long a CM must buffer packets**
- **Packet sequence counter maintained by the CM and CMTS**

Rapid Packet Loss Detection



- **The CMTS MUST transmit packets for the same DSID in increasing order on a downstream channel.**
- **As soon as the CM receives sequence number 6 on RC3, it knows that 3 has been lost.**
- **The CM doesn't wait for a "resequencing wait" time.**

Sequence Number Management



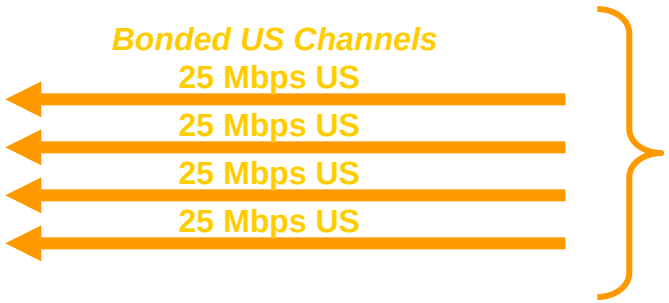
- **CM reports "Sequence Out of Range" errors to the CMTS if enabled as a "CM-STATUS" event.**
  - **M-CMTS architecture can cause *arbitrary loss of sequence numbers by the CM* during a CIN component reset.**
  - **Sequence Out of Range CM_STATUS event is the *only means* by which the CMTS can detect and correct this condition.**
- **A 1-bit "Sequence Change Count" (S) field in the 5-byte DS-EHDR identifies a "number space" of packet sequence numbers for the same DSID.**
- **CMTS changes Sequence Change Count to force CMs to restart sequencing.**
  - **E.g.: CMTS restarts sequencing after a redundancy switchover**
  - **E.g.: after "sequence out of range" errors.**

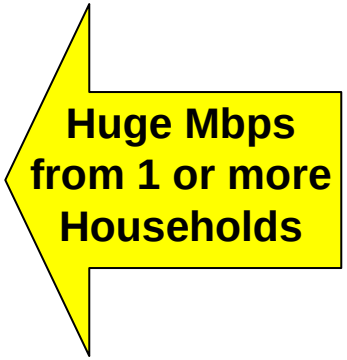
Why Upstream Bonding?

- **Downstream throughput depends on upstream throughput**
  - **Based on the amount of ACK Suppression being done**
- **Current and future applications will require increased upstream bandwidth**
  - **Uploading of Digital Pictures (Stills & Videos)**
  - **More Complex Gaming**
  - **SOHO**

High-US Bandwidth via Channel Bonding

- **Channel Bonding**
  - **Will allow bonding of multiple RF US Channels together**
    - **Huge Bandwidth Increases**
  - **Same US Module and Physical Port supports both Channel Bonding & Legacy CM**
  - **Statistical Multiplexing gain over a Single Channel equals more users and bandwidth**
    - **Real-time load balancing across upstream channels without moving CM upstreams**





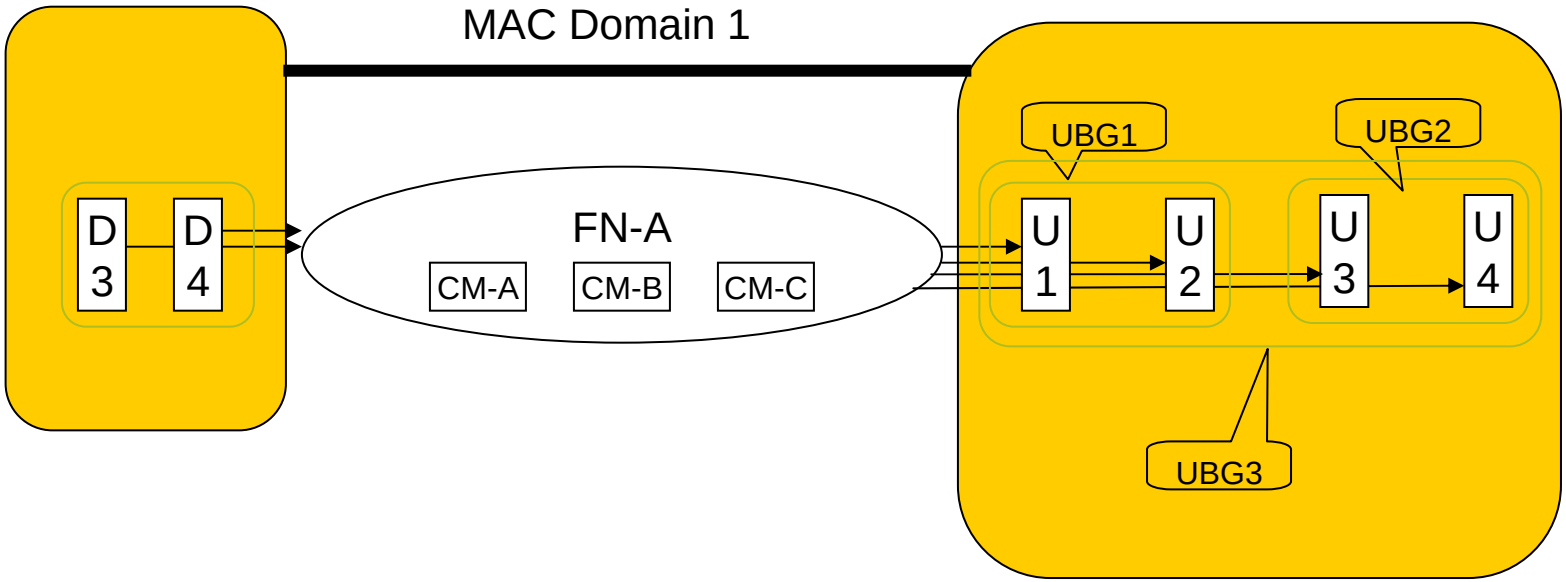
Design Goals

- **Backward compatible with DOCSIS 1.x and DOCSIS 2.0 CMs**
  - **On the same physical channel**
- **A single D3.0 CM must be able to reach 100Mbps upstream rate**
- **Upstream channels anywhere in the upstream spectrum**
  - **Do not have to be adjacent**
  - **Do not have to be within a specific range**
- **No restriction on channel configurations**
  - **Different channels can have different modulation, channel width, etc.**
- **CMTS must remain in complete control of assigning bandwidth allocation**
  - **No restriction to where grants are placed on the individual channels**

Upstream Bonding Terminology

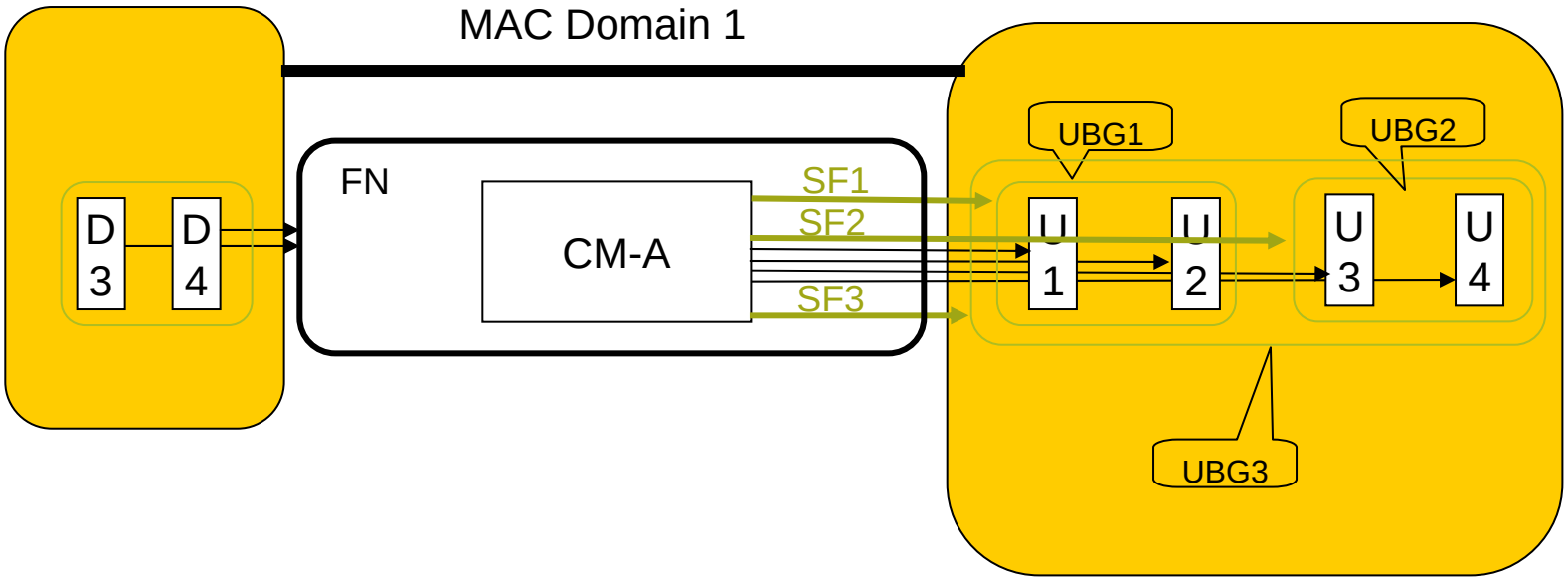
- ***Transmit Channel Set (TCS)*** **- One or more upstream channels that the CM maintains active ranging on**
  - **Assigned at registration**
  - **Can be changed by Dynamic Bonding Change (DBC)**
- ***Upstream Bonding Group (UBG/USBG)*** **– A group of upstream channels within the Transmit Channel Set that a single flow could be assigned to**
- ***Continuous Concatenation and Fragmentation (CCF)*** **-** Method of packing data into segments for upstream transmission in Multiple Transmit Channel Mode
- ***Multiple Transmit Channel Mode*** **-** Upstream operation of the CM and CMTS MAC layer using CCF to transmit the data upstream
  - Upstream Channel Bonding

