CABLE NETWORKS

INTRODUCTION TO CABLE NETWORK TECHNOLOGIES AND PROTOCOLS

Peter R. Egli
peteregli.net

Contents

1. Cable Network architecture (1/3)

Traditional cable network architecture:

In traditional cable networks, TV signals received in regional head ends by dish antennas are distributed to local head ends (LHE). LHEs distribute TV signals to residential customers via coaxial cables.

Distribution coaxial cable with amplifiers and taps

Tap

Tap

Trunk splitter

Coaxial trunk cable

Trunk amplifier

LHE

LHE

LHE

Fiber ring for CATV signal distribution

Coaxial trunk cable

LHE

LHE

Regional Head End (RHE)

LHE Local Head End
RHE Regional Head End
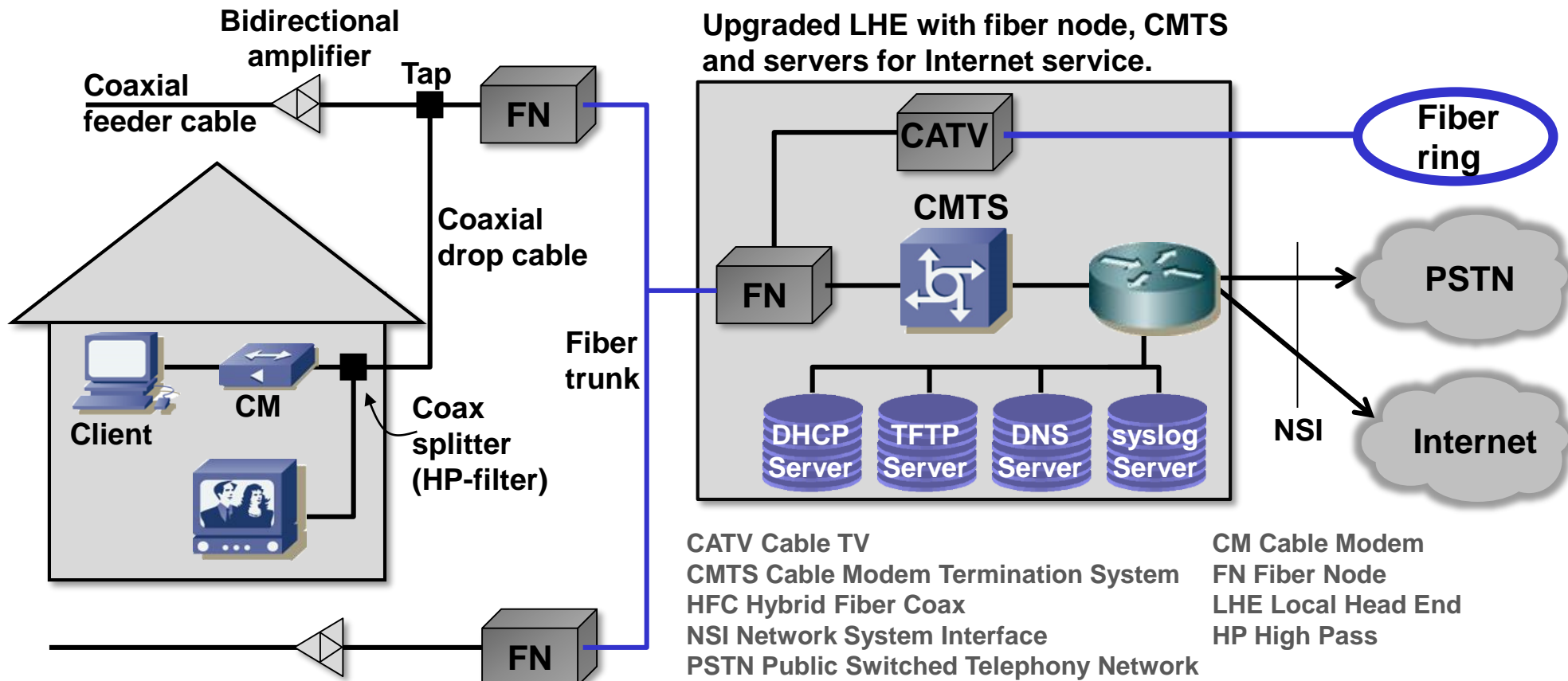**CATV CAble TeleVision**
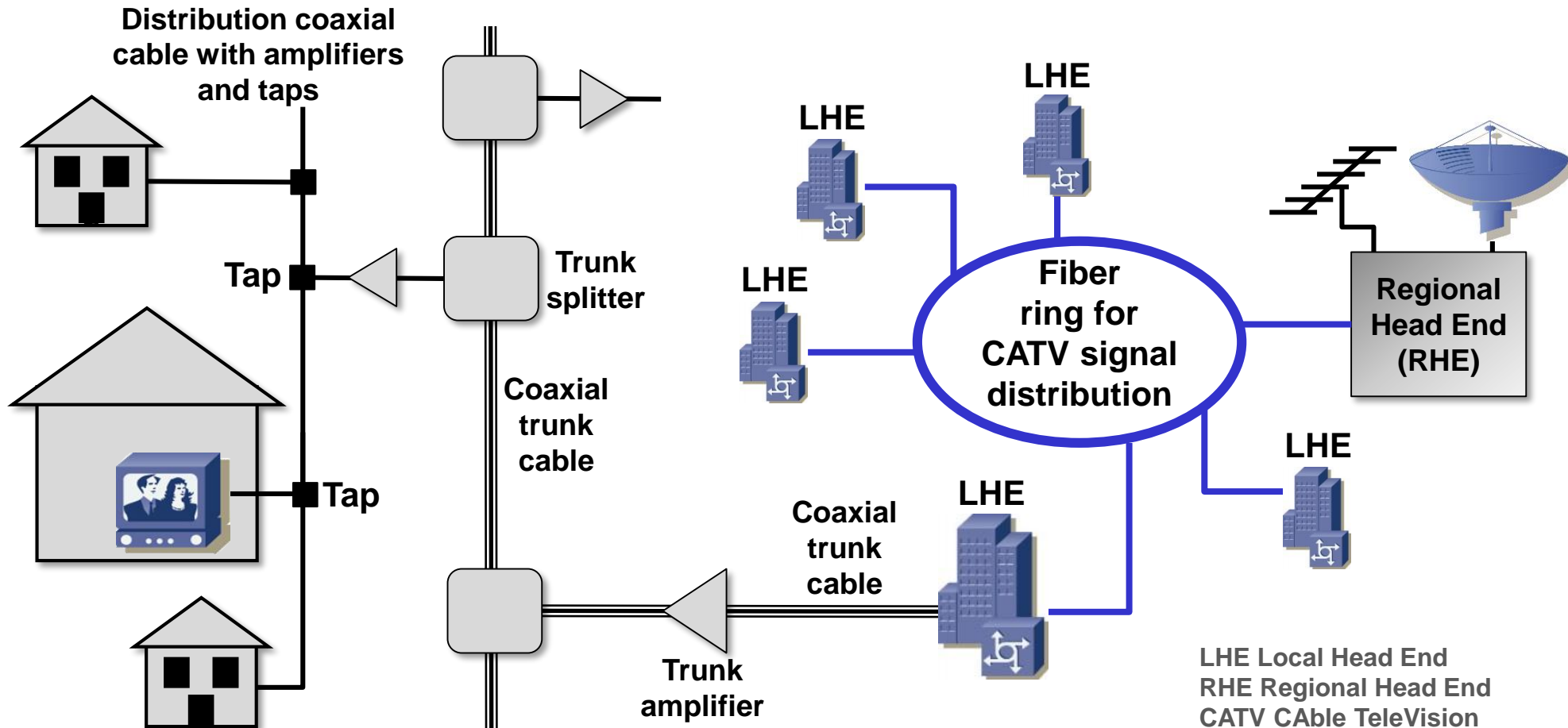
1. Cable Network architecture (2/3)

Cable network architecture for TV and data service:

Cable networks upgraded for combined TV and data service (Internet access) employ a hybrid fiber coax (HFC) cabling architecture.

Trunk coaxial cable of legacy cable networks are replaced by fibers that terminate in fiber nodes. Homes are connected to fiber nodes through coaxial cables fitted with bidirectional amplifiers.

