DOCSIS
Introduction

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Agenda

- Introduction
  - Signal transmission
  - Provisioning flow
- Docsis protocol
  - Docsis management traffic
  - QoS
  - Baseline privacy
  - Dynamic operation
- Docsis 3.0
  - Channel Bonding
  - BSoD
- Docsis 3.1

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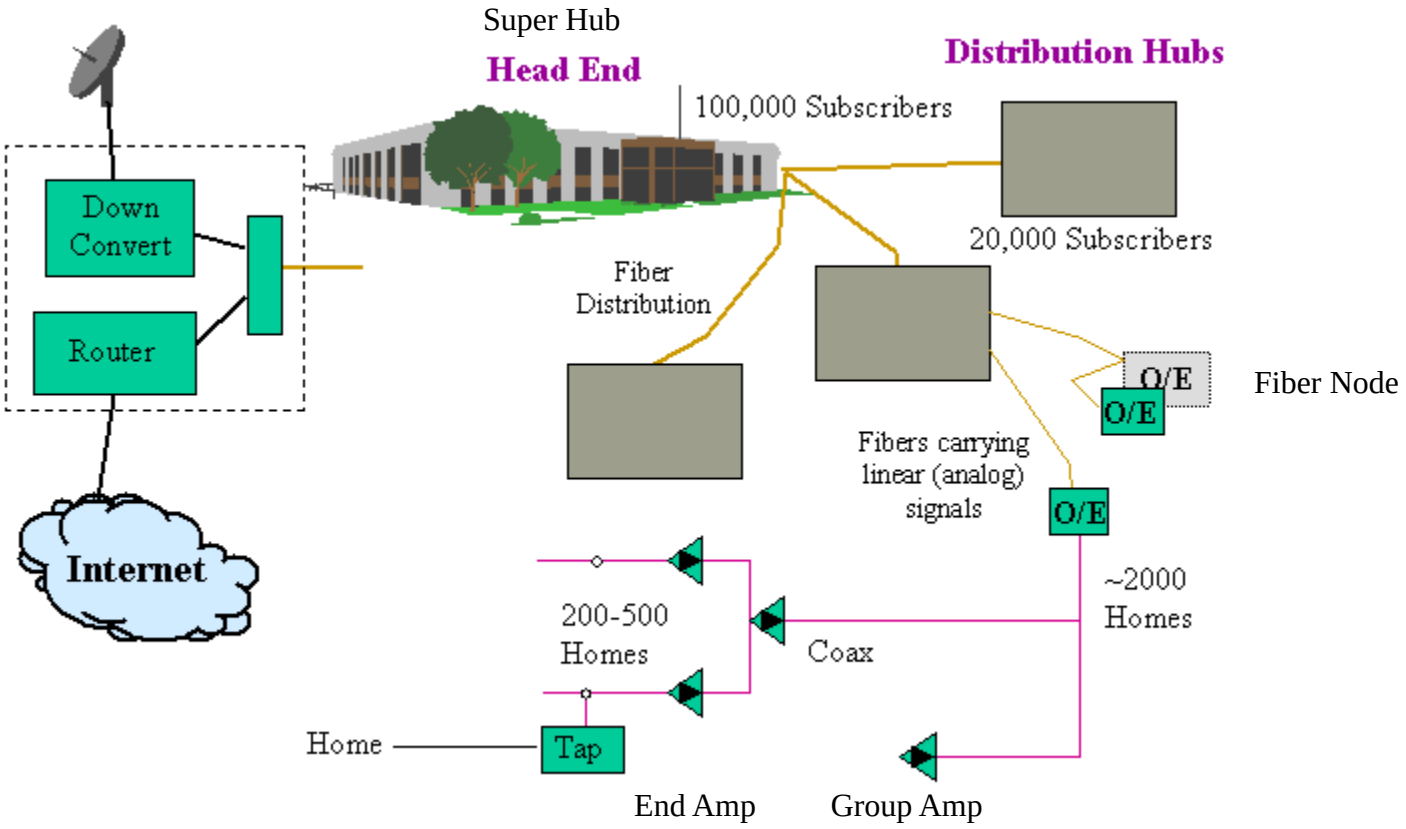
Introduction – HFC infrastructure

- DOCSIS: Data Over Cable Service Interface Specification
- CATV system was originally designed for one-way communication, has a tree topology, DOCSIS adds High Speed Data capability to this existing HFC plant.



DOCSIS evolution

- DOCSIS: Created to fit in the NTSC channel plan
  - 6 MHz wide downstream channels
- EuroDocsis: Created to fit in the PAL channel plan
  - 8 MHz wide downstream channels

- Docsis 1.0 (1997):
  - Upstream TDMA
  - Only Best effort traffic
- Docsis 1.1 (1999):
  - Service flows with QoS for VoIP
  - BPI+
- Docsis 2.0 (2001):
  - A-TDMA: Higher upstream modulations (up to 64QAM) and wider channels (6.4MHz)
- Docsis 3.0 (2006):
  - Channel bonding 4, 8 or even 24 downstream channels
- Docsis 3.1 (2013):
  - Extended spectrum, new multiplexing

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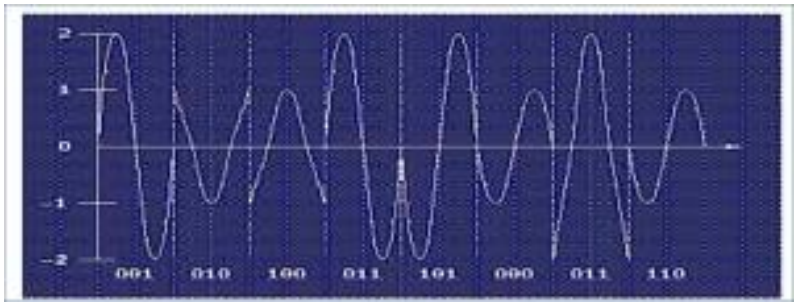
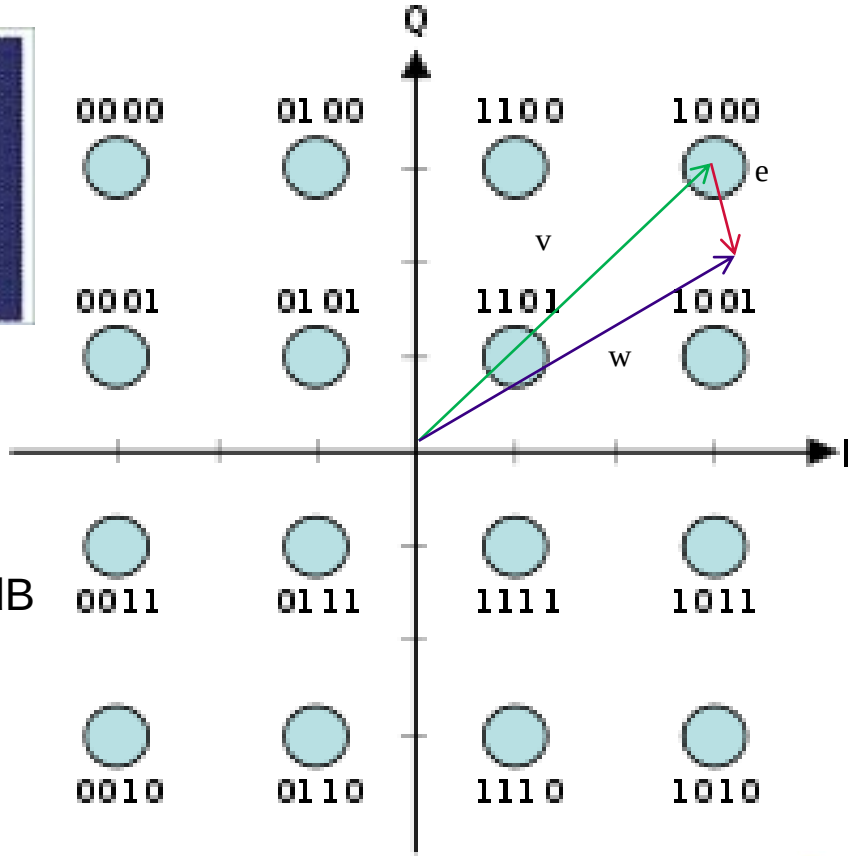
Physical layer – transmission

- QAM signal: Quadrature amplitude modulation - phase and amplitude shifting

$$s(t) = I(t) * sin(2 * \pi * f_o * t) + Q(t) * cos(2 * \pi * f_o * t)$$





- Constellation diagram, e.g. 16-QAM

- MER = 10 log (Power_v / Power_e) dB
- MER is a measure of SNR for digital signals
- BER = Bit Error Rate

