S-38.192 Verkkopalvelujen tuotanto
S-38.192 Network Service Provisioning

Lecture 3: Subscriber line technologies

Subscriber line technology

- Subscriber line is the last mile to the customer
  - Conventionally only PSTN subscriber lines
    - Twisted pair copper
      - One or several pairs to each house
  - In urban areas CATV subscriber lines provide same service
    - Hybrid fiber coax network
  - Power lines are the last to arrive to the scene
    - Power lines are used to transmit also data traffic
      - Conventionally only control messages to fusebox
- Subscriber lines are the most expensive part of the network
  - A lot of physical construction work for each customer

Subscriber line technology

- Technology options for broadband data connections are
  - XDSL over PSTN subscriber lines
  - DOCSIS over CATV lines
  - Power line communication (PLC)
  - Wireless local loops
    - 802.11 WLAN / HiperLAN
    - 802.16 WiMax

xDSL

- XDSL is based on the digitalized subscriber line technologies
  - IDSL (ISDN Digital Subscriber Line) was the initial invention
    - Also local loop can be digitized with high reliability and low bit error rate
  - Both ends of the subscriber line is equipped with modems
    - Information is modulated to frequency range that best serves the communication
      - PSTN copper pairs are in general old and contain a lot non-linearities
        - » Joints made with variable mechanisms
        - » irregular twisting of pairs
        - » Highly variable di-electric properties of insulations
        - » Optimized for frequency range below 4kHz

xDSL

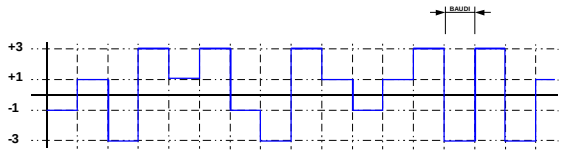
- Non-linearities cause a lot of problems in high data rate communications
  - Attenuation
  - Crosstalk
  - Distortion
- Magnitude depends on frequency and other usage of copper infrastructure
  - Copper pairs do not run individually on the ground ;-)

HDSL

- **HDSL** (High Bit-Rate Digital Subscriber Line)
  - First real xDSL-technique
  - Baseband operation (2B1Q)
    - Subscriber line cannot be used same time for POTS services
  - Symmetric operation
    - Suitable for corporate LAN interconnection
    - PBX subscriber lines
      - Part of the time-slots can be left out of usage
  - Uses multiple copper pairs
    - Two pairs – 1.5Mbps (T1)
    - Three pairs – 2Mbps (E1)
  - Maximum distance 3-4 km

2B1Q

- Four level baseband transmission
  - 2 bits per symbol
- Used in
  - ISDN subscriber line (IDSL)
  - HDSL



SDSL

- **SDSL** (Single-Line Digital Subscriber Line)
  - Single copper pair version of HDSL
    - Uses same modulation (2B1Q)
    - Transmission rates are same as in HDSL
  - More popular than HDSL
    - Copper pairs are expensive to rent in urban area
  - Maximum distance 3 km

G.SHDSL

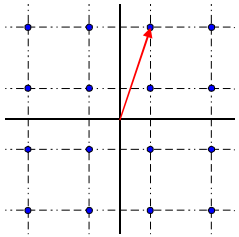
- **G.SHDSL** (Symmetric High Bit-Rate Digital Subscriber Line)
  - ITU-T Recommendation G.991.2
    - T1E1 - HDSL2
    - ETSI - SDSL
  - Transmission rates 192 kbps - 2.312 Mbps
  - Coding 16-Level TC-PAM (Trellis Coded Pulse Amplitude Modulation)
  - Single copper pair technology
  - Information is framed based on various technologies:
    - ATM
    - TDM
    - IP

ADSL

- **ADSL** (Asymmetric Digital Subscriber Line)
  - Most popular xDSL technique
  - Asymmetric uplink and downlink
  - Three bands
    - 0-3400Hz POTS
    - 20-160kHz Bidirectional data band
    - 240-1100kHz downlink data band
  - Bands are divided into 256 carriers
    - Carriers can be activated and passivated
      - Downlink maximum rate 1.5-8Mbps
      - Uplink maximum rate 1.5 Mbps
  - Maximum distance 3-4 km

