L81 - IP over WAN

IP over WAN

Address Resolution, Encapsulation, Routing, NBMA
PPP, Inverse ARP, Overview IP over ATM

Agenda

- **IP and Network Technologies**
  - Address Resolution Aspects
  - Routing Aspects
  - Examples
  - NBMA Summary
- **IP over WAN**
  - IP over Serial Line / PPP / ADSL
  - IP over X.25
  - IP over Frame Relay
  - IP over ISDN
  - IP over SMDS
  - IP over ATM

IP and Network Technologies

- **for transport of IP datagrams over a network**
  - encapsulation and address resolution must be defined
  - routing tables must be established within routers in order to forward datagram's
- **encapsulation specifies**
  - how IP datagrams must be inserted in a frame specific for the network to be used
  - how IP datagrams could be distinguished from other services available on this specific network
- **address resolution specifies**
  - how the local network address (media address) could be derived from the IP address

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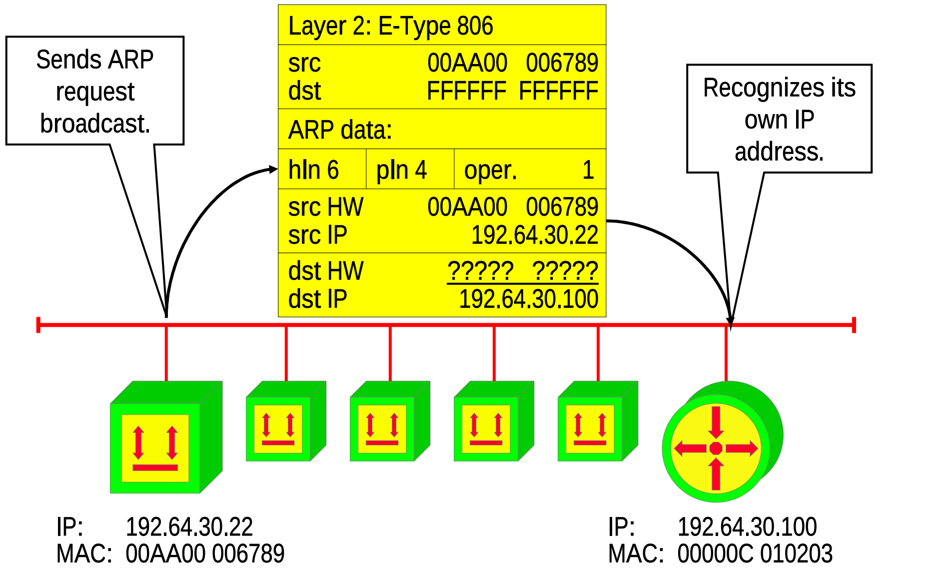
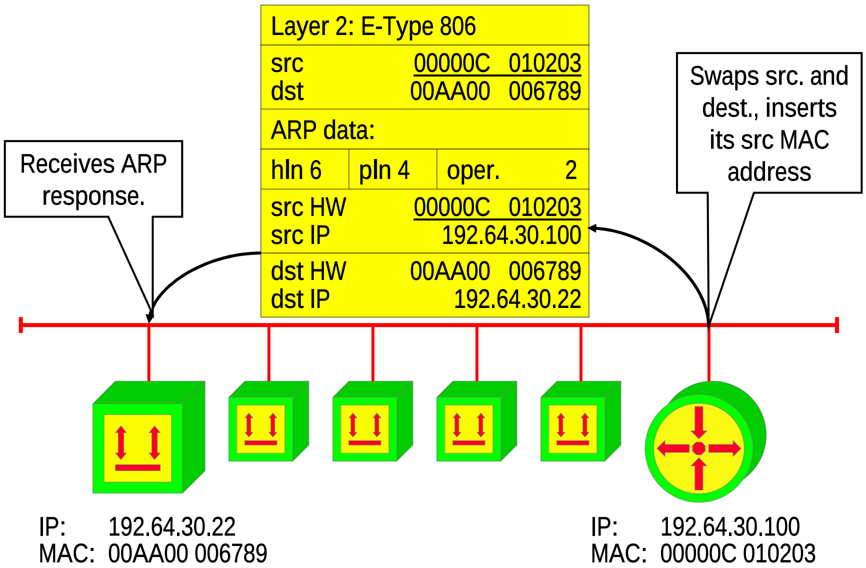
Address Resolution Aspects