CATV Cable TV
CMTS Cable Modem Termination System
HFC Hybrid Fiber Coax
NSI Network System Interface
PSTN Public Switched Telephony Network

CM Cable Modem
FN Fiber Node
LHE Local Head End
HP High Pass

1. Cable Network architecture (3/3)

Limitations of traditional cable networks for data service:
Traditional cable networks were targeted at TV distribution (broadcast TV signals to customer). As cable networks were one-way only (signals only from cable HE to customer), they were unsuited for 2-way data service. In earlier days the upstream for data service (from customer to HE) was realized with dial-up phone lines but this proved not a viable solution. In order to offer two-way data service on a cable network, additional infrastructure was required.

Cable networks tree-branch topology:
Cable networks have a tree-and-branch topology. The coax cables are simply branched for hooking up subscribers (homes). This means that a cable network is a shared medium (all signals are always present on the entire network). Amplifiers need to be installed at regular intervals (distances) to regenerate the signals. Up to some 35 amplifiers can be cascaded thus affording wide geographical coverage.

Cable network upgrade for data service:
In the course of upgrading traditional TV-distribution networks to two-way data networks, digital signaling, two-way amplifiers on coax cables and fiber trunks with greatly increased capacity were introduced. This resulted in a combined fiber-coax infra-structure (HFC - Hybrid Fiber Coax). Fibers run between LHEs and fiber nodes. Coax cables (feeder cables) connect to individual homes.
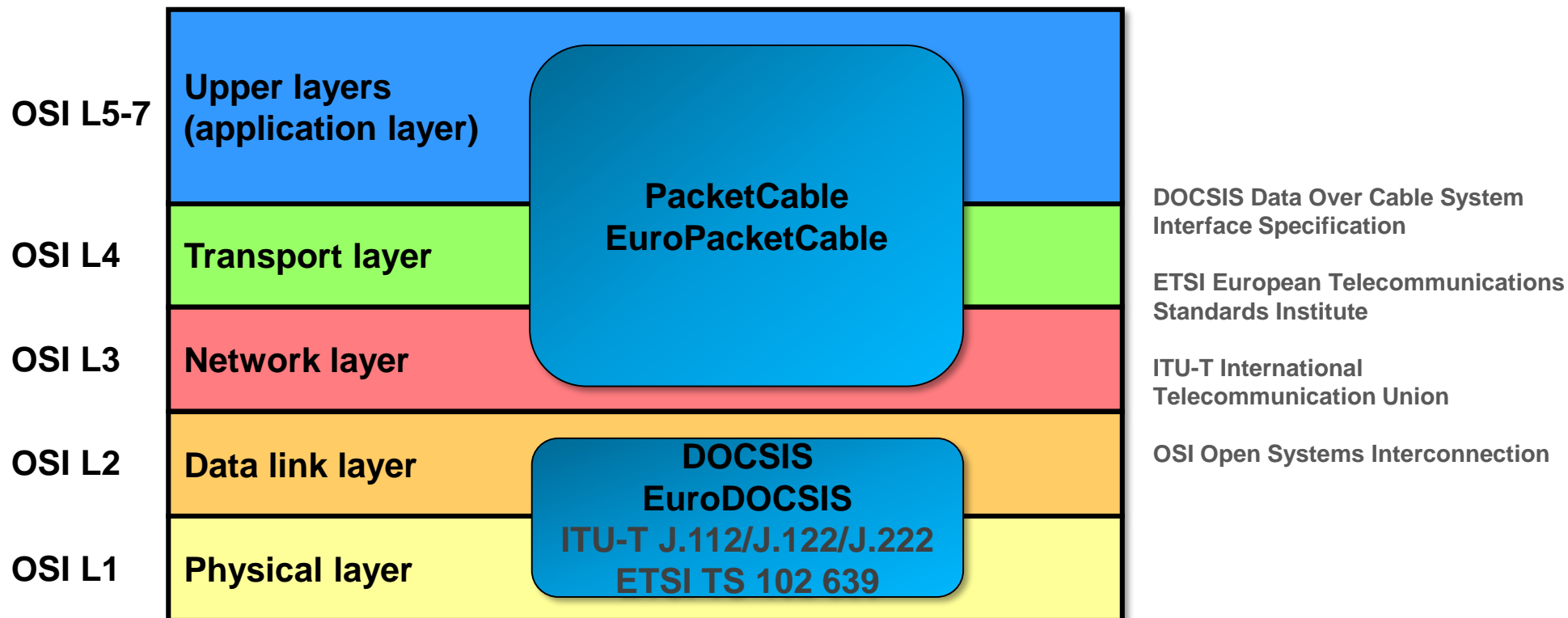Two-way cable networks provide an 'extended Ethernet' network that can span up to 100 miles.