Upstream Bonding Groups



- **Each CM may use a different upstream bonding group**
  - **CM-A is assigned to US#1 and US#2**
  - **CM-B is assigned to US#3 and US#4**
  - **CM-C is assigned to US#1, US#2, US#3, and US#4**

Transmit Channel Set



- **Each service flow of a CM can be assigned to a different bonding group**
  - **Example: TCS= US#1, US#2, US#3, US#4**
    - **Service Flow 1 is assigned to US#1 and US#2**
    - **Service Flow 2 is assigned to US#3 and US#4**
    - **Service Flow 3 is assigned to US#1, US#2, US#3, and US#4**

DOCSIS 1.x/2.0 Request/Grant Mechanism

- The CM requests bandwidth
  - For a single packet
  - For a of group packets, if concatenation is enable
- Requests are in mini-slots
  - Which includes the physical layer overhead
  - Maximum request size is limited to 255 mini-slots
- Only one request outstanding per service flow
  - Cannot requests additional bandwidth until it receives all the grants for the outstanding request
  - Request/grant latency limits the amount of bandwidth that can be assigned to a single service flow
    - Never will be able to reach speed close to 100Mbps

DOCSIS 3.0 Request/Grant Mechanism

- **“Multiple Transmit Channel Mode” ≈ “Upstream Channel Bonding”**
- **Multiple Transmit Channel Mode implies the following mechanisms:**
  - **Continuous Concatenation and Fragmentation (CCF), including the use of Segment headers**
  - **Queue-depth based bandwidth requests**
  - **Multiple requests outstanding**
  - **SID Clusters**
  - **Byte based (versus mini-slot based)**
- **Multiple Transmit Channel Mode can exist even for single channel operation**
- **If not in Multiple Transmit Channel Mode, the CM operates in the upstream per DOCSIS 1.x/2.0 mode**

Multiple Transmit Channel Mode Request

- **Multiple Transmit Channel Mode (MTCM) uses a larger request field with configurable granularity**
  - **Able to request for more bandwidth in a single request**
  - **Programmable to allow tradeoff of granularity vs. request field length**
    - **Multiplier configured per service flow (default of 4)**
- ***Unlike DOCSIS 1.x/2.0 requests which are in mini-slots, MTCM requests are in bytes or multiple of bytes***
  - **Allows the CMTS to used multiple upstream channels to satisfy the request**
  - **The CM requests for queue depth**
  - **CM's request does not include PHY overhead**
    - **Removes estimation errors when granting on channels other than requesting channel**
- **The CM can have "multiple requests outstanding"**

Multiple Outstanding Requests

- **CCF eliminates the wasted bandwidth caused by requests and grants "out of sync"**
  - **This allows multiple outstanding requests for a single service flow and SID**
- **The CM can piggyback request for NEW packets at any time**
  - **Within restriction of the service flow**
- **To detect lost requests, the procedure is the same as in DOCSIS 1.x/2.0, the CM starts an ACK timer. If the ACK time "expired" and no grant pending is present, the CM will re-issue the request**
  - **Request for additional bandwidth can be made for *NEW* packets**

SID Clusters

- **Service Identifier (SID) defined in the MAP grant is used to identify the specific service flow and CM the grant is allocated to**
- **With upstream channel bonding and service flow bandwidth being supported across multiple upstreams, how does the CM associate the bandwidth (grants) on these different upstreams to one service flow?**
  - **The CMTS will assign SIDs to a bonded upstream service flow independently for each upstream channel**
    - **Within an upstream channel the SID must be unique, but it does not have to be unique across upstream channels**
  - **The group of SIDs defined for a single service flow across the bonded upstream channels is called a *"SID CLUSTER"***

SID Cluster	US#1 SID	US#2 SID	US#3 SID	US#4 SID
Cluster_0	58	479	85	1001

One or More SID Clusters per Service Flow

- **The CM and CMTS could get out of sync if a request is lost or if a MAP, with a grant for that CM is lost**
  - **The CM and CMTS will recover from this temporary "out of sync"**
    - **But until the CM and CMTS recovers data delay and throughput will be impacted**
- **To reduce the impact of the CM and CMTS getting "out of sync" DOCSIS 3.0 support multiple SID Clusters per service flow**
  - **The CM can make requests on one SID Cluster while another SID Cluster is recovering**
  - **Support for two SID Clusters per service flow is required, but up to seven SID Clusters can be used**
- **CM decides when to switch SID Clusters**
  - **But must switch under certain conditions**
- **The set of SID Clusters associated with a service flow is called "*SID Cluster Group"***
  - **DOCSIS 3.0 "SID Cluster Group" ~ DOCSIS 1.x/2.0 SID**

Granting Bandwidth

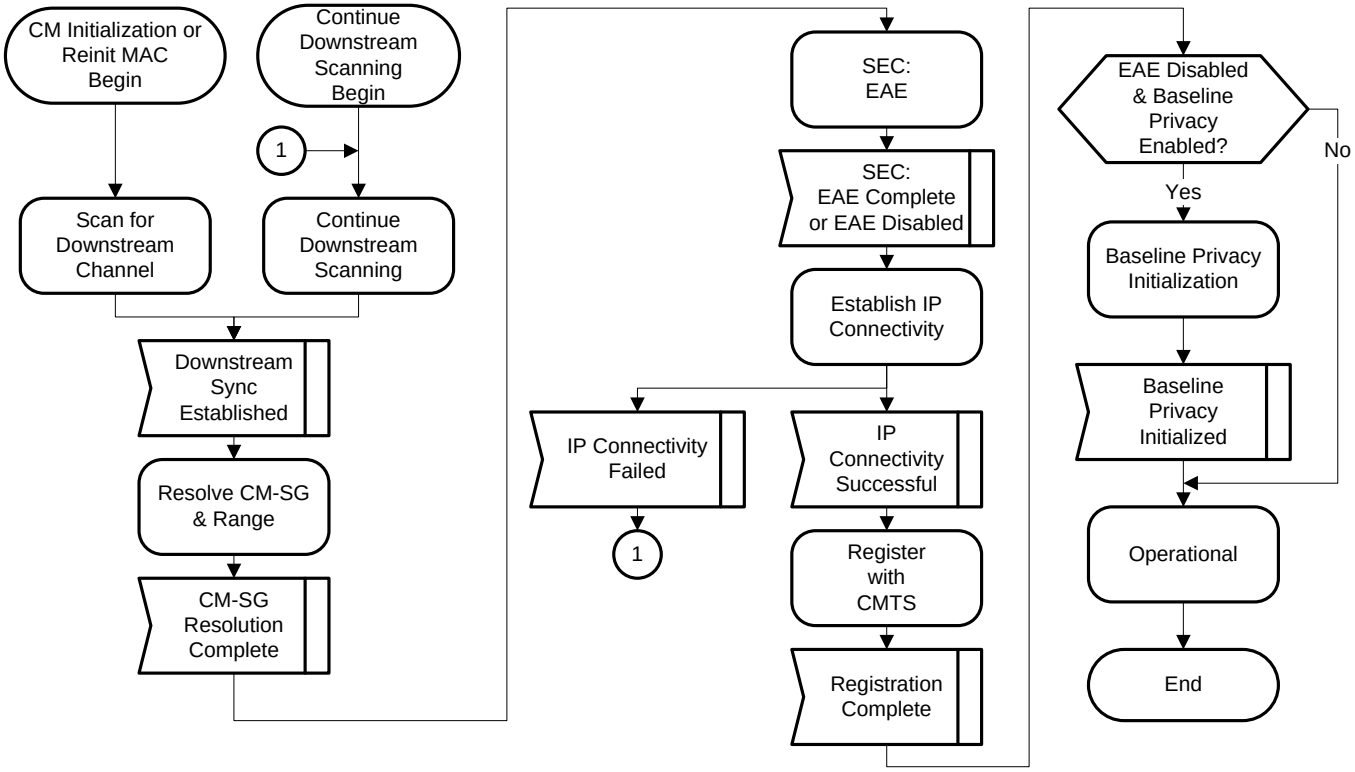
- DOCSIS MAP mechanisms has not changed for DOCSIS 3.0
  - Each MAP message is associated with a single upstream channel
  - MAPs do not need to be aligned across channels
  - Mini-slot sizes do not need to be the same across channels
- DOCSIS 1.x, 2.0 and 3.0 CMs are all supported using the same MAP
- CMTS has complete control in granting the bandwidth
  - Can grant the entire requested bandwidth of a portion of it
  - Can combine requests from the same SID Cluster into a single grant
  - Can provide grants on any or all upstream channels associated with the service flow
- The CMTS adds segmentation and PHY overheads to the grant size
  - The CM does not know the segmentation overhead or which upstream channel(s) will be used