- **address resolution is easy**
  - whenever the network technology supports broadcasting or multicasting
    - e.g. address resolution protocol (ARP) for LANs, for SMDS
  - review ARP:
    - IP host uses layer 2 broadcast (or multicast) to query all (or a group of) other network stations for a certain IP address
    - in response to the query the concerned IP host will sent a reply with its media specific address (MAC address)
- **address resolution is not necessary**
  - for physical point-to-point links like leased lines
    - there are only two IP stations sharing one line, hence knowing the net-id of the link (done by configuration of station) is sufficient

ARP Request



ARP Response



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Address Resolution and NBMA

- **address resolution is harder to solve**
  - for non-broadcast-multi-access (NBMA) network technologies
    - e.g. X.25, frame relay, ATM, ISDN
    - technologies based on virtual circuits (= CO packet switching) or circuits (CO circuit switching)
- **NBMA network aspects:**
  - one physical network interface can be used for multiplexing many logical point-to-point connections (virtual circuits)
  - all IP stations reachable via virtual circuits share the same net-id (same IP subnet) because an IP address identifies a physical network interface only
    - assumption: no sub-interface technique used

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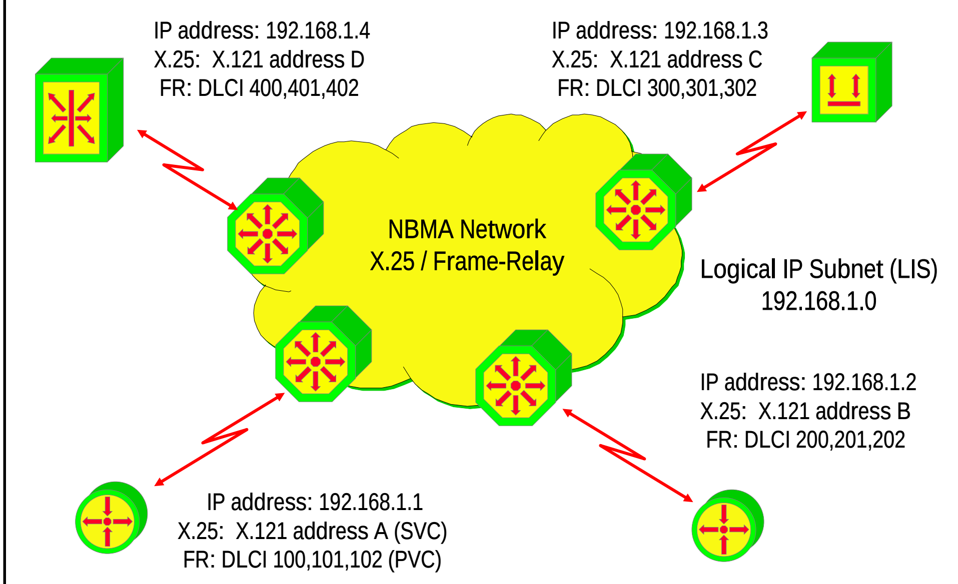
NBMA (physical View)