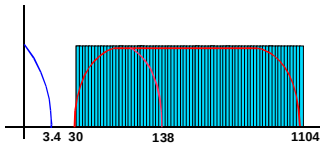
CAP/QAM

- Carrierless AM/PM - Quadrature Amplitude Modulation
  - Two dimensional code space
    - Orthogonal components
      - Amplitude
      - Phase
- Used in
  - ADSL
  - VDSL
  - DOCSIS



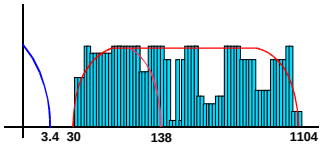
DMT

- Discrete Multitone
  - *N* x CAP/QAM
    - Linecode in divided into N subcomponents
      - ADSL -> N = 256
    - Subcomponents are produced with Fourier transformation (DFT)
  - Used in
    - ADSL
    - VDSL



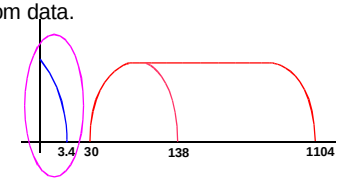
ADSL

- DMT based ADSL system measures the quality of copper pair and adapts symbol rate in each carrier to compensate possible defects
  - Crosstalk
  - Bit error rate
  - Attenuation



ATU-R

- ADSL Transceiver Unit Remote
  - Subscriber network termination
    - Either
      - Separate active device (bridge, router)
      - NIC in PC
    - Can be equipped with low pass filter to extract voice signal (analog)from data.



ATU-C

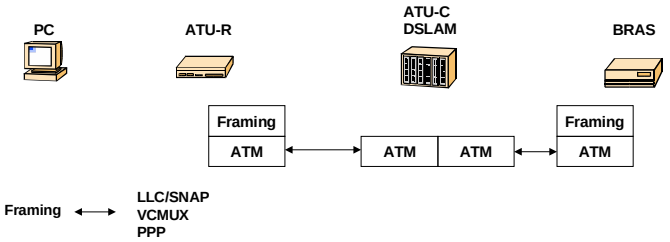
- ADSL Transceiver Unit Central Office
  - Core network termination
    - Counterpart for user side mode
  - Usually build into larger unit (DSLAM)
    - Several modems
    - Multiplexing unit which concentrates the traffic into high speed backbone link
      - ATM 155 – ATM 622

XDSL Framing

- XDSL systems are typically build for data transmission
- Data is transmitted between
  - Residential subscriber and ISP (Internet)
  - Residential subscriber and corporate network (Intranet)
  - Corporate offices (LAN interconnection)
- In all cases subscriber can be operated as
  - Routed
    - Subscriber has its own subnet
  - Bridged
    - Several subscribers share one subnet

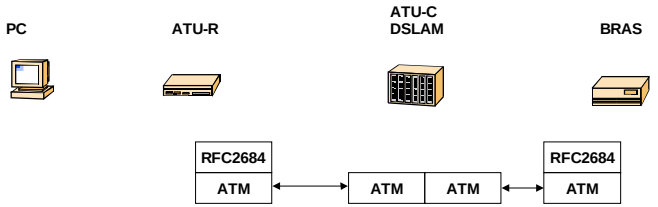
XDSL Framing

- RFC2684: Multiprotocol Encapsulation over ATM Adaptation Layer 5
- RFC2364: Point to Point Protocol over ATM
- RFC 2516: A Method for Transmitting PPP Over Ethernet (PPPoE)
- Point to Point Protocol over Ethernet over ATM



RFC 2684

- **RFC 2684**: Multiprotocol Encapsulation over ATM Adaptation Layer 5
  - Previous version RFC 1483 (Classical IP)

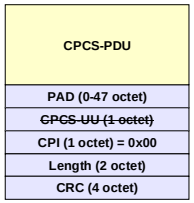


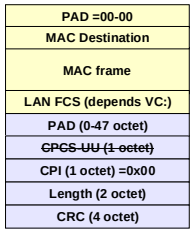
RFC2684

- Two modes
  - **VC-multiplexing**
    - No framing -> individual ATM PVC can be used only for transmitting one type information
    - Both ends of the connection must share common view of the structure of information
    - Efficient
  - **LLC-encapsulation**
    - IEEE 802.2 encapsulation is added to information -> contains pointer to data type