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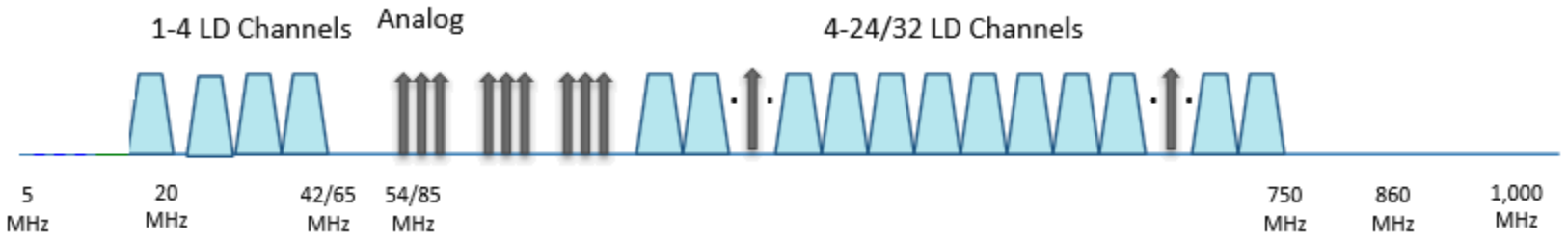
Physical layer - downstream

- Spectrum is split into two distinct range : upstream and downstream



- Downstream (112 MHz – 750/860MHz)
  - CMTS to CM, one speaker, multiple listener
  - Standard modulation is 256QAM in the downstream - this is 8 bits/symbol
  - 8 MHz wide channels in Euro DOCSIS
  - 55.62 Mbit/s raw throughput per channel (50Mbps usable throughput)

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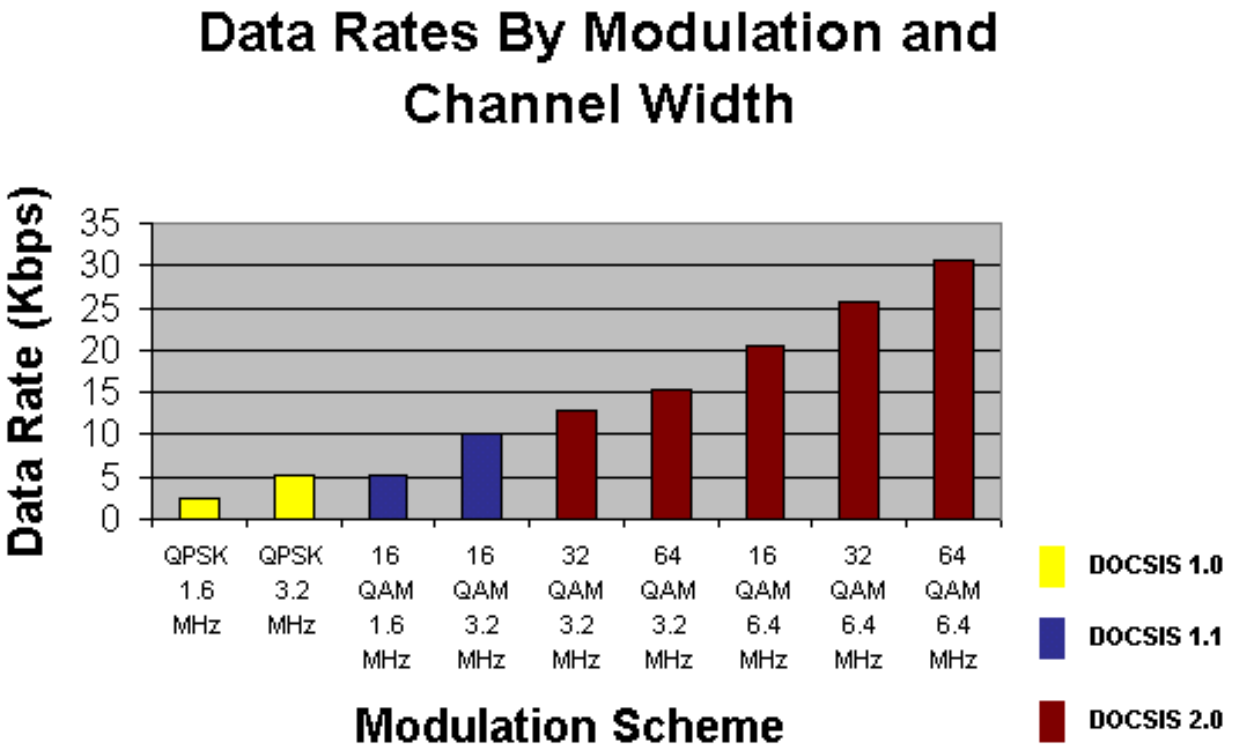
Physical layer - upstream

- Upstream (5 MHz – 65MHz)
  - CM to CMTS, Multiple speaker, one listener
  - Modulation 16 or 64QAM
  - Channel width can be 0.8, 1.6, 3.2 or 6.4 MHz
  - employs a deterministic access method (A-TDMA) – so it is mainly Collision Free protocol



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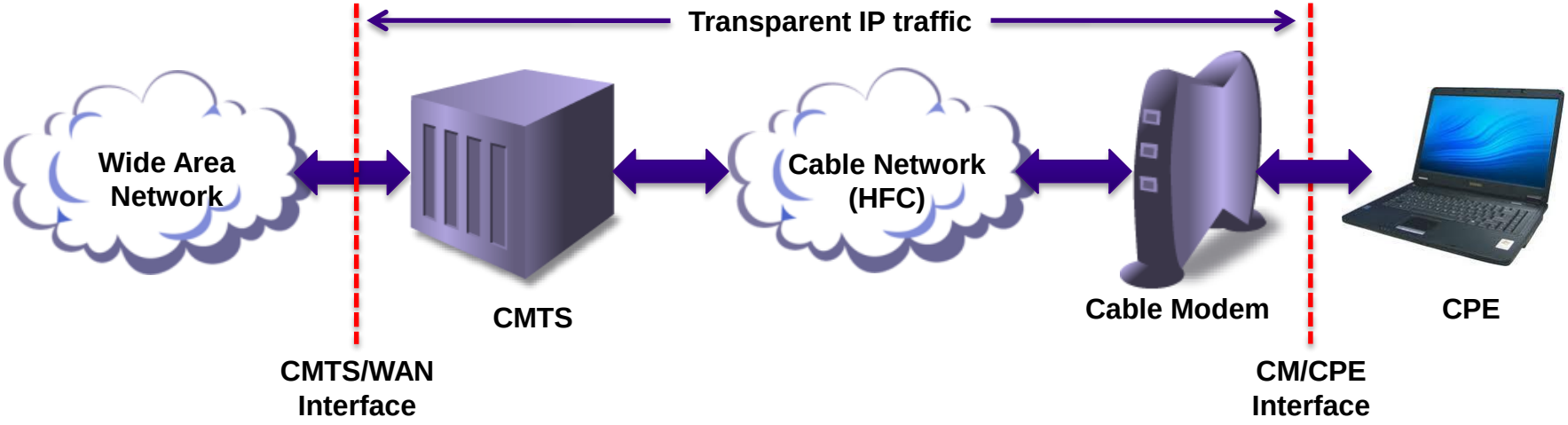
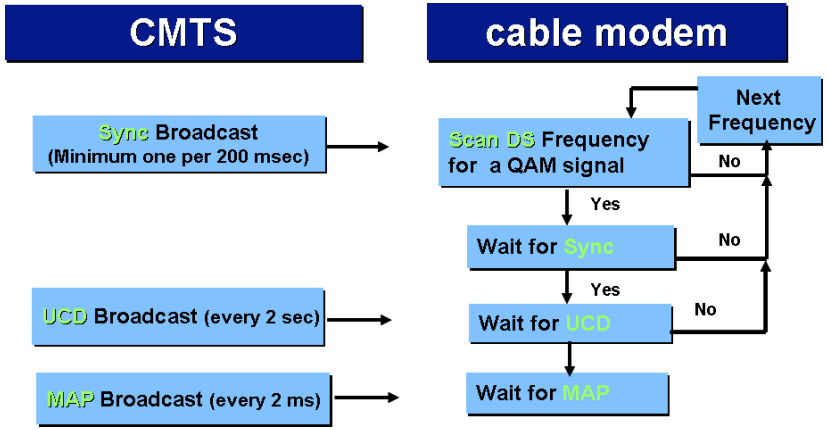
Modem boot-up