How D3.0 Bonded Modem Registers

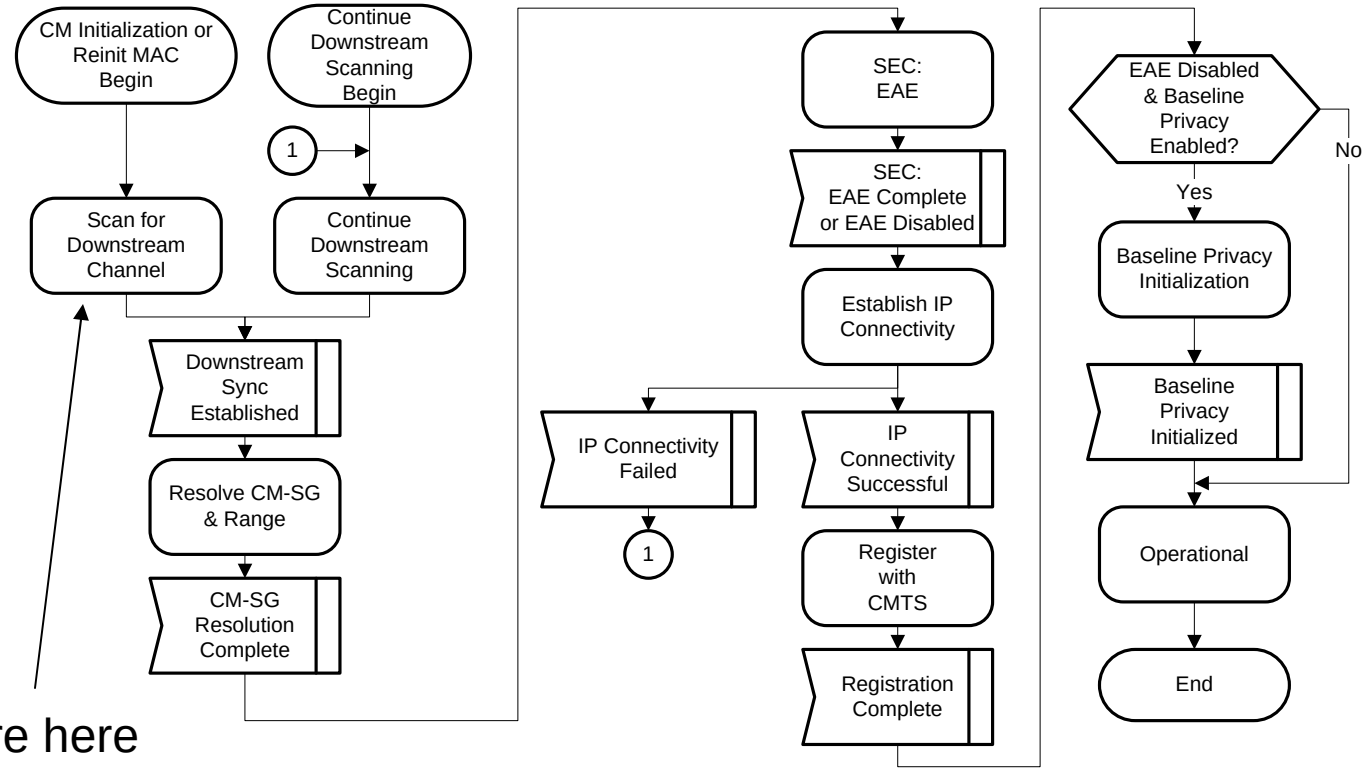
Cable Modem Initialization

- **The procedure for initializing a cable modem and for a CM to reinitialize its MAC can be divided into the following phases:**
  - **Scanning and synchronization to downstream (including scanning continuation when necessary)**
  - **Service group determination and ranging**
  - **Authentication**
  - **Establish IP connectivity**
  - **Registration**

The Flow



The Flow



We are here

Scanning and synchronization to downstream

- **The cable modem MUST acquire a Primary-Capable downstream channel.**
  - **Synchronization of the Physical Media Dependent and Transmission Convergence sublayers**
  - **Recognition of SYNC downstream MAC messages.**
  - **The CM MUST attempt to determine its MAC Domain Downstream Service Group ID (MD-DS-SG-ID) if an MDD is present on the downstream.**

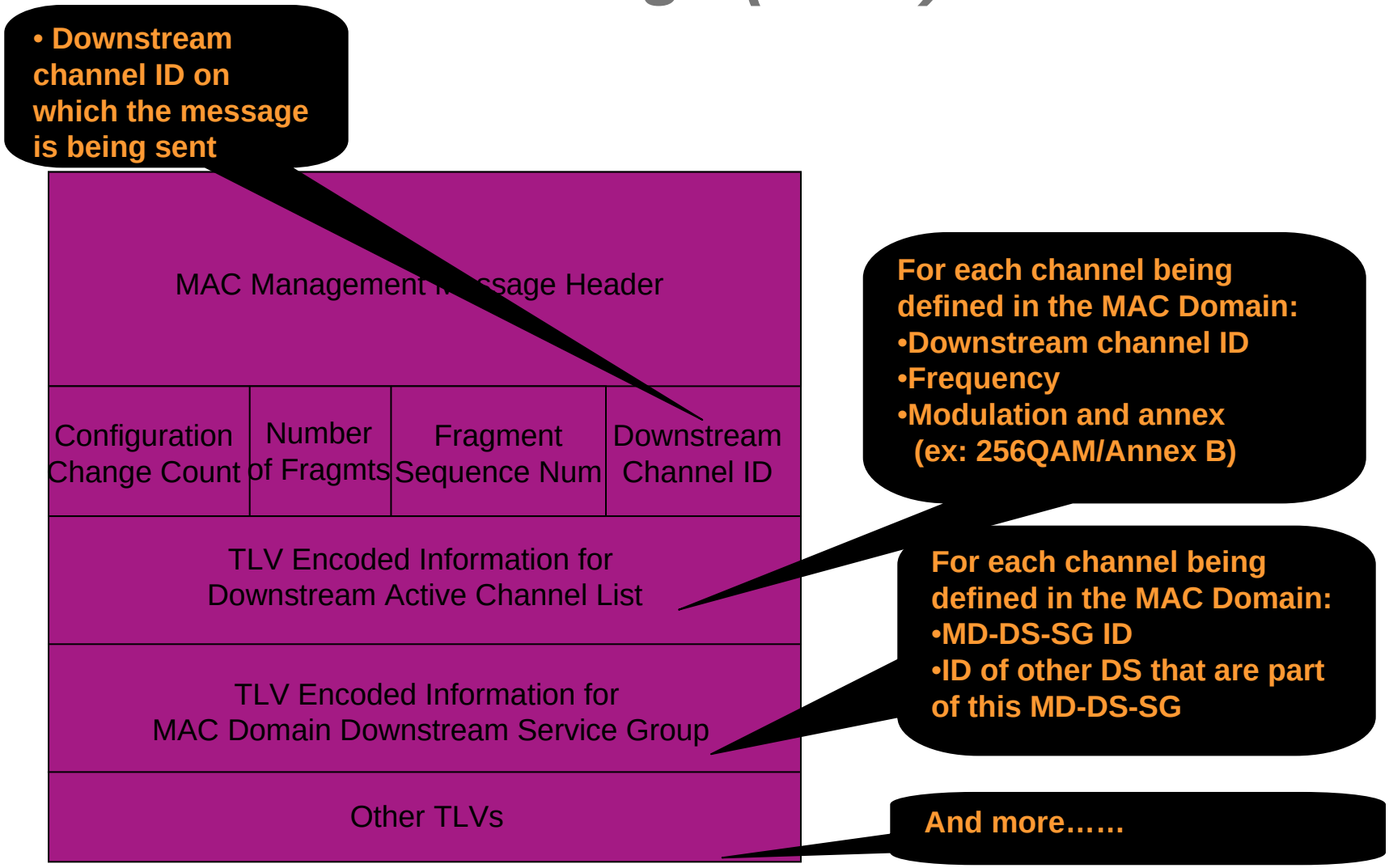
Scanning and synchronization to downstream cont..

- **Finding the Downstream**
  - The bonding CM will activate only one of its receivers to scan the downstream
  - The bonding CM will lock on the primary downstream and use the MAC Domain Descriptor (MDD) message to discover the bonding groups that are available

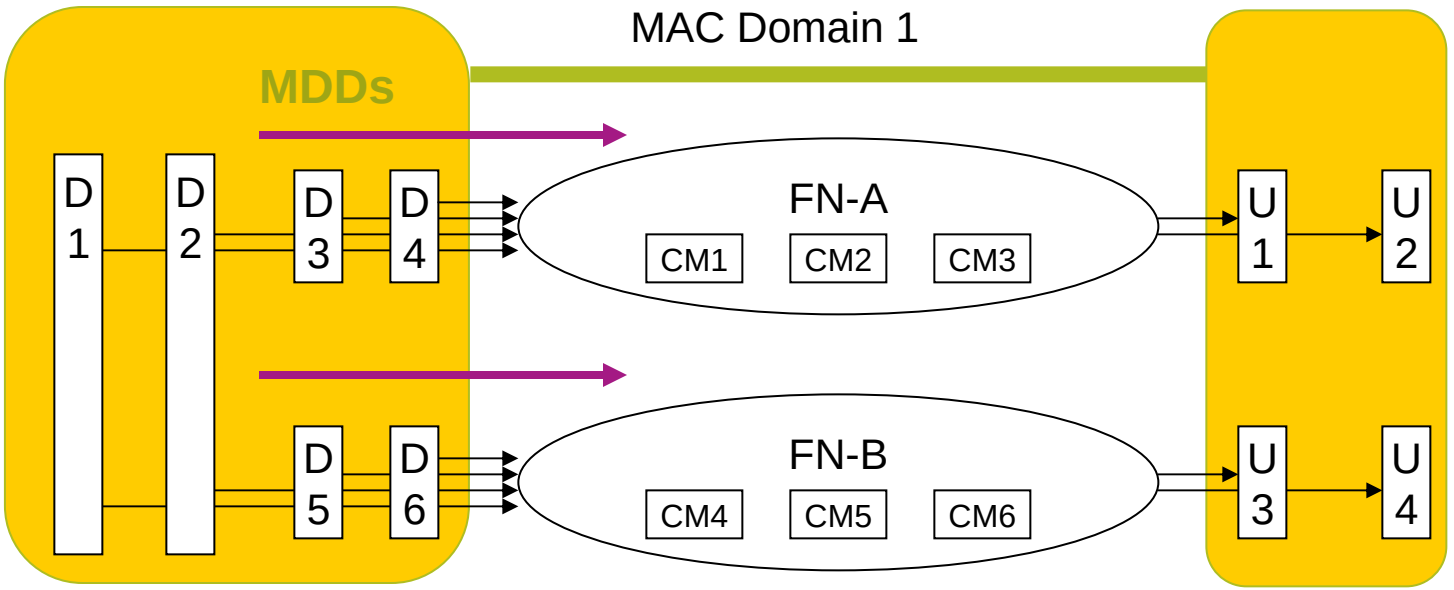
MAC Domain Descriptor Message (MDD)