2. Relevant cable network standards (1/2)

Most of the relevant cable network standards were developed and published by CableLabs Inc. (see www.cablelabs.com).

DOCSIS addresses physical and data link layer operation while PacketCable defines the upper layers for providing additional services like IP and VoIP.

ITU-T and ETSI have adopted CableLabs DOCSIS standards and published these under their respective nomenclature.

OSI L5-7	Upper layers (application layer)
OSI L4	Transport layer
OSI L3	Network layer
OSI L2	Data link layer
OSI L1	Physical layer

PacketCable EuroPacketCable

DOCSIS EuroDOCSIS ITU-T J.112/J.122/J.222 ETSI TS 102 639

DOCSIS Data Over Cable System Interface Specification

ETSI European Telecommunications Standards Institute

ITU-T International Telecommunication Union

OSI Open Systems Interconnection

Cable Networks

2. Relevant cable network standards (2/2)

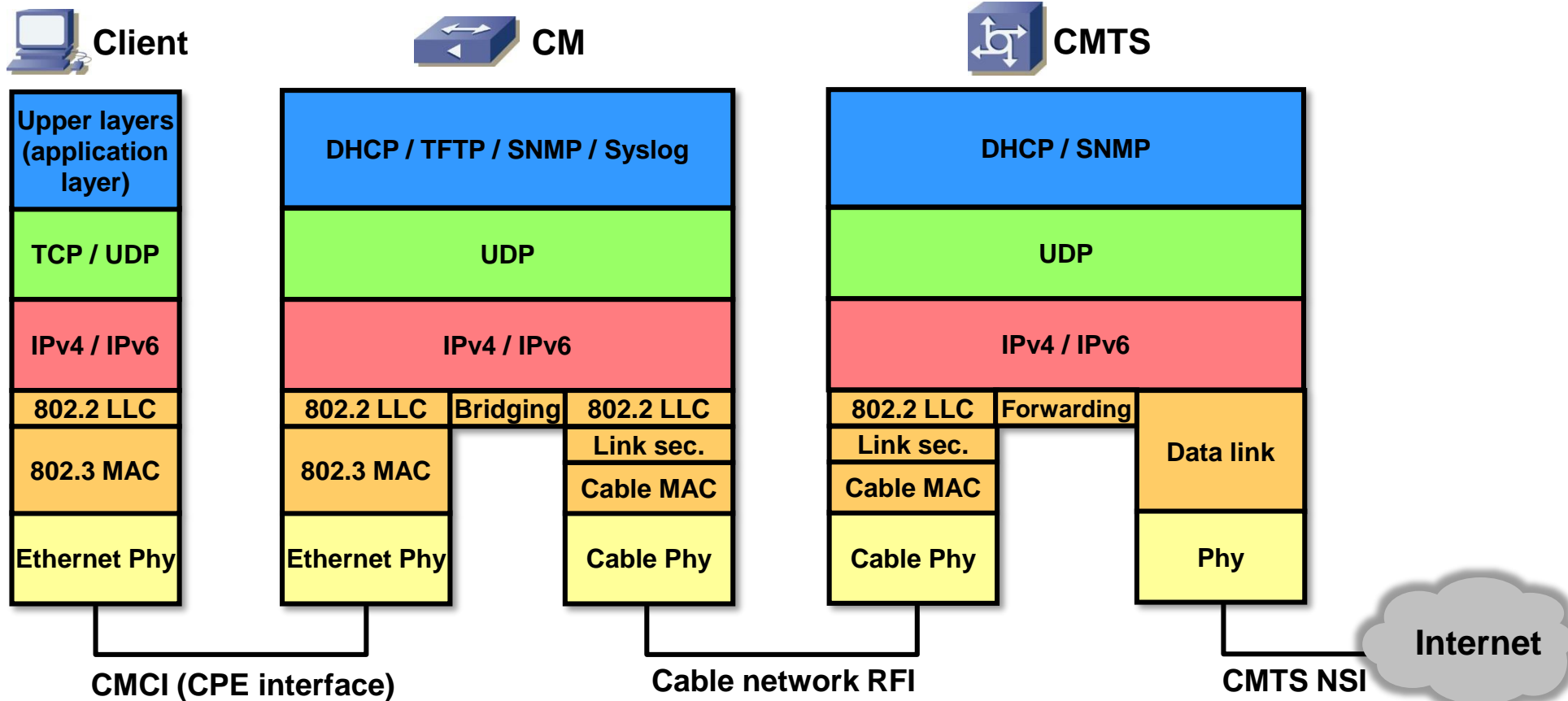| Standard	Issuer	Scope	Description
DOCSIS	CableLabs	Physical layer & data link layer	Data Over Cable Service Interface Specification. Version 1.0 through 3.0 based on 6MHz TV channels (8MHz in Europe). Version 3.1 (October 2013) based on 20kHz-50kHz OFDM sub-carriers bonded inside a 200MHz spectrum. All DOCSIS versions are downwards compatible.
EuroDOCSIS	Cable Europe	Physical layer & data link layer, European specialties	Frequency allocations for European CATV systems based on 8MHz channels affording more digital bandwidth per channel. Activities of Cable Europe were transferred to CableLabs in 2013.
ES 102 639	ETSI	Same as EuroDOCSIS	EuroDOCSIS adopted by ETSI.
J.112, J.122, J.222	ITU-T	Physical layer & data link layer	DOCSIS adopted by ITU-T. J.112 = DOCSIS 1.0. J.122 = DOCSIS 2.0. J.222 = DOCSIS 3.0.
PacketCable	CableLabs	Layer 3 – 7	PacketCable builds on top of DOCSIS and addresses OSI layers 3 (IP) through 7 for the provisioning of Internet access and real-time multimedia services like VoIP.
EuroPacketCable	Cable Europe / CableLabs	Same as PacketCable	Only minor differences to PacketCable.