- Main components



- (1) Initialization



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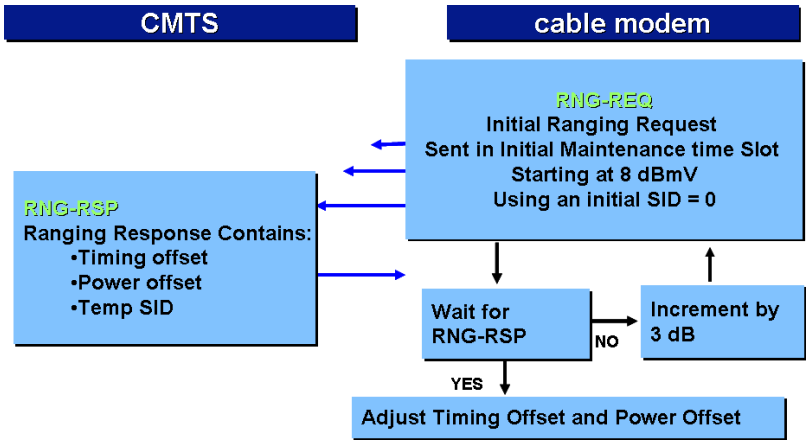
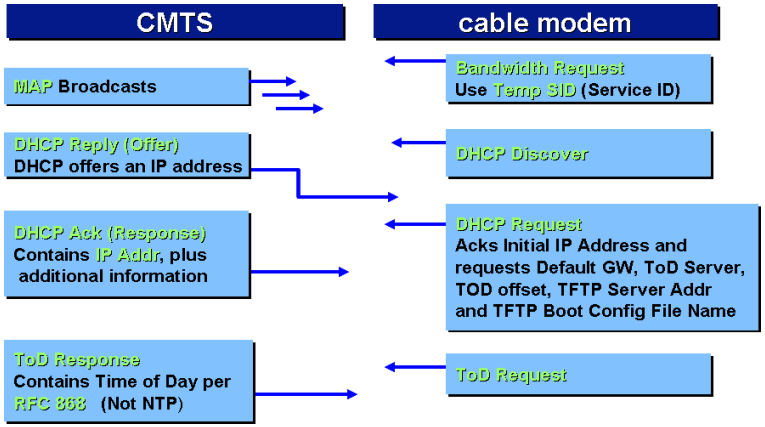
Modem boot-up (2)

- (2) Ranging

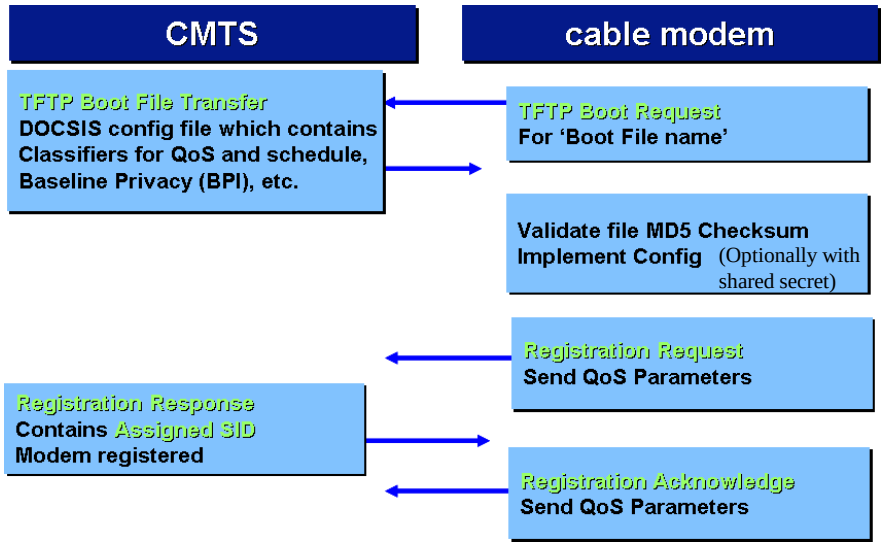


- (3) Obtain IP and time



Modem boot-up (3)

- (4) Modem configuration and registration



- (5) Baseline Privacy (BPI/BPI+) : Establish encryption and decryption keys:
  - KEK: Key encryption key
  - TEK: Traffic encryption key

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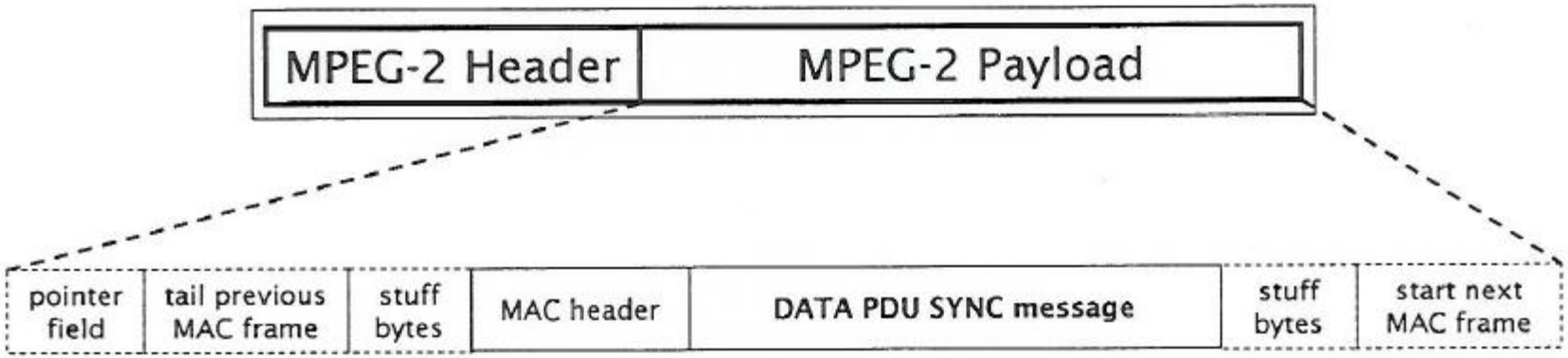
Synchronization

- SYNC message:
  - time synchronization sent by CMTS at periodic interval to provide common time reference to all CM's



- Sent at a periodic interval of max. 200 ms.

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Upstream Channel Descriptor

- Describes RF Characteristics of the US channel
  - Frequency
  - Modulation
  - Channel-width (symbol rate)

- Set of burst profiles corresponding with Interval Usage Code (IUC):

  - Request (1)
  - Request w/ contention data (2)
  - Initial maintenance (3)
  - Periodic ranging (4)
  - Short data (5)
  - Long data (6)
  - Advanced short data (9) - only Euro-DOCSIS 2.0
  - Advanced long data (10) - only Euro-DOCSIS 2.0
  - UGS (11) - only Euro-DOCSIS 2.0

- Sent at an interval of max. 2s

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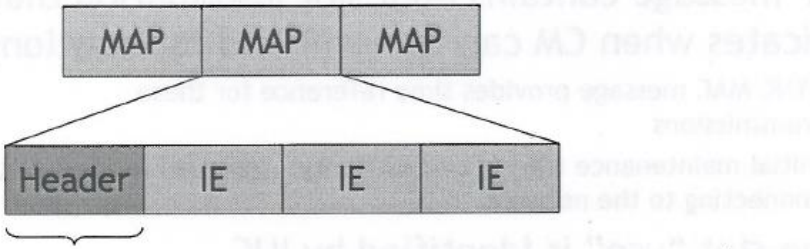
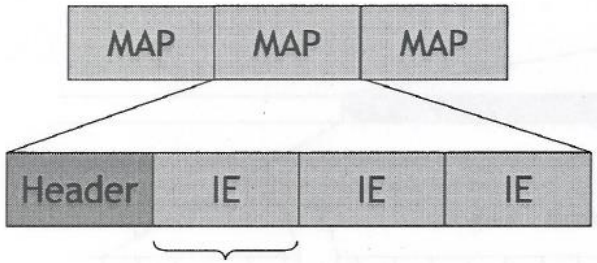
US bandwidth allocation Map (MAP)

- Allocate bandwidth to modems at an interval of tens of ms



- Start time first mini-slot
- Acknowledge time
  - Identifies last time-slot CMTS has processed before building this MAP
- Channel ID
  - US channel to which map refers



- SID
  - Identifies user of time slot (can be broadcast)
- IUC
  - Identifies use of time slot (initial ranging, periodic ranging, data, ...)
- Offset
  - Number of mini slots in time slot

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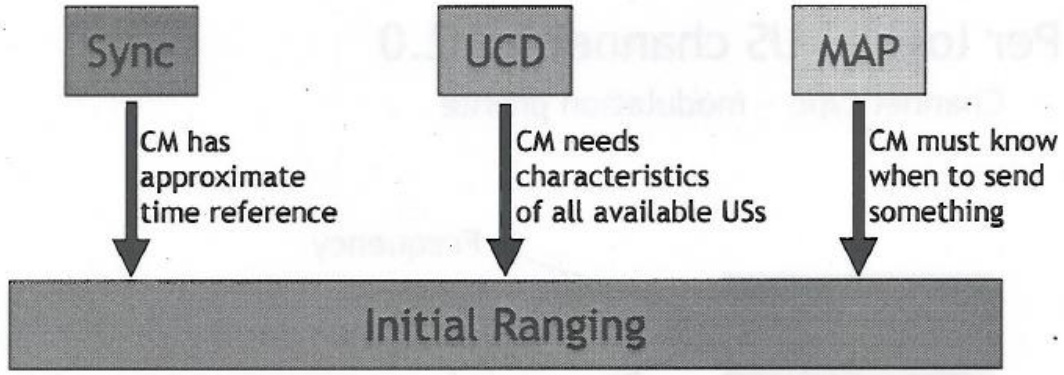
Ranging

- Initial ranging



- Periodic Ranging
  - Correction on the time offset
  - Fine tuning the transmit frequency
  - Correction on the transmit power

Periodic tuning of timing, transmit frequency and transmit power ensures continued reliable communications between CMs and CMTS.