- **Message advertises topology initialization parameters**
- **Sent periodically on every downstream channel in the MAC domain**
- **‘mdd-interval’ ranges from 0 to 2000 msec**
  - ‘0’ value disable sending MDD message on the DS
  - Default -> 2000

MAC Domain Descriptor Message (MDD)

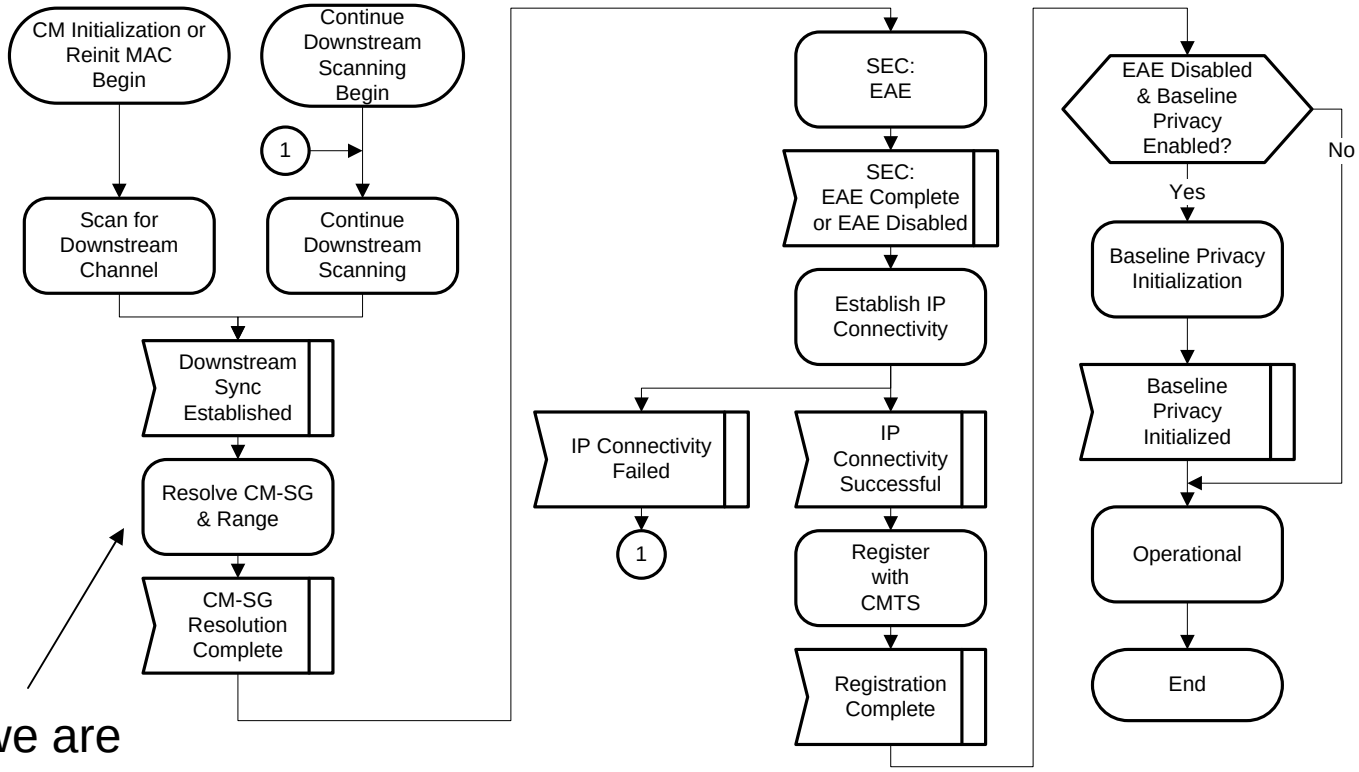


MAC Domain Descriptor (MDD)



- **Each CMTS MAC Domain sends a MAC Domain Descriptor (MDD) on each of its downstream channels.**
- **The MDD is used by CMs initializing (ranging and registering) on that MD.**
- **The header of the MDD contains the Downstream Channel ID (DCID) assignedby the MD.**
- **Bonding CMs use the DCID of their MD's MDD to identify secondary channels.**

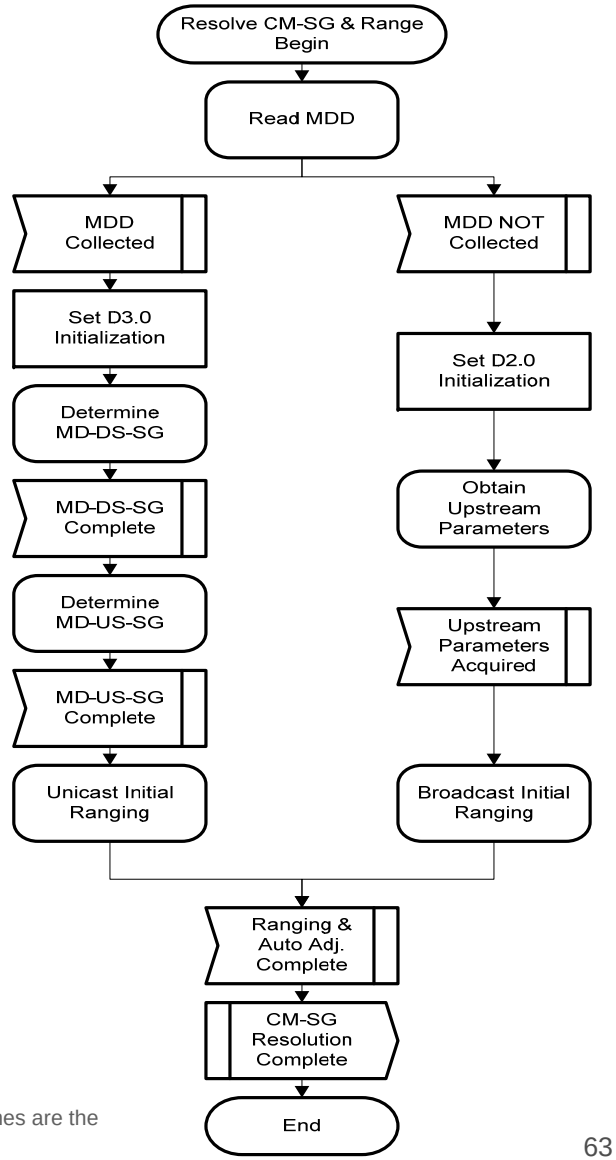
The Flow



Now we are here

Resolve Service Group

- **The CM MUST attempt to determine its MAC Domain Downstream Service Group ID (MD-DS-SG-ID) if an MDD is present on the downstream.**
- **If successful, the CM MUST provide the MD-DS-SG-ID it has selected to the CMTS in the Bonded Initial Ranging Request (B-INIT-RNG-REQ) message.**
- **In order to resolve the upstream service group (MD-US-SG) associated with this CM, the CMTS may include an Upstream Channel Adjustment in this RNG-RSP message.**



Ranging Messages for Cable Modems

- **B-INIT-RNG-REQ (new for D3.0 CMs)**
  - **Used by a DS CB cable modem to range. Includes the MD-DS-SG-ID in this message from the DS serving group resolution**

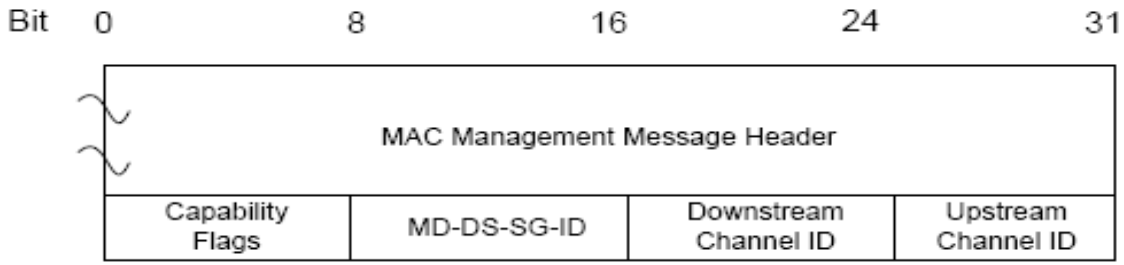
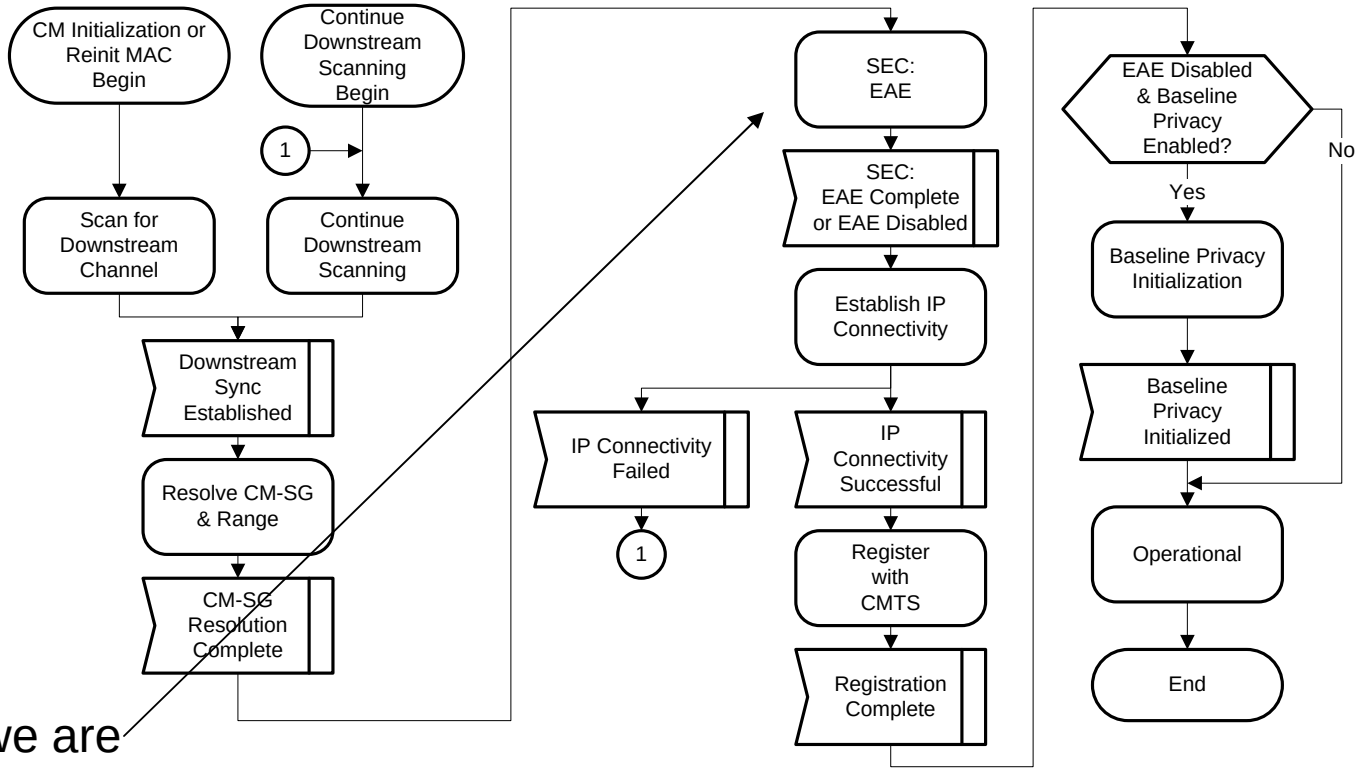