3. DOCSIS (1/8)

Cable network protocol stack:

User traffic is typically bridged on the cable modem (CM).

The application layer protocols DHCP, TFTP and SNMP on the CM are used for configuration and management of the cable modem.

The CMTS performs bridging or IP forwarding.

Client

Upper layers (application layer)
TCP / UDP
IPv4 / IPv6
802.2 LLC
802.3 MAC
Ethernet Phy

CM

DHCP / TFTP / SNMP / Syslog		
UDP		
IPv4 / IPv6		
802.2 LLC	Bridging	802.2 LLC
802.3 MAC		Link sec.
		Cable MAC
Ethernet Phy		Cable Phy

CMTS

DHCP / SNMP		
UDP		
IPv4 / IPv6		
802.2 LLC	Forwarding	Data link
Link sec.		
Cable MAC		
Cable Phy		Phy

CMCI (CPE interface)

Cable network RFI

CMTS NSI

Internet

3. DOCSIS (2/8)

Cable network physical layer (1/2):
**In DOCSIS 1.0 and 2.0, downstream and upstream transmission use TDM access (TDMA).**
The frequency spectrum is divided into timeslots and temporarily assigned to modems.
This dynamic timeslot allocation is managed by the CMTS.
DOCSIS 3.0 uses TDMA or S-CDMA (Synchronous CDMA).

DOCSIS 1.0 and 2.0 provided a single 6 or 8 MHz channel per customer. DOCSIS 3.0 introduced channel bonding that allows combining multiple 6 or 8MHz channels for a single customer.