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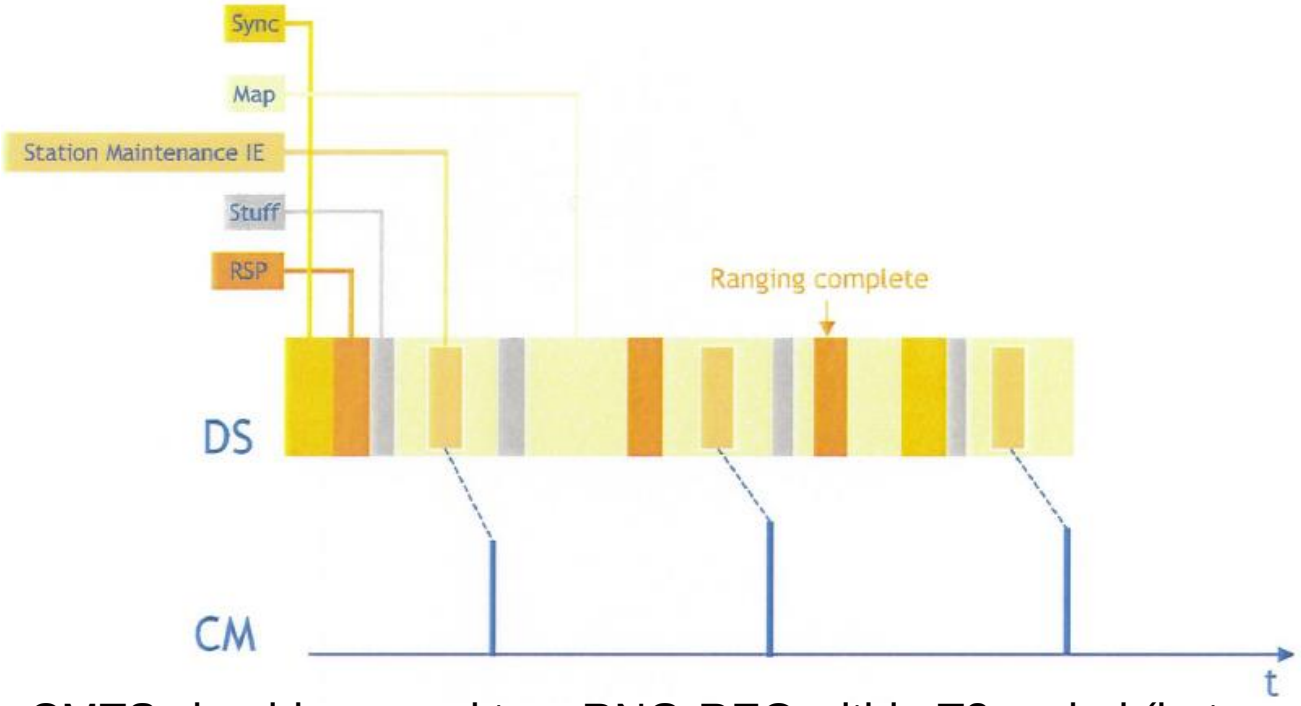
Periodic Ranging

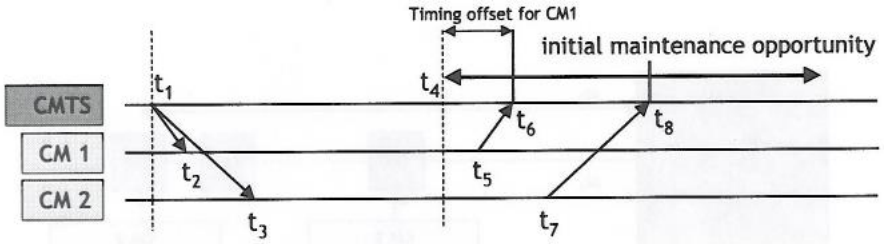
- Modem ranging opportunity at least 1 every T4 seconds (between 30 and 35)



- CMTS should respond to a RNG-REQ within T3 period (between 50 and 200 ms)
- Reinit MAC after T4 timeout or 16 x T3 timeouts

Timing offset

- Timing offset is an indication of round-trip delay between CMTS and CM plus other delays (DS interleaver, processor, internal modem)
- Timing offset unit [tick/64], 1 tick is 6.25μs
- Maximum supported one-way delay is 800 μs or 160 km (timing offset ~16384)
- CMTS measures timing offset:



t_1: CMTS transmits a MAP containing starting boundary t_4 of initial maintenance transmit opportunity

t_2, t_3: CM receives MAP

t_5, t_6: CM 1 transmits ranging request and CMTS receives request

t_7, t_8: CM 2 transmits ranging request and CMTS receives request

- When CMTS has incorrect timing offset values, modems may get unusable transmit opportunities in the past.

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RNG-REQ

```
DOCSIS
    11.. .... = FCType: MAC Specific (0x03)
    ..00 000. = FCParm: Timing Header (0x00)
    .... ...0 = EHDRON: Extended Header Absent
    MacParm: 0x00
    Length after HCS (bytes): 28
    Header check sequence: 0xea1d
Mac Management
    Destination Address: Casa_02:14:0f (00:17:10:02:14:0f)
    Source Address: Scientif_9e:40:25 (00:16:92:9e:40:25)
    Message Length - DSAP to End (Bytes): 10
    DSAP [0x00]: 0x00
    SSAP [0x00]: 0x00
    Control [0x03]: 0x03
    Version: 1
    Type: Ranging Request (4)
    Reserved [0x00]: 0
Ranging Request
    Service Identifier: 70
    Downstream Channel ID: 1
    Pending Till Complete: 0
```


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RNG-RSP

```
⊞ DOCSIS
⊞ Mac Management
⊟ Ranging Response
    Service Identifier: 72
    Upstream Channel ID: 2
    Timing Adjust (6.25us/64): 1640
    Power Level Adjust (0.25dB units): 0
    Offset Freq Adjust (Hz): 0
    Transmit Equalisation Adjust: 0801180000000000000000000000000000000000000000...
    Ranging Status: Continue (1)
```

```
⊞ DOCSIS
⊞ Mac Management
⊟ Ranging Response
    Service Identifier: 72
    Upstream Channel ID: 2
    Timing Adjust (6.25us/64): 0
    Power Level Adjust (0.25dB units): 0
    Offset Freq Adjust (Hz): 0
    Transmit Equalisation Adjust: 0801180000000000000000000000000000000000000000...
    Ranging Status: Success (3)
```


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CoS versus QoS

- EuroDocsis 1.0 -> Class of Service
  - No guarantee of service in terms of bandwidth and delivery
  - Only “best effort”

- EuroDocsis 1.1 and higher -> Quality of Service
  - Guarantees on transmission rates, jitter and other characteristics
  - Scheduling types
    - Upstream
      - Best Effort
      - Non-Real-Time Polling
      - Real-Time Polling
      - Unsolicited Grant Service
      - Unsolicited Grant Service w/ Activity Detection
    - Downstream
      - “Undefined” , vendor specific behavior

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Service Flows & Classifiers

- Service Flow
  - A QoS parameter set is assigned to a Service Flow (virtual channel)
  - Service flow types:
    - Static - Provisioned in (modem) configuration file
    - Dynamic
      - Created as needed, on demand, e.g.: voice call
      - DOCSIS DSx messages, like Addition, Change, Deletion
  - Primary service flows must always be defined, used for MAC-management signalling
- Classifier
  - Set of matching criteria applied to each packet entering cable network
    - Ethernet LLC criteria
    - IP criteria (L3 and L4)
    - VLAN criteria
  - Matching packets get classified onto referenced Service Flow
  - Different classifiers in US and DS