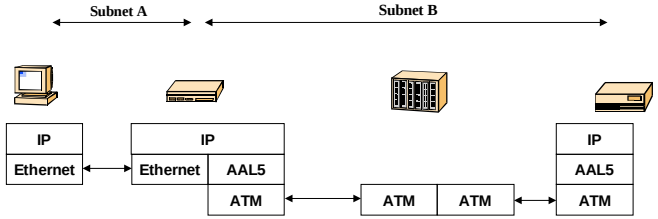
RFC 2684

- **VC-multiplexing** is based on raw ATM AAL5:n CPCS-interface
  - **Routed protocols** are interleaved directly in to CPCS-PDU
  - **Bridged protocols** require destination MAC-address for delivery





Routed protocols

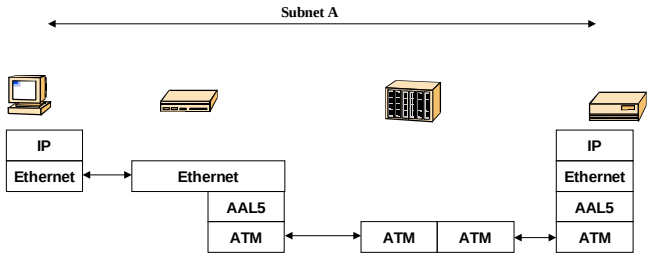


RFC 2684

- **LLC-encapsulation**
  - LLC header expresses frame type (protocol)
  - **IP** uses LLC/SNAP encapsulation

Destination SAP =AA	AA-AA-03 -> SNAP
Source SAP =AA	
Frame Type =03	
OUI =00-00-00	00-00-00 -> Ethertype
Ethertype =08-00	08-00 -> IPv4
IPv4 packet	
PAD (0-47 octet)	
~~CPCS-UU (1 octet)~~	
CPI (1 octet) =0x00	
Length (2 octet)	
CRC (4 octet)	

Bridged protocols



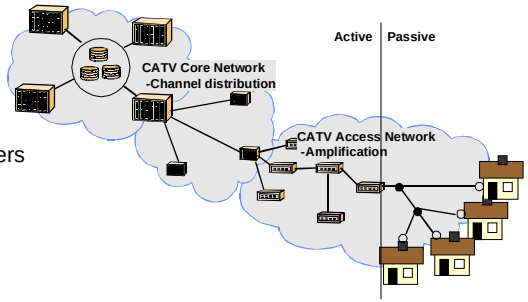
RFC 2684

- Ethernet bridging uses same LLC/SNAP encapsulation as IP does

Destination SAP =AA	
Source SAP =AA	
Frame Type =03	AA-AA-03 -> SNAP
OUI =00-80-C2	00-80-C2 -> Bridging
PID =00-01 / 00-07	00-01 -> FCS preserved 00-07 -> FCS not preserved
MAC Destination	
MAC frame	
LAN FCS (PID=00-01)	
PAD (0-47 octet)	
~~CPCS-UU (1 octet)~~	
CPI (1 octet) =0x00	
Length (2 octet)	
CRC (4 octet)	

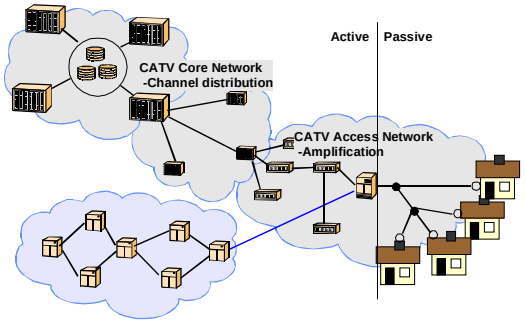
Classical CATV Network

- Designed for transmission of TV/Radio signals
  - 6 - 446 Mhz
- Access network
  - Amplifier lines
  - Passive tap network at last mile
    - Up to 500 subscribers