Upstream transmission uses lower frequency bands which are noisier by nature. Thus noise on the medium is aggregated in the upstream direction which requires far less bandwidth than upstream (asymmetric traffic pattern of residential users).
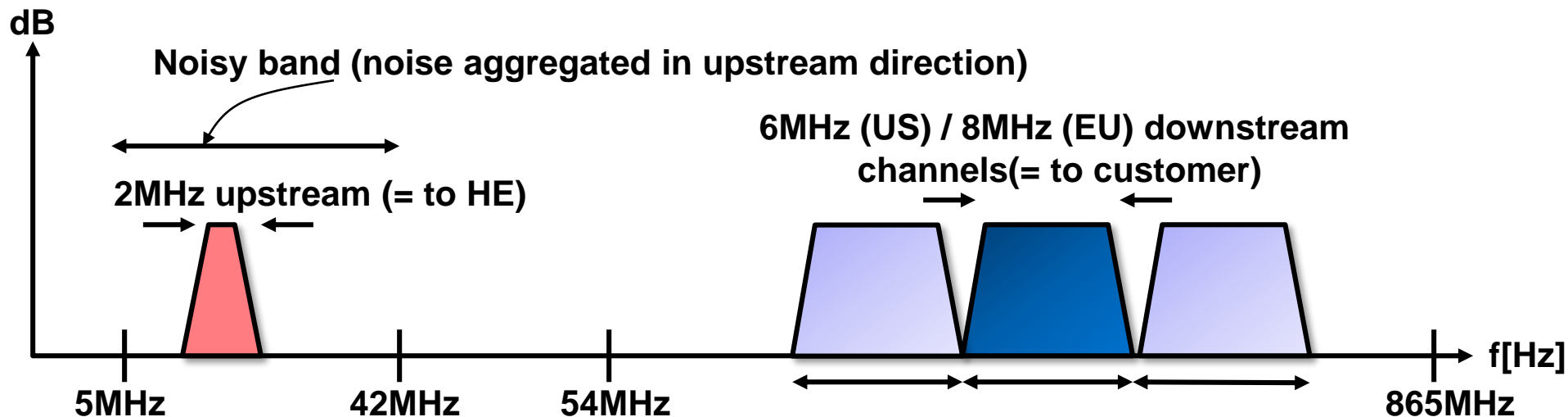
3. DOCSIS (3/8)

Cable network physical layer (2/2):

Downstream modulation and bandwiths:

Channel bandwidth / standard	QAM64 modulation	QAM256 modulation
6MHz (DOCSIS 1.0, 2.0)	31.2MBit/s	41.6MBit/s
8MHz (EuroDOCSIS 1.0, 2.0)	41.4MBit/s	55.2MBit/s
6MHz (DOCSIS 3.0)	m*31.2MBit/s	m*41.6MBit/s
8MHz (EuroDOCSIS 3.0)	m*41.4MBit/s	m*55.2MBit/s

Upstream modulation and bandwidths:

One 2MHz QAM16 or QPSK upstream channel yields about 0.5-10Mbit/s.

Upstream and downstream bandwidth is typically shared by 500-2000 subscribers. With cable equipment becoming cheaper, the number of customers per LHE is falling.

Direction	Modulation	Standards
Upstream	QPSK, 16QAM	DOCSIS 1.x.
Upstream	QPSK, 8QAM, 16QAM, 32QAM, 64QAM, 128QAM	DOCSIS 2.0, 3.0.
Upstream	4096QAM	DOCSIS 3.1.

© Peter R. Egli 2017

3. DOCSIS (4/8)

Cable MAC (Media Access Control):

Cable networks use TDMA (Time Division Multiple Access) as MAC protocol (CM and CMTS are synchronized). The synchronization is necessary since cable networks span large distances and thus a simple collision detection algorithm like Ethernet MAC cannot be used.

Upstream TDMA MAC:

The upstream channel is divided into mini-slots (time division).
There are 3 types of time slots:
  a. Ranging (used to synchronize CM and CMTS for TDMA operation)
  b. Contention (used by CM to send Request frames).
  Contention slots are accessed by CM with a truncated binary backoff
  algorithm similar to Ethernet.
  c. Reserved (for ordinary data transmission)

Before transmitting the CM requests a channel by sending a „Req" frame indicating the amount of data to be transmitted; the CMTS responds with a „Grant" frame.

The CMTS runs a Bandwidth allocation algorithm (fair share among CMs, maybe prioritizing certain classes of service, e.g. voice).
For this purpose, the CMTS sends an upstream bandwidth allocation map message to the CMs indicating when which CM may transmit data (1 entry per CM indicates the allowed transmit duration).