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DHCP, TFTP

- Cable modem obtains an IP address via DHCP protocol (4 way handshake)
  - DISCOVER, OFFER, REQUEST, ACK
- In DHCP Offer both TFTP server address and bootfile name are provided
- Cable modem download bootfile from TFT server
- Bootfile is a TLV encoded configuration file
  - Upstream/downstream service flows and classifiers
  - SNMP MIB Objects
  - BPI settings
  - MIC (Message Integrity Check)
- TLV : Type – Length – Value
  - E.g.: 0x0a 0x01 0x01

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Registration

- 3 way handshake
  - CM parses the bootfile, and based on its content generates REG REQ message containing:
    - Modem capabilities
    - Baseline privacy parameters
    - Classifiers/Service flows
    - MIC (Message Integrity Check)
  - CMTS sends REG RSP to cable modem
    - Assigned IDs of Classifiers and Service Flows
    - Response code (okay = 0)
    - In Docsis 3.0 mode Transmit and Receive Channel Sets
  - CM accepts (or denies) the response by sending REG ACK

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REG-REQ

```
Registration Request
  Service Identifier: 72
  TLV Data
    3 Network Access: On
    18 Max # of CPE's: 2
    28 Max # of Classifiers: 20
    29 Privacy Enable: Enable
    17 Baseline Privacy Encoding: 01040000000a02040000000a03040000025804040000000a...
    VSIF Encodings (Unknown)
    VSIF Encodings (Unknown)
    22 Upstream Packet Classifier (Length = 20)
    22 Upstream Packet Classifier (Length = 27)
      .1 Classifier Ref: 2
      .3 Service Flow Ref: 1
      .5 Rule Priority: 16
      .6 Activation State: Active
      9 IP Classifier (Length = 12)
        ..3 Source Address: 10.0.0.0 (10.0.0.0)
        ..5 Source Mask: 255.0.0.0 (255.0.0.0)
    22 Upstream Packet Classifier (Length = 19)
    23 Downstream Packet Classifier (Length = 27)
    23 Downstream Packet Classifier (Length = 28)
    23 Downstream Packet Classifier (Length = 27)
    23 Downstream Packet Classifier (Length = 35)
    23 Downstream Packet Classifier (Length = 19)
```


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REG-REQ (2)

```
⊟ 24 Upstream Service Flow (Length = 25)
    .1 Service Flow Ref: 2
    .6 QOS Parameter Set: Apply to Provisioned, Active and Admitted Sets; Admission Control and Activate
    .7 Traffic Priority: 1
    .8 Maximum Sustained Traffic Rate (bps): 128000
    .15 Scheduling Type: Best Effort Service (0x00000002)
  ⊟ .16 Request/Transmission Policy: 0x0000008a
      Service flow MUST NOT use priority multicast request opportunities
      Service flow MUST NOT use Request/Data opportunities for data
      Service flow MUST NOT suppress payload headers
⊞ 25 Downstream Service Flow (Length = 16)
⊞ 25 Downstream Service Flow (Length = 16)
  6 CM MIC: b68e45abf24baf5fdb72d3230934efc7
  7 CMTS MIC: dcd8cac167632534ed9b85f0361bb216
⊟ 5 Modem Capabilities Type (Length = 39)
    .1 Concatenation Support: On
    .2 Docsis Version: Unknown (2)
    .3 Fragmentation Support: On
    .4 PHS Support: On
    .6 Privacy Support: On
    .7 # Downstream SAIDs Supported: 15
    .8 # Upstream SAIDs Supported: 16
    .10 Xmit Equalizer Taps/Sym: 1
    .11 # Xmit Equalizer Taps: 24
    .12 DCC Support: On
    .15 Expanded Unicast SID Space: On
    .... .... .... .... .... .... .... ...0 = .16 Ranging Hold-Off (CM): Off (0)
    .... .... .... .... .... .... .... ..0. = .16 Ranging Hold-Off (ePS or eRouter): Off (0)
    .... .... .... .... .... .... .... .1.. = .16 Ranging Hold-Off (eMTA or EDVA): On (1)
    .... .... .... .... .... .... .... 0... = .16 Ranging Hold-Off (DSG/eSTB): Off (0)
  8 Vendor ID: 001692
  12 Modem IP Address: 10.9.133.134 (10.9.133.134)
```


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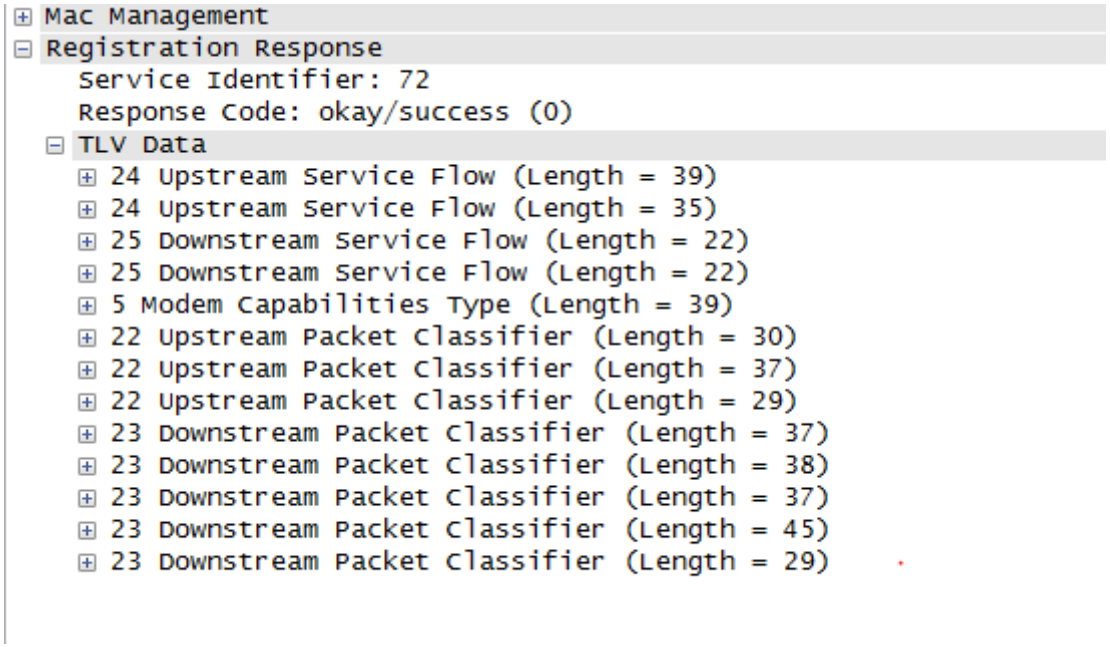
REG-RSP


Mac Management
Registration Response
Service Identifier: 72
Response Code: okay/success (0)
TLV Data
24 Upstream Service Flow (Length = 39)
24 Upstream Service Flow (Length = 35)
25 Downstream Service Flow (Length = 22)
25 Downstream Service Flow (Length = 22)
5 Modem Capabilities Type (Length = 39)
22 Upstream Packet Classifier (Length = 30)
22 Upstream Packet Classifier (Length = 37)
22 Upstream Packet Classifier (Length = 29)
23 Downstream Packet Classifier (Length = 37)
23 Downstream Packet Classifier (Length = 38)
23 Downstream Packet Classifier (Length = 37)
23 Downstream Packet Classifier (Length = 45)
23 Downstream Packet Classifier (Length = 29)

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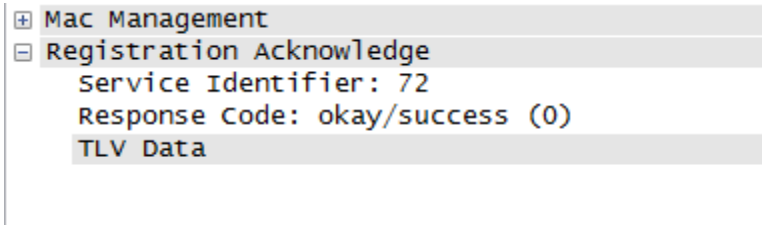
REG-ACK


Mac Management
Registration Acknowledge
Service Identifier: 72
Response Code: okay/success (0)
TLV Data

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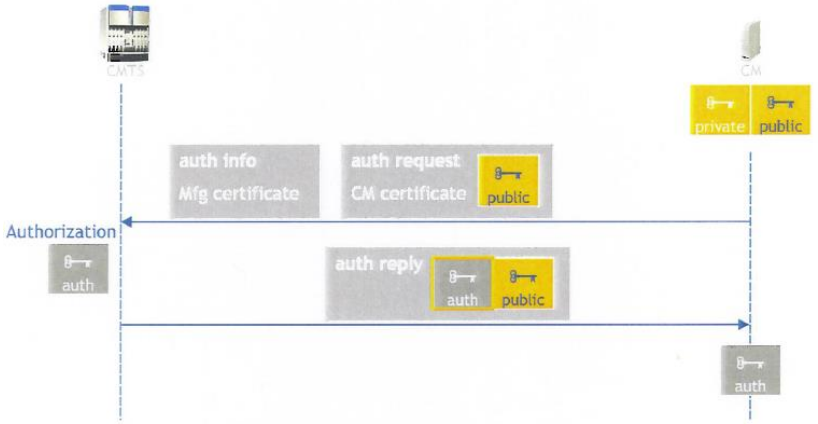
Baseline Privacy Interface