Figure 6–22 - B-INIT-RNG-REQ Format

- **INIT-RNG-REQ or RNG-REQ**
  - **Used by D1.x/2.0 CMs or by D3.0 CMs if no MDD messages were present on the downstream**

The Flow

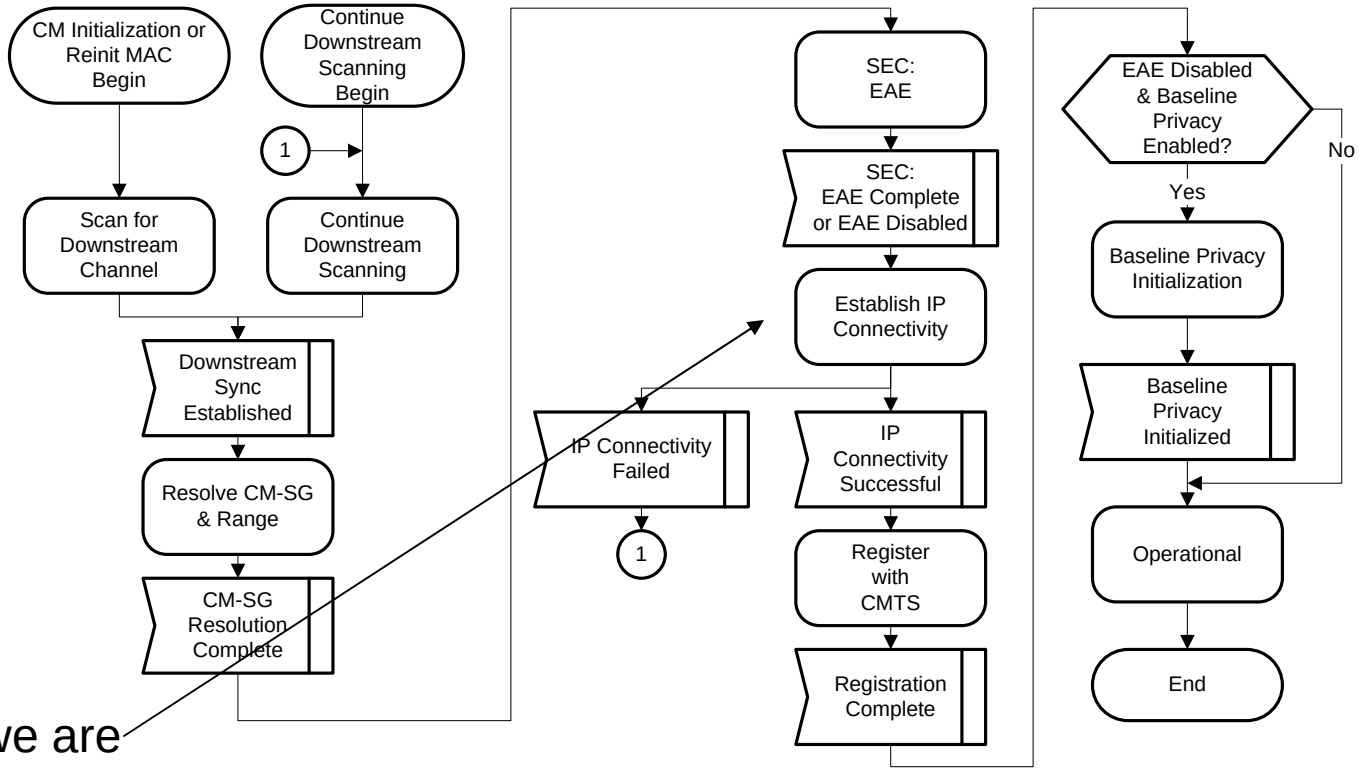


Now we are here

Authentication

- **Once a CM has completed ranging, if Early Authentication and Encryption (EAE) is enabled in the MDD the CM will initiate EAE before continuing with the initialization process.**
- **EAE helps prevent unauthorized CMs from accessing IP provisioning servers**
- **Provides confidentiality/privacy for IP provisioning messages between the CM and CMTS**