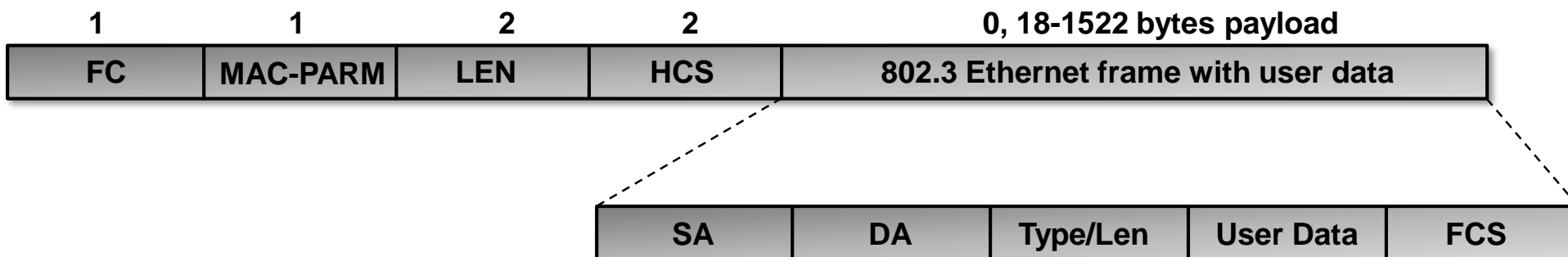## 3. DOCSIS (5/8)

Cable MAC frame format:

MAC header:

DOCSIS defines a number of frame types all of which use the following frame format.

1	1-2	2	0-240	2	0, 18-1522
FC	MAC-PARM	LEN / SID	EHDR	HCS	Payload

User data frame:

End user traffic is encapsulated in user data frames.
The payload carries a complete 802.3 MAC frame.

1	1	2	2	0, 18-1522 bytes payload
FC	MAC-PARM	LEN	HCS	802.3 Ethernet frame with user data

SA	DA	Type/Len	User Data	FCS

FC Frame Control   MAC-PARM MAC Parameter
LEN Length   SID Service Identifier
EHDR Extended MAC Header   HCS Header Check Sum
DA Destination Address   SA Source Address

3. DOCSIS (6/8)

Link layer security:

Since cable networks are shared networks (logical bus), link layer encryption is required to achieve 'wire equivalent privacy' (privacy equivalent to dedicated wires for each customer).

DOCSIS security has the following goals:
a. Data privacy across cable network (HFC)
b. Protection of cable MAC from unauthorized access

DOCSIS main security features:

Feature
128 bit AES traffic encryption (MAC frame payload only, header remains unencrypted)
Source IP address verification
Certificate revocation
Key management and exchange protected by digital certificates and 3DES for key exchange between CM and CMTS

6. DOCSIS (7/8)

Boot sequence (1/2):

1. Scanning:

The CM scans for available downstream channels for the synchronization with the CMTS (CMTS sends synchronization broadcast frames as a timing reference).

2. Receive upstream parameters:

The CM receives the upstream parameters and informs the CMTS of its presence.

3. Ranging (frame synchronization CM with CMTS):

a. 3 consecutive time slots are reserved for ranging.

b. The CM sends in the second of the three time slots (1st and 3rd timeslots are gaps to ensure that ranging burst does not collide with data in other time slots).

c. The CMTS measures CMs transmission and instructs CM to adjust its internal clock. Ranging is necessary due to physical distance between the CM and the CMTS (delay, varying attenuation levels).

d. The CMTS informs the CM of upstream and downstream frequencies.

6. DOCSIS (8/8)

Boot sequence (2/2):

4. The CM acquires an IP address by DHCP and a TFTP server address along with the name of the configuration file.

5. The CM downloads its configuration from the TFTP server.

6. The CMTS checks that the CM received the configuration from a legitimate TFTP server.

7. Link security startup with the exchange of keys for encryption.

8. The CM registers with the CMTS.

9. The CMTS assigns a SID (Service Identifier) to the CM and authorizes the CM to send traffic onto the network.