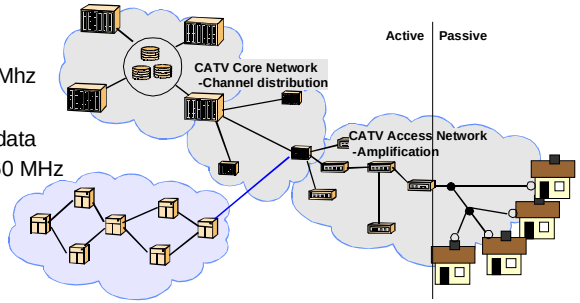
CATV Network with data connections

- Root amplifier of tap network is changed
  - Connection to data network (Internet)
  - Modulates the data to high frequency area
    - 470 – 860 MHz



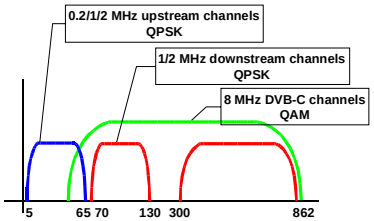
(Euro) DOCSIS CATV Network

- Amplifiers in coax segment are changed to bidirectional
  - Uplink
    - Data
      - 5 – 42 Mhz
  - Downlink
    - Video and data
      - 50 – 860 MHz



(Euro) DOCSIS

- US
  - Frequency ranges
    - Uplink 5 – 42 MHz
    - Dowlink 50 – 750 MHz
  - 6 MHz video channels
- Europe
  - Frequency ranges
    - Uplink 5 – 65 MHz
    - Downlink 50 – 860 MHz
  - 8 Mhz video channels

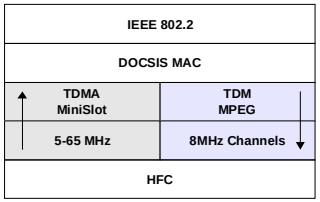


(Euro) DOCSIS

- Architecture requires two different components
  - Cable modem (CM)
    - User device which modulates and demodulates the information to/from coax network
      - Ethernet interface for end-user
  - Cable modem termination system (CMTS)
    - Modem unit on CATV head-end or distribution hub
      - Controls the uplink channel usage
        - » Separate CMTS for each frequency that is used for DOCSIS
      - Modulates and demodulates the data to proper frequency

(Euro) DOCSIS

- Framing is based on Ethernet framing but within the HFC network separate framing is used for data communication
  - Downlink: TDM based MPEG-2 frames
  - Uplink: TDMA based minislots



(Euro) DOCSIS

- Downlink framing based on MPEG-2
  - 204 bytes
  - Similar with video
    - Mix and match in single channel
  - Header contains info what frame content is
    - PID field 0x1FFE equals to MCNS Data over Cable
  - FEC is used to correct possible (probable) errors on transmission
    - Coax networks with multiple amplifiers are prone to bit errors
      - Reed Solomon coding

Sync (1 byte)	Header (3 bytes)	Data (184 bytes)	FEC (16 bytes)

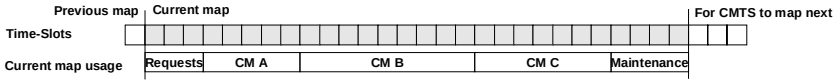
(Euro) DOCSIS

- Uplink framing is based on timely division of link capacity for different subscribers
  - Similar than PDH
  - Individual time-slot 6.25 us
  - Amount of bytes depends on modulation and coding
  - Required amount of time-slots is requested from CMTS to send data
  - Length of sync field depends on physical transmission rate
  - Data is normal Ethernet frame

Sync (x bytes)	Header (6 bytes)	Data (18-1518 bytes)	FEC (x bytes)

(Euro) DOCSIS

- CMTS controls the resource usage on uplink by allocating certain time-slots for certain CM:s
  - Done in granularities of MAP PDU
    - Several time-slots



(Euro) DOCSIS

- Downlink (per CMTS channel)
  - 64-QAM: 38 Mbps
  - 256-QAM: 52 Mbps
- Uplink
  - Capacity depends on
    - Version of specification
    - Modulation method
    - Symbol rate (channel size)

DOCSIS 1.0 and 1.1

Symbol Rate	Bandwidth Used (KHz)	QPSK Data Rate (Kb/s)	16-QAM Data Rate (Kb/s)
160	200	320	640
320	400	640	1280
640	800	1280	2560
1280	1600	2560	5120
2560	3200	5120	10240