The Flow

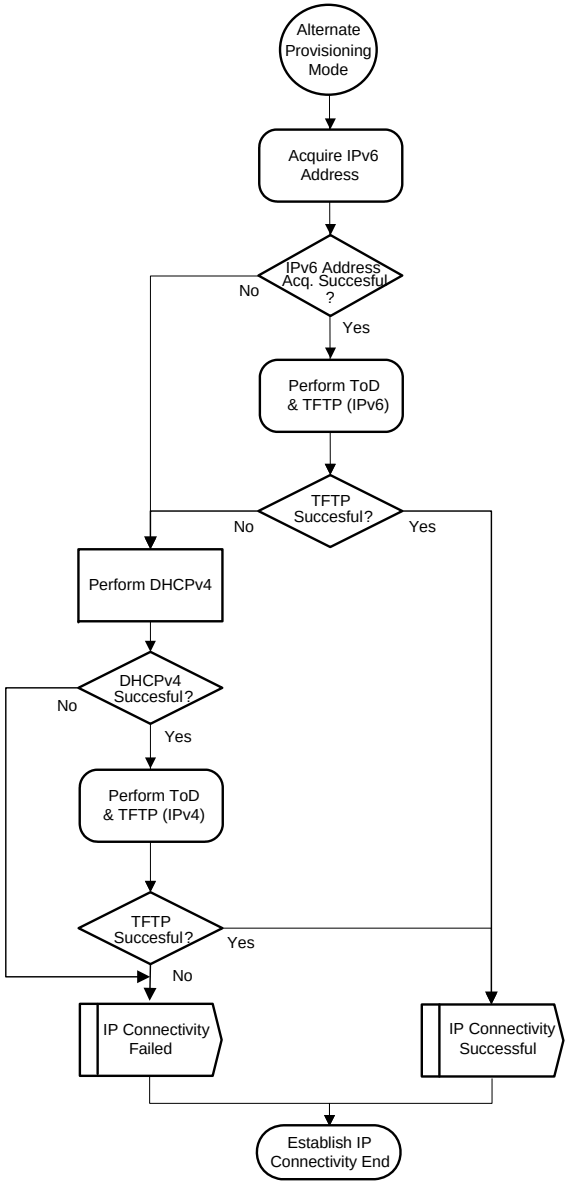


Now we are here

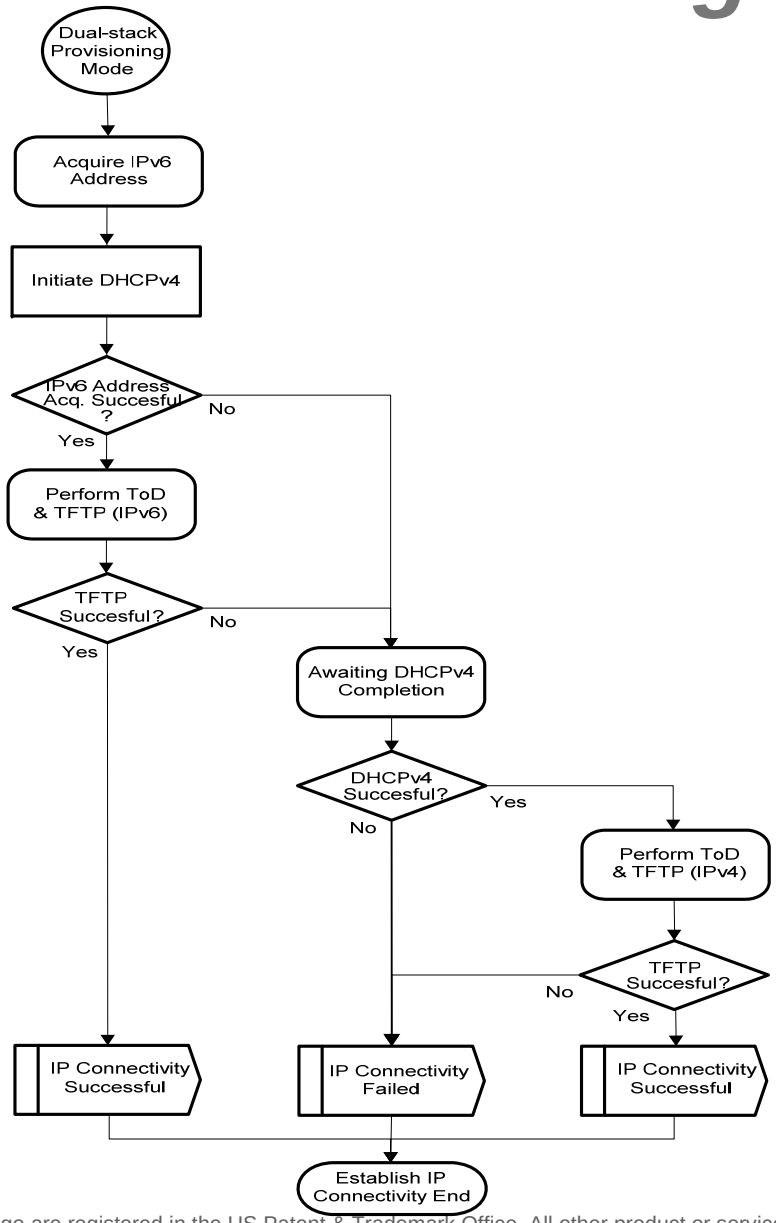
Establish IP Connectivity

- **The CM performs IP provisioning in one of four modes:**
  - **IPv4 Only**
  - **IPv6 Only**
  - **Alternate Provisioning Mode (APM)**
  - **Dual-stack Provisioning Mode (DPM)**
- **The CM uses the provisioning mode directed by the MDD IP Provisioning Mode TLV**

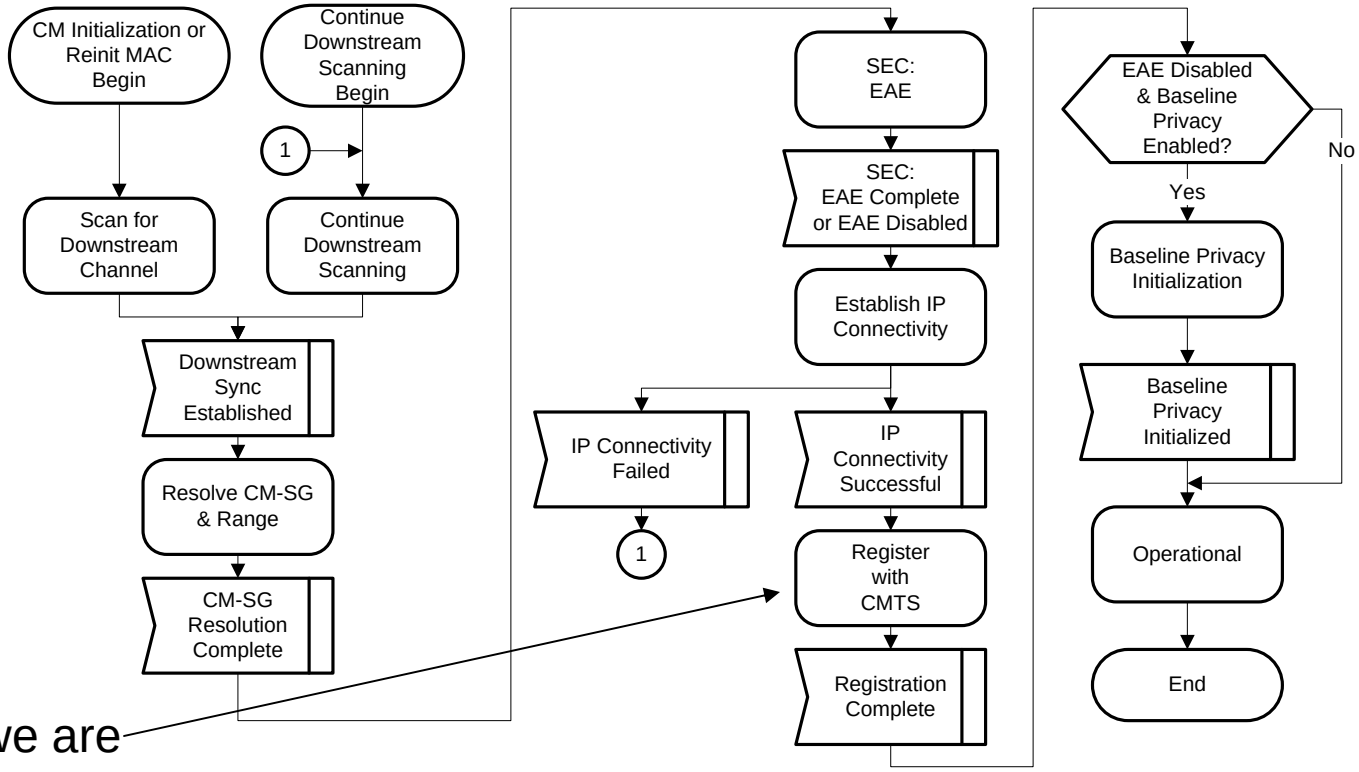
Alternate Provisioning Mode



Dual-stack Provisioning Mode



The Flow



Now we are here

Registration Request/Response

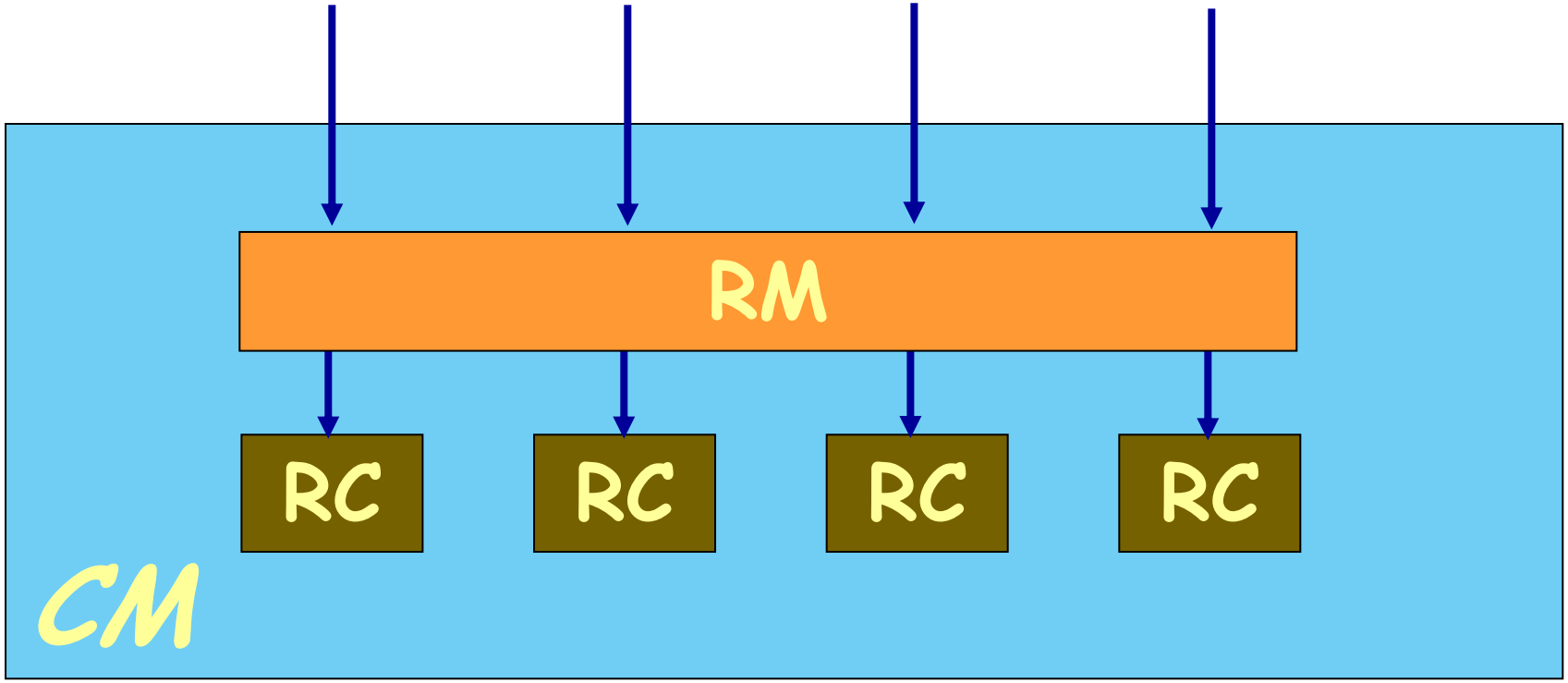
- **CM sends a REG-REQ-MP if the DS contains MDD messages**
- **REG-REQ-MP: advertise the CM downstream bonding capabilities:**
  - **RCP encodings**
- **If the CM sent a REG-REQ-MP message, the CMTS responds with a REG-RSP-MP message**
- **REG-RSP-MP:** the CMTS configures the CM's physical layer components to specific downstream frequencies
  - **RCC encodings**
- **If there are no BGs that matches the CMs RCPs, the CMTS will not include a RCC into the REG-RSP-MP**

RCP and RCC

- **Receive Channel Profile (RCP)**
  - **An RCP defines two or more Receive Channels (RCs)**
  - **TLV encodings that represent the CM Receive Channels and Receive Modules**
  - **CableLabs defines 6 standard profiles**
    - **Three 6 MHz**
    - **Three 8 MHz**
    - **All modems will support at least one standard profile: e.g. CLAB_6M_004**
  - **Non standard profiles**
- **Receive Channel Configuration (RCC)**
  - **Profile selected by the CMTS (center frequency)**
  - **May be a subset of the advertised profile**
  - **Returned by the CMTS in the registration response**

RC & RM

- **RC – Receive Channel:** Refers to the component of a Cable Modem that receives a single Downstream Channel on a single center frequency.
- **RM – Receive Module:** Refers to the component of a Cable Modem physical layer implementation shared by multiple Receive Channels, e.g. an analog tuner or a demodulator block.