- BP+ Key management (Docsis 1.1 and higher) – With Authentication
- Docsis and/or EuroDocsis root certificate must be (pre)installed on the CMTS
- Manufacturer certificates may be manually added on CMTS
- CM MAC address tampering is detected



- KEK and HMAC (hash key) are generated from Auth Key
- Symmetric encryption with TEK of payload data traffic
- Typically TEK lifetime is few hours, while KEK lifetime is few days
  Time synchronization is required between CM and CMTS (time and NTP)

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BPKM Key Request

```
⊞ DOCSIS
⊞ Mac Management
⊟ BPKM Request Message
    BPKM Code: Key Request (7)
    BPKM Identifier: 2
    BPKM Length: 205
⊟ BPKM Attributes
  ⊟ 5 CM Identification
      1 Serial Number: 106576270
      2 Manufacturer Id: 001692
      4 RSA Public Key: 30818902818100c643728c42e37c95882a0fea9f6e1c55b8...
      3 Mac Address: Scientif_9e:40:25 (00:16:92:9e:40:25)
    10 Key Sequence Number: 1
    12 SAID: 72
    11 HMAC Digest: 8f0ad5d7c8bfb3ab853f742c9c2b3208c5f85e61
```


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BPKM Key Reply

```
⊞ DOCSIS
⊞ Mac Management
⊟ BPKM Response Message
    BPKM Code: Key Reply (8)
    BPKM Identifier: 2
    BPKM Length: 104
⊟ BPKM Attributes
    10 Key Sequence Number: 1
    12 SAID: 72
  ⊟ 13 TEK Parameters
      8 Traffic Encryption Key: 3e85cbde6545857f
      9 Key Lifetime (s): 21600
      10 Key Sequence Number: 1
      14 CBC IV: 31c9598238add010
  ⊟ 13 TEK Parameters
      8 Traffic Encryption Key: 1ce633015567b34d
      9 Key Lifetime (s): 43200
      10 Key Sequence Number: 2
      14 CBC IV: d7c9df1b7e9b5d85
    11 HMAC Digest: 0807c8f419423cecc84a813ff66ea15ae1a1addc
```


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Dynamic Operation

- US and/or DS channel changes within MAC domains, during operation
- DOCSIS 2.0: Dynamic channel change
  - Initialization techniques
    - Reinitialize MAC - Long interruption is not acceptable for dynamic load balancing
    - Broadcast/Unicast/Direct - Move to new channel without interruption
- DOCSIS 3.0: Dynamic bonding change
  - Add or remove channels from channel set during operation

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DCC-REQ

```
⊞ DOCSIS
⊞ Mac Management
⊟ DCC-REQ Message
    Transaction ID: 32792
    Up Channel ID: 2
    Initialization Technique: Broadcast Init RNG on new chanbefore normal op (1)
    UCD Substitution: 0202040101011002040 2c895e00350ccccccc0df20f0f0f...
    UCD Substitution: 680402000005010c06014b07020152080106090108 0a0102...
  ⊟ 7 DCC-REQ Service Flow Substitution Encodings (Length = 16)
      SF Sub - SFID Current Value: 383
      SF Sub - SFID New Value: 383
      SF Sub - SID Current Value: 72
      SF Sub - SID New Value: 72
  ⊟ 7 DCC-REQ Service Flow Substitution Encodings (Length = 16)
      SF Sub - SFID Current Value: 292
      SF Sub - SFID New Value: 292
      SF Sub - SID Current Value: 73
      SF Sub - SID New Value: 73
    Auth Key Sequence Number: 1
    HMAC-DigestNumber: 5eda296d93dd57bcd9de21b09447c4b5f686e03b
```


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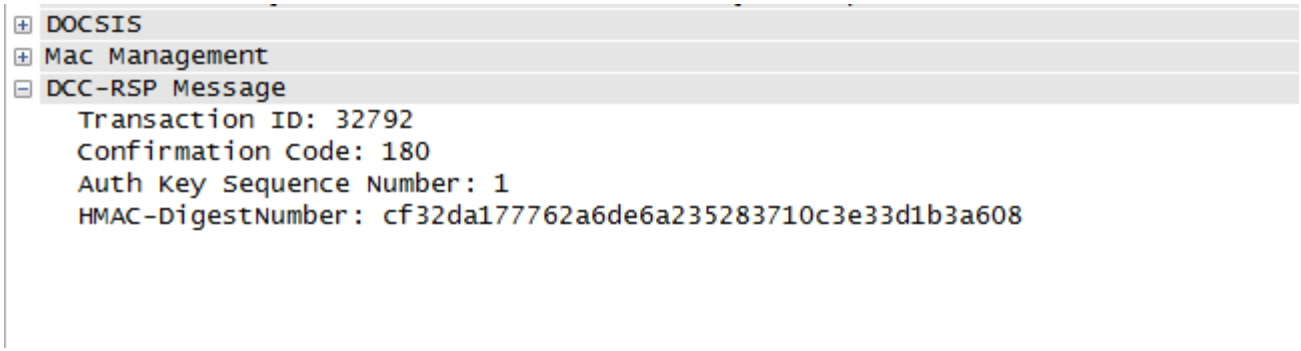
DCC-RSP


DOCSIS
Mac Management
DCC-RSP Message
Transaction ID: 32792
Confirmation Code: 180
Auth Key Sequence Number: 1
HMAC-DigestNumber: cf32da177762a6de6a235283710c3e33d1b3a608

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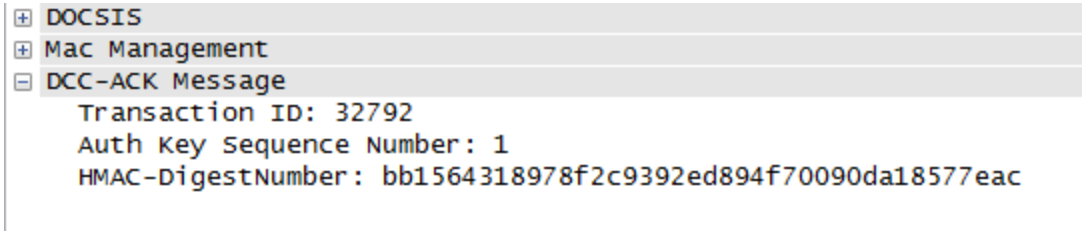
DCC-ACK


DOCSIS
Mac Management
DCC-ACK Message
Transaction ID: 32792
Auth Key Sequence Number: 1
HMAC-DigestNumber: bb1564318978f2c9392ed894f70090da18577eac

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  - BSoD
- Docsis 3.1

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Terminology

- MAC Domain
  - Set of downstream and upstream channels that belong together
- Primary downstream
  - Carries SYNC, MAP, UCD for Docsis 3.0 modem
  - Carries new Docsis 3.0 MDD (MAC Domain Descriptor)
- Secondary downstream
  - Carries no Docsis signalling for the MAC domain it is secondary for.
- DCID and UCID
  - Downstream and Upstream Channel ID
  - Unique for each channel in a MAC domain
  - Used to identify which channels a modem can use
- Channel bonding
  - Use multiple downstream and/or upstream channels concurrently to increase speed
  - Sequence numbers in extended header allows proper ordering of the packets