DOCSIS 2.0

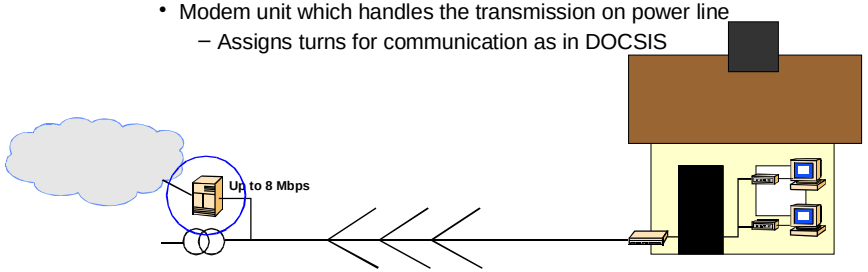
Symbol Rate	QPSK (Kb/s)	8-QAM (Kb/s)	16-QAM (Kb/s)	32-QAM (Mb/s)	64-QAM (Mb/s)	128-QAM (Mb/s)
160	320	480	640	0.96	1.28	1.92
320	640	960	1280	1.92	2.56	3.84
640	1280	1920	2560	3.84	5.12	7.68
1280	2560	3840	5120	7.68	10.24	15.36
2560	5120	7680	10240	15.36	20.48	30.72
5120	10240	15360	20480	30.72	40.96	61.44

Power Line Communications

- Based on fact that majority of houses are connected power grid
  - Same cabling system can be used to transmit information other than 50Hz electricity
  - Modulation of data information to frequency range that operates in power network
    - Power line twisting
      - outdoors is optimized for low frequencies
      - Indoors is basically none
    - High frequencies
      - Power line operates as antenna
        - » Regulations to control the emissions

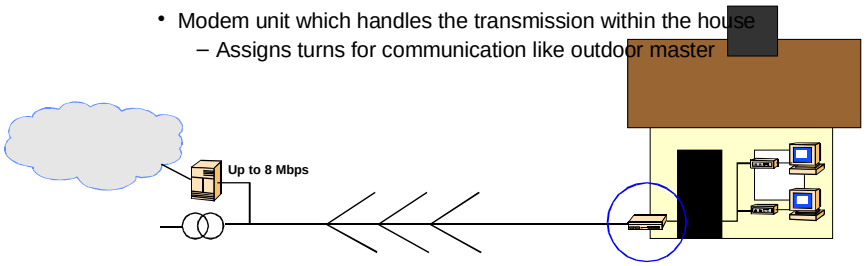
PLC

- Based on three components
  - Power line master unit
    - Connects into power line after last transformer
    - Modem unit which handles the transmission on power line
      - Assigns turns for communication as in DOCSIS



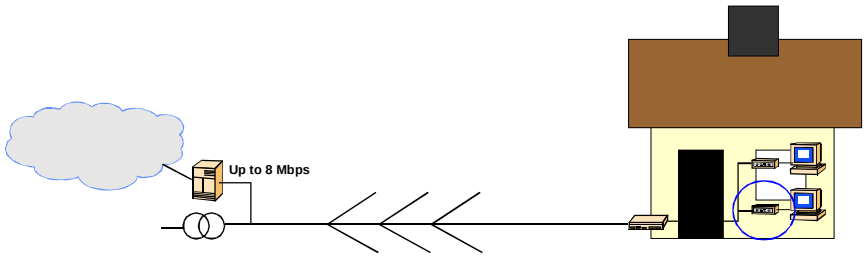
PLC

- Based on three components
  - Indoor/Outdoor converter
    - Changes the frequency range which used within the house to one which is used outside the house
    - Modem unit which handles the transmission within the house
      - Assigns turns for communication like outdoor master



PLC

- Based on three components
  - Indoor modem unit
    - Provides Ethernet connection to PC and modem services to indoor PLC network



PLC

- Frequency range 1.6MHz to 30 Mhz
  - Several independent carriers (4-8 normally)
  - Overall datarate 8Mbps
    - Next generation will bring 16-40 Mbps (depending on source of estimation)
- Locally several power companies have tested technology but only few are really offering services based on it

Point to Point Protocol (PPP)