Registration Completed

- **CM will use the RCC information in the REG-RSP message to tune the remaining receivers to achieve sync/lock on the other bonded downstreams**
  - If no RCC is present in the “REG-RSP” the CM will complete registration as a non-bonding CM
  - The CM attempts FEC, MPEG and SYNC lock on the Primary Downstream Channel
  - FEC and MPEG lock on the non-primary downstream receive channels.
- **Once the CM has achieved sync/lock on all secondary receivers it will send the reg-ack to the CMTS**
  - If the CM fails to achieve “sync/lock” on all receivers the CM enter in “partial service” mode and proceeds to acquire the transmit channels.
- **The set of channels received by a CM is called its “Receive Channel Set” (RCS)**

Registration Completed cont..

- **If Multiple Transmit Channel Support is enabled, and the CM is able to successfully range on one or more (but not all) of the upstream channels in the TCS, the CM will start Multiple Transmit Channel Mode in a partial service mode of operation in the upstream.**
- **If Multiple Transmit Channel Support is disabled and the CM was able to successfully range on its one upstream channel, the CM does not enable Multiple Transmit Channel**

Partial Service

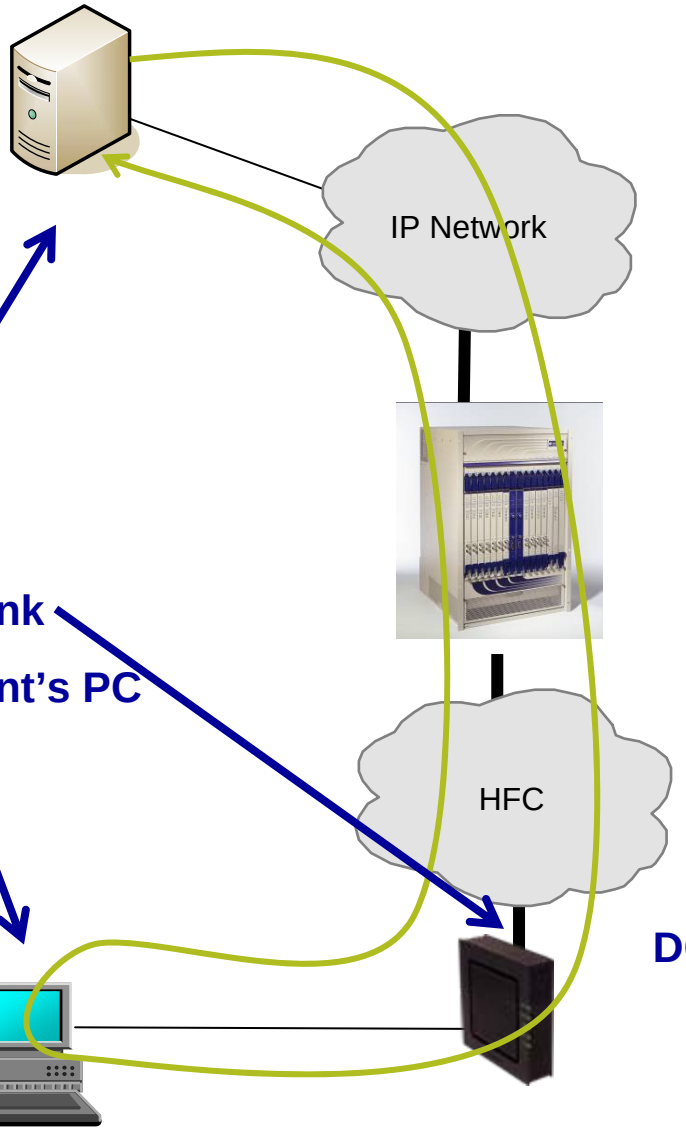
- When one or more of the upstream Transmit Channel Set (TCS) or downstream Receive Channel Set (RCS) is not usable by the CM, the CM will enter into a **“partial service”** state
- The CM signals that it is in a **“partial service”** mode of operation to the CMTS via the appropriate means:
  - The REG-ACK if the channel is not acquired during registration
  - The DBC-RSP if the channel is not acquired during Dynamic Bonding Change
  - The CM-STATUS message, if a channel becomes unusable during normal operation
    - Could result in the CMTS sending a DBC

Channel Changes

- **DOCSIS 1.0**
  - Upstream Channel Descriptor (UCD) **change modifies the physical characteristics of a upstream channel**
  - Upstream Channel Change (UCC) **moves a CM from one upstream channel to another upstream channel**
- **DOCSIS 1.1/2.0**
  - Upstream Channel Descriptor (UCD) **change modifies the physical characteristics of a upstream channel**
  - Upstream Channel Change (UCC) **moves a CM from one upstream channel to a new upstream channel**
  - Dynamic Channel Change (DCC) **moves a CM from one upstream and downstream channel to another upstream and/or downstream channel**
- **DOCSIS 3.0**
  - Upstream Channel Descriptor (UCD) **change modifies the physical characteristics of a upstream channel**
  - Upstream Channel Change (UCC) **moves a CM from one upstream channel to a new upstream channel**
  - Dynamic Channel Change (DCC) **moves a CM from one upstream and downstream channel to another upstream and/or downstream channel or re-initializes a CM when moving it to a new MAC domain**
  - Dynamic Bonding Change (DBC) **moves a CM from one or more upstream and downstream channels to new upstream and/or downstream channel(s) and configures downstream multicast characteristics**

End-User Considerations

Key Factors for FTP Performance



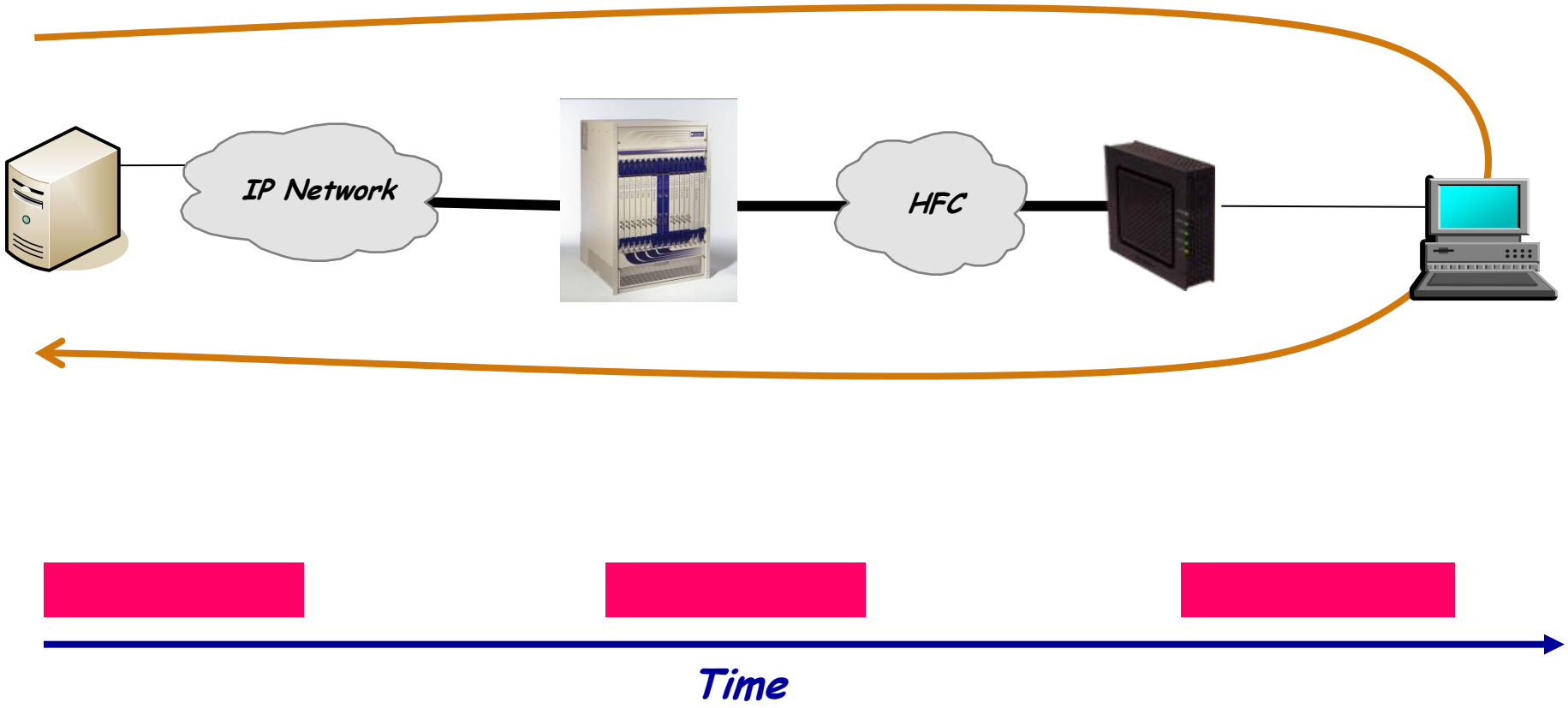
Key Factors

1. **Round Trip Time (RTT)**
2. **TCP Window Size**
3. **Speed of the Slowest Link**
4. **Performance of the Client's PC**