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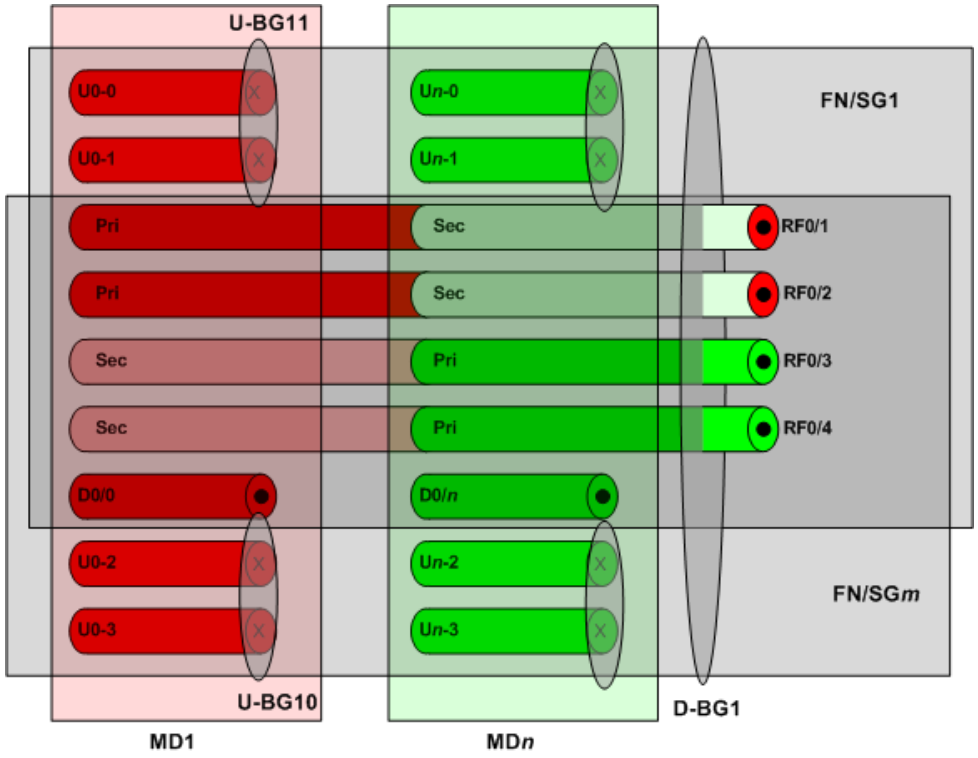
Service Groups

- Docsis 3.0 requires Service-Groups (SG) configurations
  - SG corresponds to a Fiber Node (FN)
  - An SG can span multiple MAC domains (MD)
- A DS Channel is primary in at most 1 MAC domain and secondary in others
- A downstream bonding group can encompass both primary and secondary channels



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MAC Domain Descriptor (MDD)

- Fiber Node configuration table info allows CMTS to generate MDD messages
- MDD Messages describe:
  - MAC Domain configuration, including DCID
  - Service Groups in the MAC domain
- Periodically transmitted on every downstream channel, but a modem will only interpret DOCSIS signalling on its primary downstream.
- MDD received on a channel
  - Carries DCID for that downstream
  - Carries TLV (Type Length Value format) that provide information required by modem during ranging/registration
    - Provisioning mode (IPv4, IPv6, APM, Dual)
    - Upstream frequency range
    - Security

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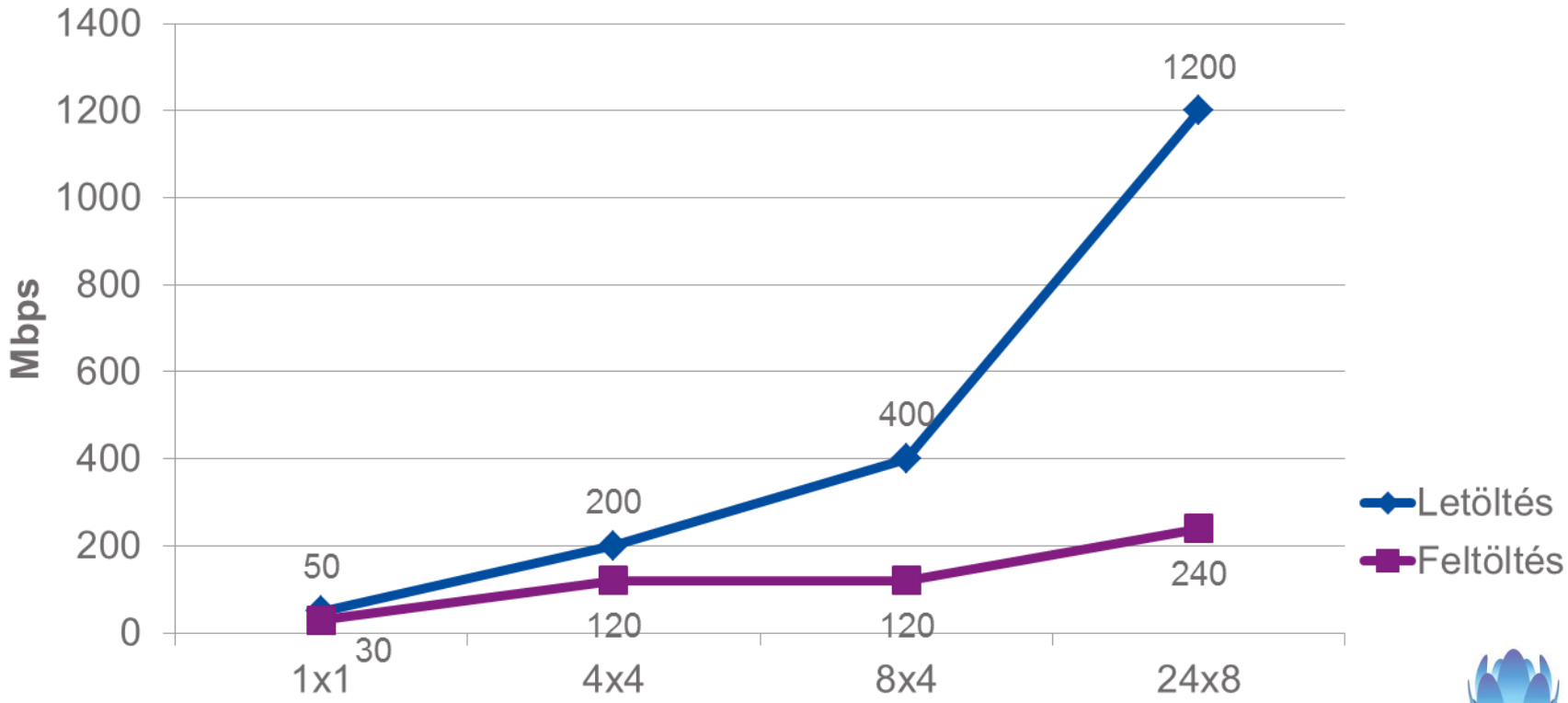
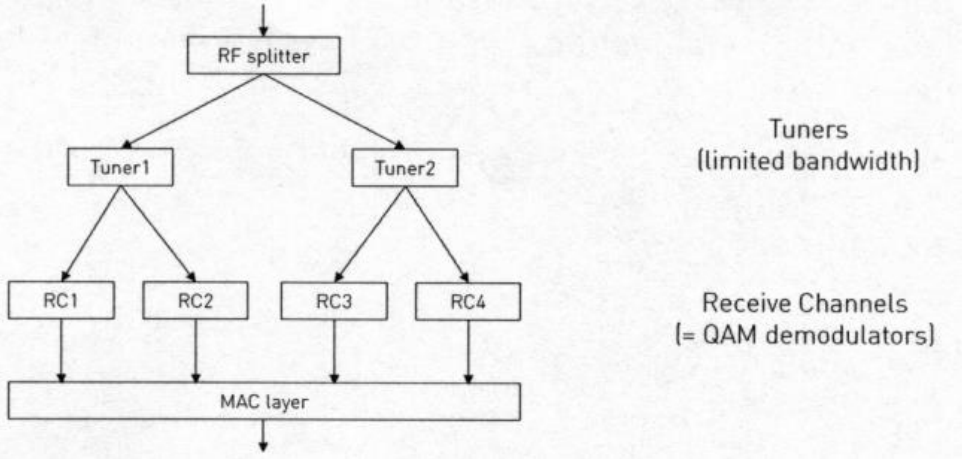
Downstream Channel bonding

- Docsis 3.0 requires at least 4 DS bonded channels to be supported in a 64MHz wide capture range
- Theoretical maximum speed per cable modem depends on the number of channels



Receive Channel Profile (RCP)

- CM bonding capabilities are limited by its tuner



- Older tuner's receive window is typically 96MHz
- New modems can see the full spectrum

- During registration the CM signals these capabilities to the CMTS using RCP message
- Standard RCP defined
  - Modem must support at least 1 standard "CLAB-8M-004"

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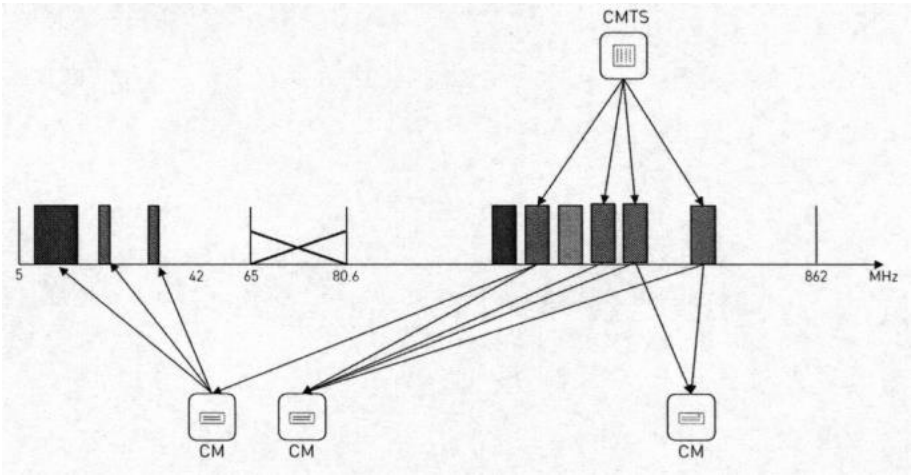
Upstream Channel bonding