- **RFC 1661**: Point-to-Point Protocol (1994)
- Point-to-Point Protocol (PPP) provides common interface for different network protocols on point-to-point manner
- Three parts:
  - Encapsulation, generic encapsulation for all protocols
  - Link Control Protocol used to setup, control and tear down of link level point-to-point connections
  - Network Control Protocol used to setup, control and tear down of network level point-to-point connections

PPP encapsulation

- Based on encapsulation of network protocol into
  - 1-2 bytes long protocol identifier
  - PAD

Protocol identifier (1-2 bytes)	Network protocol (N bytes)	PAD (M bytes)

- L2 encapsulation depends on used technology
  - PSTN
  - ISDN
  - Ethernet
  - ATM
  - FrameRelay

PPP – signaling

- Datalink connection open
  - LCP sets the layer dependent parameters
- Authentication
  - Authentication is optional feature which must be indicated in opening of datalink connection
- Network connection open
  - Process of opening network layer connection depends on protocol used. NCP sets layer specific parameters
- Datalink / Network level tear down
  - Multiple network level connections can be setup and torn down from individual datalink connection
  - Tearing down datalink connection disconnects all network level connections from that particular datalink

PPP – LCP parameters

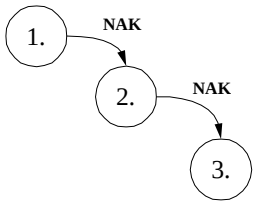
- Compression
  - Protocol-Field-Compression
    - Possibility to compress PPP header protocol field to one byte (50% reduction ;-)
  - Address-and-Control-Field-Compression
    - In point-to-point connections after negotiation of full addresses both ends know entities of other end of line
      - Replacement with integer
        - » Good compression ratio
        - » Modification of headers at both ends -> calculation

PPP – LCP parameters

- Maximum Receive Unit
  - Expresses maximum size of packet that can be processed within terminal
  - Default value 1500 bytes (Ethernet MTU)
    - Depending on media rate large MRU can seize the link for a long time
      - 1500 bytes in 56 kbps modem line (without framing) lasts 210 ms
      - 1500 bytes in 10 Mbps Ethernet (without framing) lasts 1.2 ms

PPP – LCP parameters

- Authentication
  - Iterative process
    - Both end points declare their set of preferred authentication methods
  - Can be done in both directions
    - Neither of parties is trusted
    - Independent methods in both directions



PPP – Authentication

- Password Authentication Protocol (PAP)
  - RFC 1334
  - Uses simple hand-shake
    - Client sends
      - User ID
      - Password
    - Server acknowledges
  - Operation is secured for packet losses by client
    - Sends frequently ID/password combinations for server
- Weaknesses
  - Clear text operation
    - ID and password are not encrypted
    - Can be eyes dropped
  - No locking
    - ID / password pairs can be scanned by machine

PPP – Authentication

- Challenge Handshake Authentication Protocol (CHAP)
  - RFC 1994
  - Two way hand-shake
    - Server sends a challenge to client
    - Client responds with hash value of correct answer to the challenge
    - Server checks the answer
- Hand-shake can be done every N minutes or per transaction
  - Reduces the damage from compromised key
- Secret key which is used in calculation of hash values can be based any technology
  - Bank keys
- Weaknesses
  - Secret key has to be in clear text format in server side (or accessible for server in clear text format)

PPP – Authentication

- CHAP problems
  - Challenge is based on knowledge of customer capabilities
    - Customer identity has to be solved first
      - PAP
      - Subscriber line
- CHAP problems
  - How to deliver correct answers to challenges to customers
  - How to secure secret key in case of multiple access points
    - Same key should be available in each access points
    - Access points can not be trusted every time
      - Co-located RAS functionalities

PPP – Authentication

- PPP Extensible Authentication Protocol (EAP)
  - RFC 2284
  - Possibility to use several authentication methods
  - Delegates the selection process from LCP to separate authentication phase
    - Makes possible to gather additional information from the customer before selection of algorithm
    - Ability to use separate authentication system
      - RADIUS
      - DIAMETER
      - KERBEROS

PPP – Authentication

- EAP is based on multilevel handshake
  - Server sends one or several requests to client
    - First request relates to identity of client
    - Each request contains a field which expresses the nature of request
      - Identity
      - ID / Password (PAP)
      - One time password
      - MD5 challenge
  - Client answers to requests based on their nature