DOCSIS 3.0 Channel Bonding CMTS

DOCSIS 3.0 Channel Bonding CM

RTT and TCP Window Size



Channel Bonding FTP

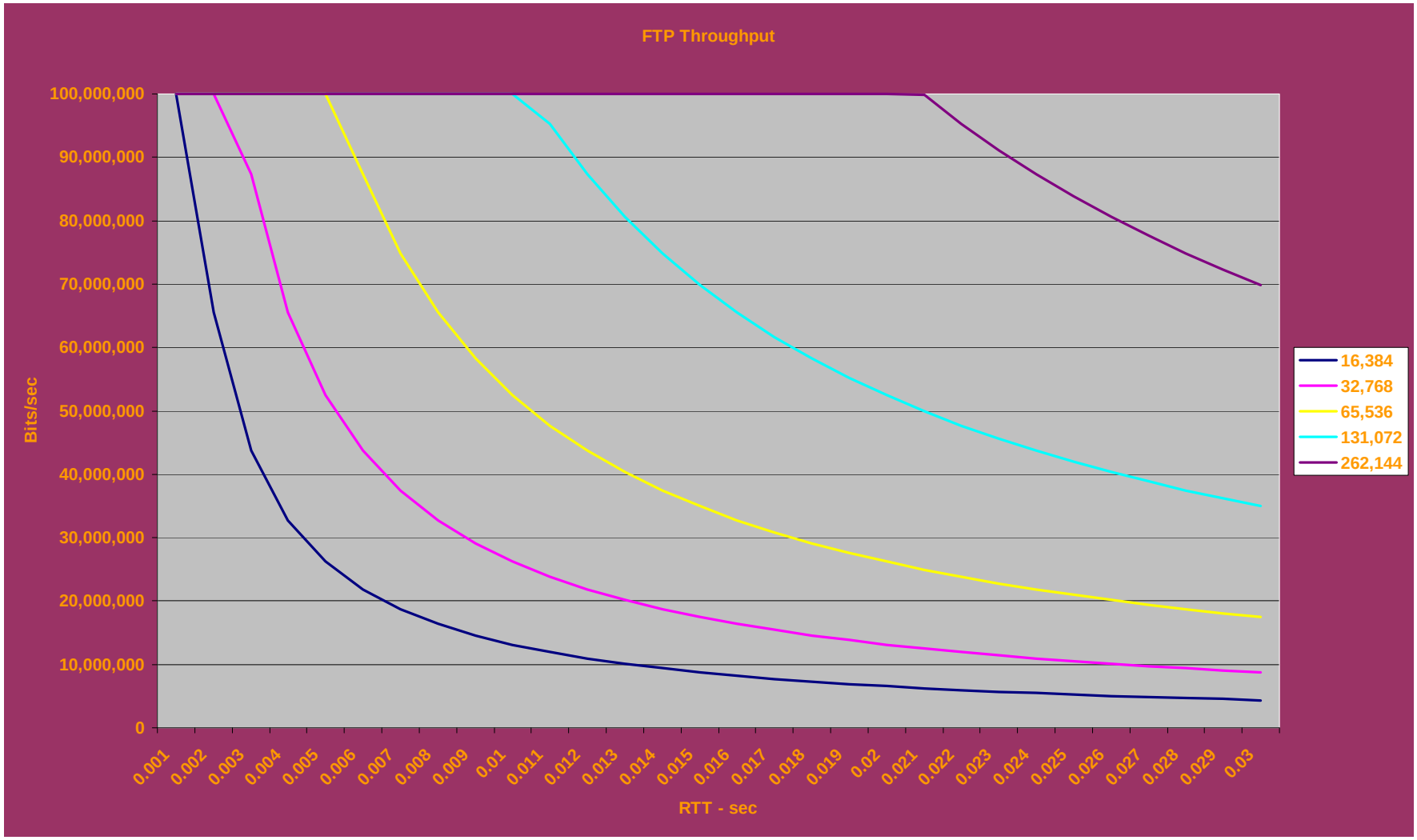
Max_FTP_Throughput =

(((‘TCP_window_size’ * 8) / ‘Link_Speed’) / RTT) * ‘Link_Speed’

Or just

((‘TCP_window_size’ * 8) / RTT)

FTP Throughput Vs. Round Trip Time (RTT)



Default Window Size

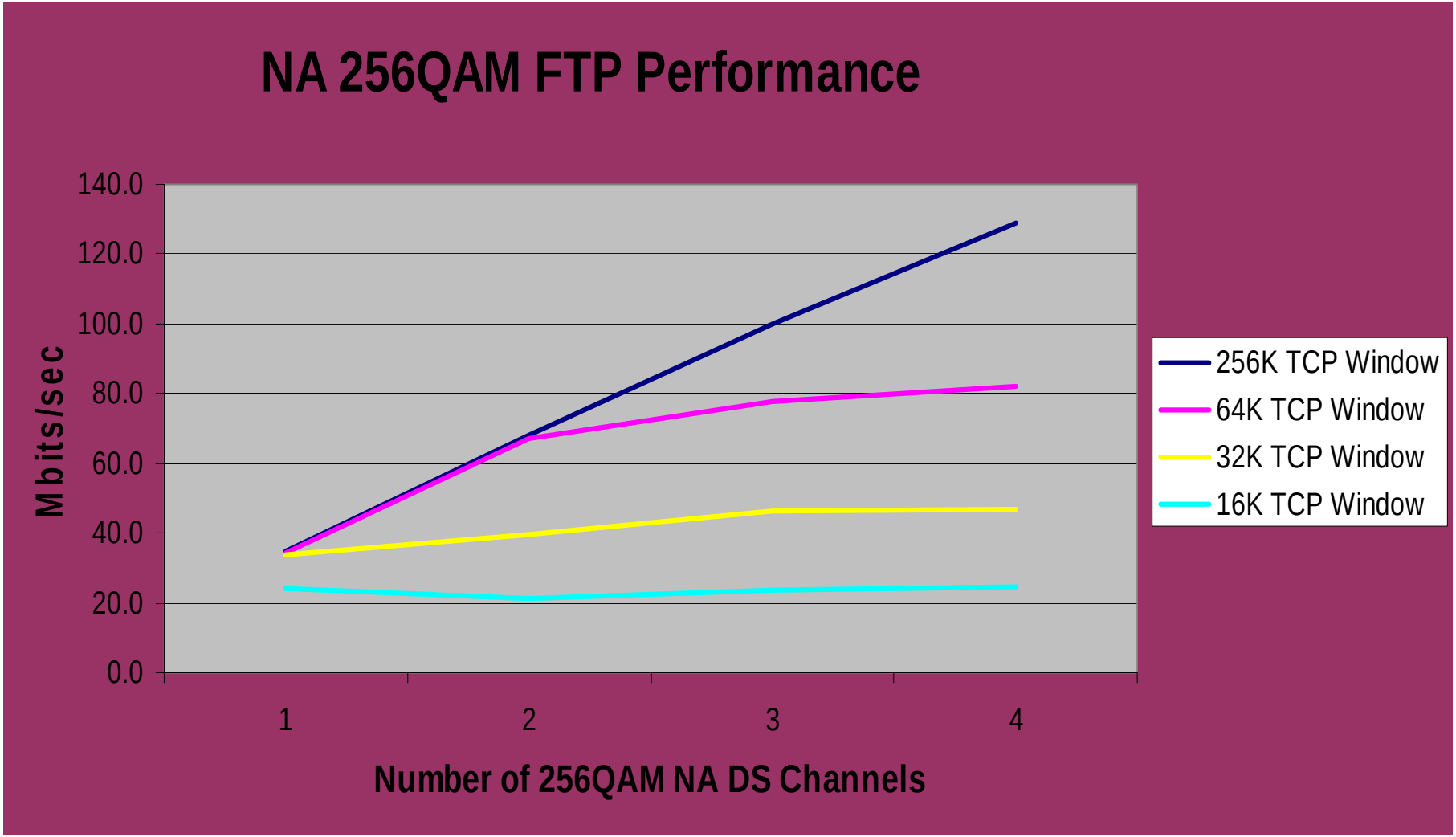
Operating System	Standard RWIN Value (TCP Receive Window Size) in Bytes
Windows 95/98/98SE/NT	8K
Windows ME/2000/XP	16K
Windows XP SP2	64K
Windows Server 2003	64K
Windows Vista/Windows 7	*Receive Window Auto-Tuning*
Macintosh OS X	32K
Linux Redhat 9	32K

“Real World FTP Performance”

4-DS Channel Bonding	Lab Test – FTP Server Connected Directly to CMTS	FTP Server within MSO’s Network (< 30msec RTT)	FTP Server outside MSO’s Network (<100msec RTT)
Single TCP Thread with 64K TCP Window Size	75 to 85 Mbps	10 to 20 Mbps	3 to 5 Mbps
Multiple TCP Thread with 64K TCP Window Size	90 to 95 Mbps	50 to 70 Mbps	10 to 20 Mbps
Single TCP Thread with 256K TCP Window Size	125 to 134 Mbps	60 to 70 Mbps	15 to 20 Mbps
Multiple TCP Thread with 256K TCP Window Size	125 to 134 Mbps	90 to 100 Mbps	90 to 95 Mbps
Single TCP Thread with 1M TCP Window Size	125 to 134 Mbps	90 to 95 Mbps	70 to 80 Mbps
Multiple TCP Thread with 1M TCP Window Size	125 to 134 Mbps	90 to 100 Mbps	90 to 95 Mbps

The above numbers reflect the average transfer rate for the entire FTP transfer, typical file size was 200Mbytes

FTP Performance vs. TCP Window Size and Number of NA DOCSIS DS Bonded Channels



Throughput Testing

- Use of Intranet FTP Server sites.
  - “True” throughput results without the impact of external traffic bottlenecks.
  - Actual byte/second count instead of HTTP site speed calculation algorithm.
- Use of Intranet “Speed test” HTTP sites
  - Removes external traffic conditions.
- Use of modem’s internal FTP client
  - Removes customer P.C software/hardware