- Channels with different characteristics can be bonded within an upstream bonding group



- Each Service flow is assigned to an US bonding group
  - Primary service flow: US#1, US#2, US#3
  - Voice UGS flow: US#1
- CM signals upstream capabilities to CMTS during registration
  - Minimum of 4 transmitters of 6.4MHz must be supported
  - Upstream channel must be able to be anywhere in the 5 to 65 MHz band. Note: American Docsis 3.0 version allows 85MHz extended range
  - Maximum difference between channel transmit powers of 12dB

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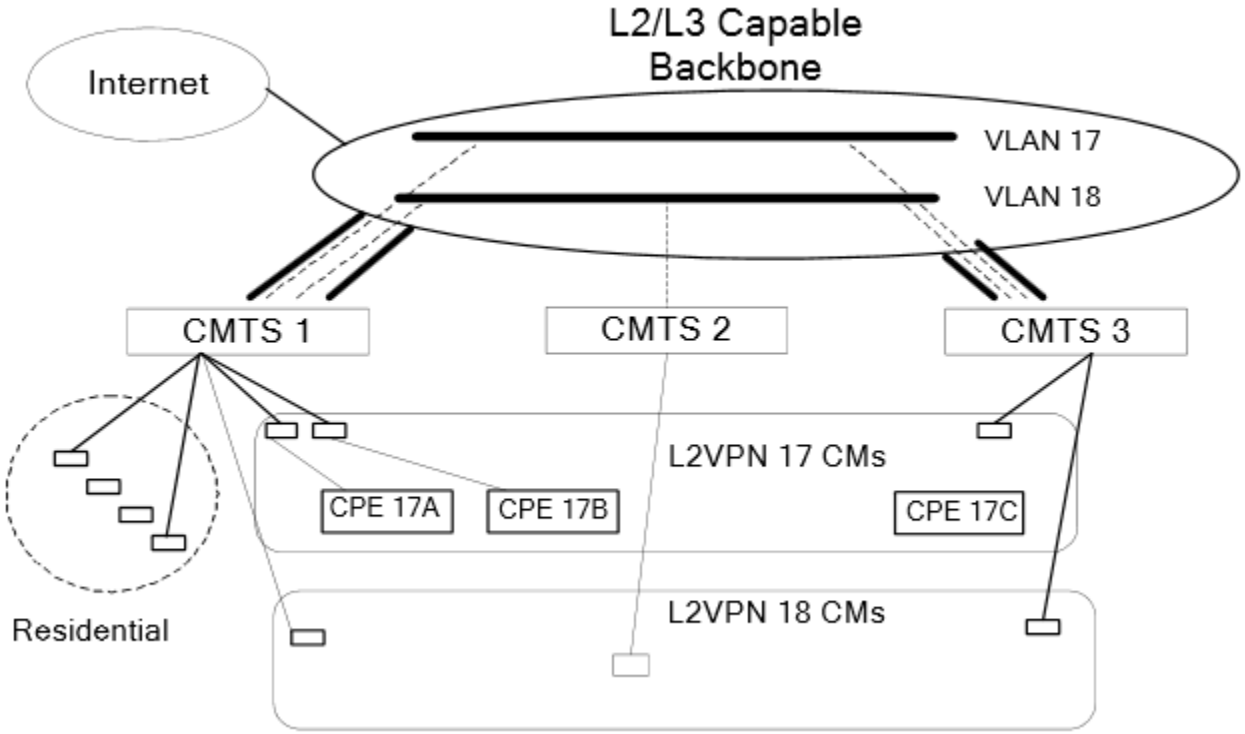
BSoD

- Business Services Over DOCSIS – extension to core DOCSIS specification
- Together with MPLS backbone it provides transparent E2E L2 service
- Tagging/tag removing are done by the CMTS based on a predefined value in cable modem's bootfile



Agenda

- Introduction
  - Signal transmission
  - Provisioning flow
- Docsis protocol
  - Docsis management traffic
  - QoS
  - Baseline privacy
  - Dynamic operation
- Docsis 3.0
  - Channel Bonding
  - BSoD
- Docsis 3.1

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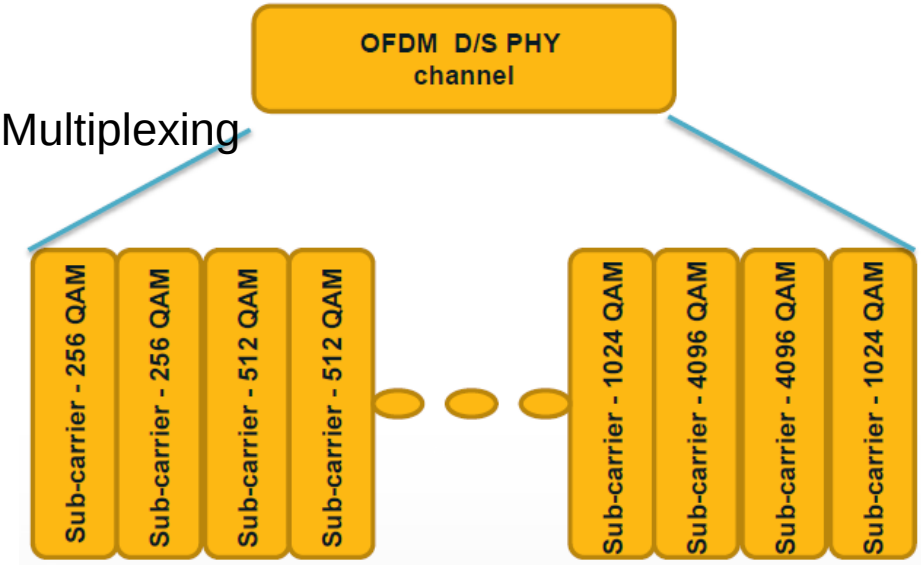
DOCSIS 3.1 new features

- New specification released in October 2013
- Aim is 10Gbps+ download és 1Gbps+ upload speed
- Extended spectrum, up to 200 MHz in upstream, and up to 1.2 GHz in downstream
- New multiplexing : OFDM
  Orthogonal Frequency Division Multiplexing
- 20-50KHz wide channels with adaptive modulation profile capability
-



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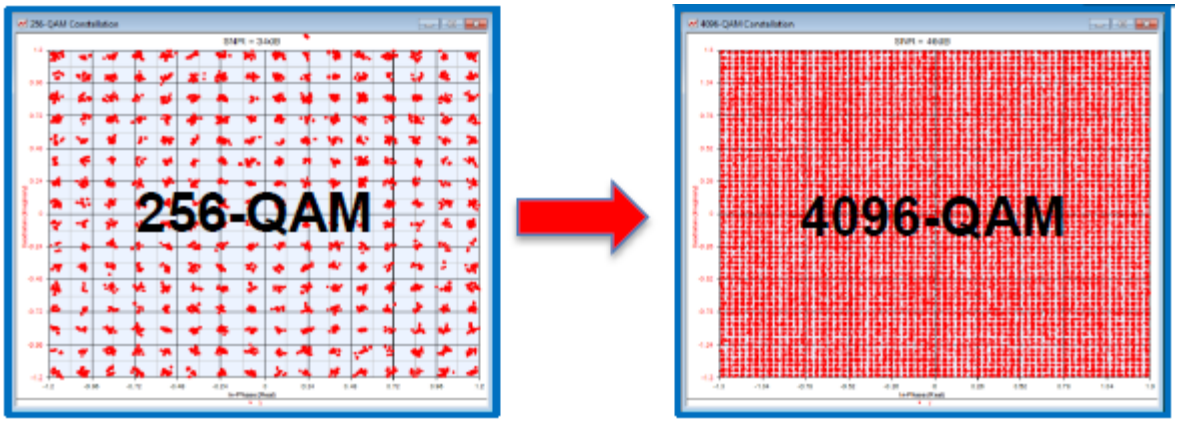
DOCSIS 3.1 new features (2)

- Due to the higher level of modulation (4096 QAM instead of 256QAM) 12 bits are transmitted in one symbol instead of 8 bits. +50% efficiency



- New forward codeword error correction algorythm : LPDC (Low Density Parity Check)

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Thank you!