PPP – LCP parameters

- Quality Protocol
  - PPP is designed to work in diverse environments
  - Some L2 techniques cause more bit errors and/or packet losses
    - PPP can measure the quality of L2 connection and re parametrize the connection based on the results
    - Both directions on point-to-point connection are independent
      - Separate measurement of quality

PPP – LCP parameters

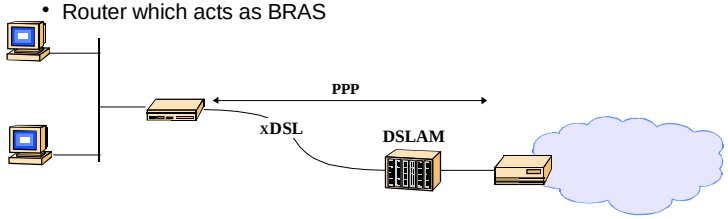
- Magic Number
  - End-point identifier which is based on randomness
    - Generated from real-time clock, MAC address of NIC or other source which leads with high probability to unique result
      - Makes easier to detect malfunctions on link
        - » echo

PPP over ATM (PPPoA)

- RFC 2364: PPP over AAL5
  - PPP packets are encapsulated into AAL5 frames
    - VC multiplexing
    - LLC/SNAP framing
  - AAL5 provides to PPP
    - Point-to-point connection which is implemented in bit synchronous manner
    - Control signals
      - Connection UP
      - Connection DOWN

PPP over ATM (PPPoA)

- PPP-connection is terminated between ATM end systems
  - ATU-R
    - Modem in PC
    - Separate device (router, bridge)
  - At network side termination point is not ATU-C
    - Router which acts as BRAS



PPP over ATM

- VC-multiplexing
  - AAL5 frame does not contain information about structure of communication

Protocol ID	
PPP Information	PPP
Padding	
PAD (0-47 octet)	
CPCS-UU (1 octet)	
CPI (1 octet)	AAL5 -trailer
Length (2 octet)	
CRC (4 octet)	

- LLC encapsulation

Destination SAP	
Source SAP	LLC-header
Frame Type (UI)	
NLPID (PPP)	Network Layer Protocol ID
Protocol ID	
PPP Information	PPP
Padding	
PAD (0-47 octet)	
CPCS-UU (1 octet)	
CPI (1 octet)	AAL5 -trailer
Length (2 octet)	
CRC (4 octet)	

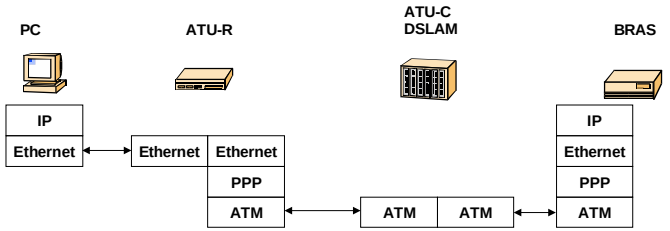
PPP over ATM (PPPoA)

- Information which is transmitted over PPP connection is either
  - Ethernet frames
    - Bridged service
    - Network layer control protocol -BCP
  - IP packets
    - Routed service
    - Network layer control protocol -IPCP

PPP - BCP

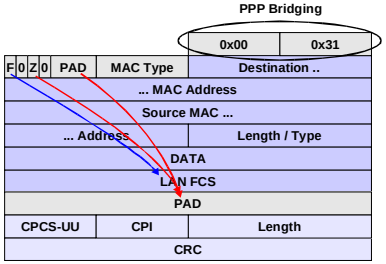
- **RFC 2878**: PPP Bridging Control Protocol
  - Bridge ID – if customer device is part of distributed bridge
  - MAC support – (802.3, 802.4, 802.5)
  - Tinygram compression – padding for minimum frame length is removed
  - MAC-address – possibility to advertise own MAC-address to receiver (Access Control)
  - IEEE 802 Tag - VLAN tag usage

Bridged PPP connection

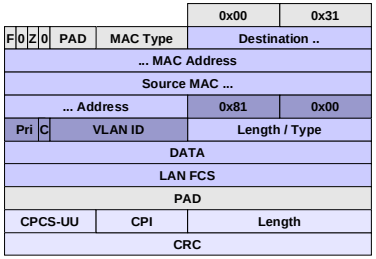


PPP - BCP

- 802.3 encapsulation



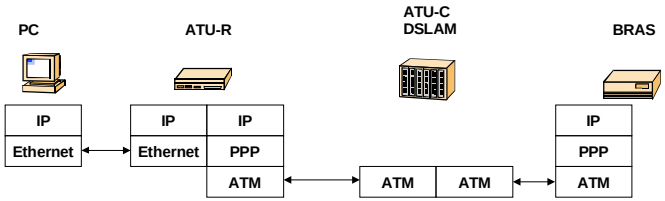
- 802.3 encapsulation (VLAN support)



PPP - IPCP

- **RFC 1332**: The PPP Internet Protocol Control Protocol
  - IP address delivery for client
  - TCP/IP header compression
    - Van Jacobson compression
      - 40 bytes -> 2-5 bytes
  - Mobile IPv4
  - DNS (primary, secondary)

Routed PPP connection



PPP over ATM (PPPoA)

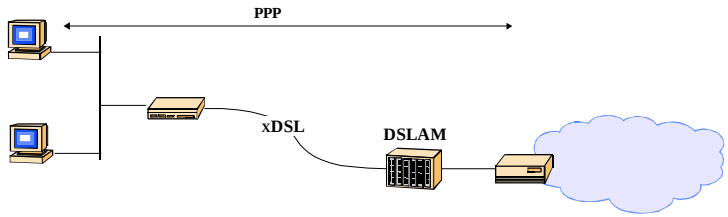
- **Pros**
  - ATM connection is truly provisioned for individual clients
    - Capacity is guaranteed
    - Security is guaranteed
- **Cons**
  - Connection is from provider BRAS to customer xDSL termination point
    - Authentication needs to be set over network layer protocol
    - Client computer can be switched off but network is not aware of it
      - LCP session is up if the modem has power on

PPP over Ethernet (PPPoE)

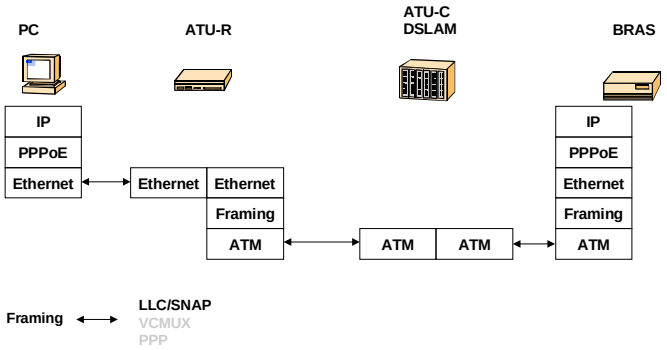
- RFC 2516: A Method for Transmitting PPP Over Ethernet (PPPoE)
  - PPP packets are framed with Ethernet headers
    - PPP acts as resource broker in Ethernet network
  - Makes possible to build building networks (HPNA)
    - Within building
      - Share Ethernet network
      - One (or several) connections to service providers
        - » Bridged traffic
    - Each client
      - Individual agreement with service provider
        - » Separate account
        - » Separate bill

PPP over Ethernet (PPPoE)

- Two phases
  - Discovery stage
    - Where is my BRAS
  - PPP session stage



Framing



PPP over Ethernet (Discovery)

- Initiation phase
  - Client sends initiation packet into Ethernet broadcast address (all ones)
    - Point to multipoint
  - Packet contains
    - Name of the ISP
    - Name of the service
- Offer phase
  - BRAS devices which deliver service that is requested for answer to the client with unicast
    - point-to-point
  - Offer contains
    - Name of the BRAS
    - Name of the service

PPP over Ethernet (Discovery)

- Request phase
  - Customer chooses one of the BRASes that deliver proper service
    - Point-to-point
  - Contains name of the service
- Session confirmation phase
  - BRAS answer to client request
    - Point-to-point
  - Contains
    - Name of the service
    - PPP session ID

PPP over Ethernet (Session)

- During the session packets are delivered to BRAS with session ID that is generated in discovery phase
- MRU of the PPP packet cannot exceed 1492 bytes
  - 2 bytes protocol ID
  - 6 bytes PPPoE header
  - 1500 bytes
    - Maximum payload for Ethernet frame