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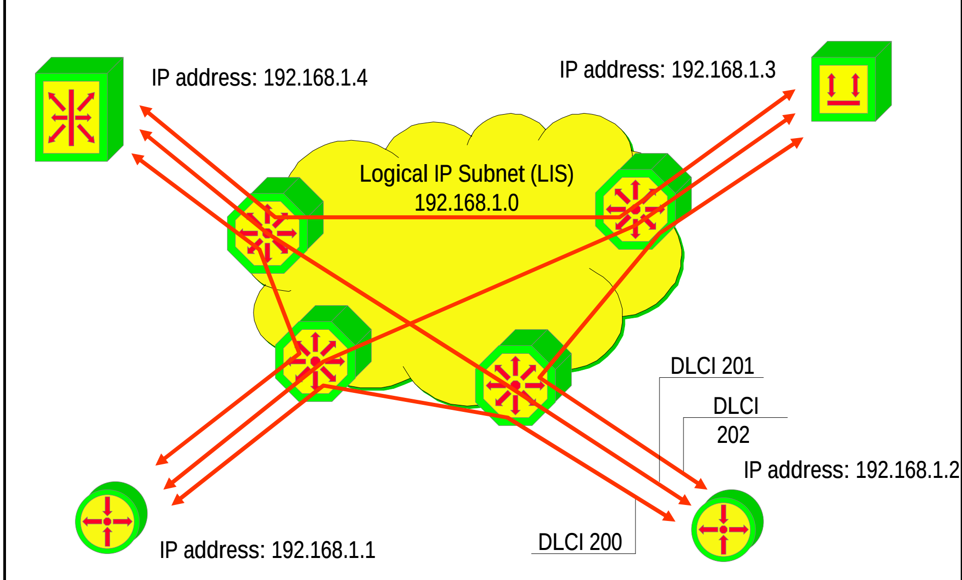
NBMA (View of virtual circuits)



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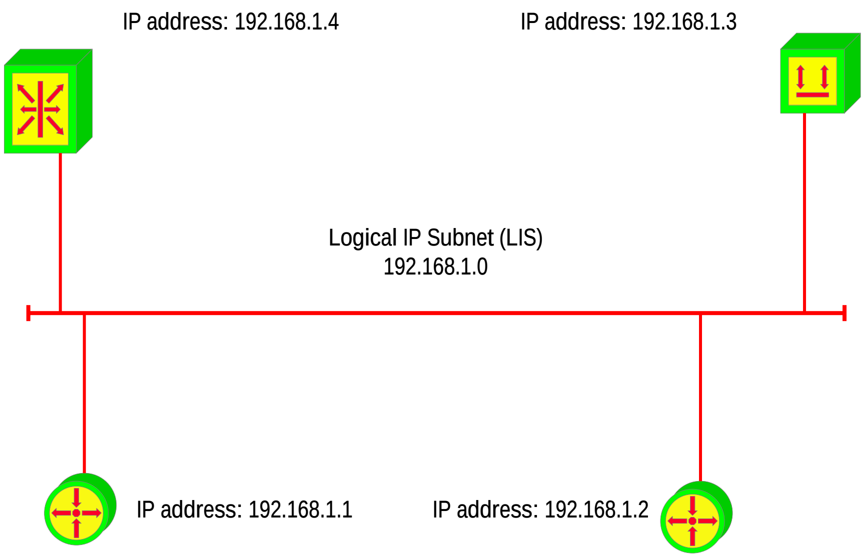
NBMA (Logical IP View)



NBMA Aspects (cont.)

- **LAN-like broadcasts can not be used**
  - to query all IP stations within the same subnet at the same time
- **LAN-like broadcasts could be emulated only by duplicating messages for every virtual circuit**
  - router performance issue
- **but how does a system know which virtual circuits are available or should be used?**
  - in case of PVC mapping of IP addresses to corresponding PVC channel identifiers (e.g. LCN, DLCI, VCI) is necessary
  - in case of SVC mapping of IP addresses to corresponding network media addresses (X.25, X.121, E.164, ISO DCC NSAP) is necessary
  - mapping could be static (done by configuration of stations) or dynamic (with the help of ARP-servers)

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Routing and Network Technologies

- **for routing of IP datagrams over a network**
  - routing tables must be established within routers
  - routing protocols are needed between routers in case of dynamic routing
- **routing protocols use**
  - IP limited broadcasts (255.255.255.255)
    - e.g. RIP (distance vector) for periodical routing updates
  - or IP multicasts (Class D)
    - e.g. OSPF (link state) for periodical hello (keepalive) messages and for link state advertizements (LSA) on demand
  - to discover partners, networks, to maintain topology information, to adapt topology changes, etc.

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Routing Aspects

- **because of overlay technique**
  - dynamic routing can be done in principle over every network technology
- **but again mapping of IP broadcast or IP multicast routing messages to layer 2 broadcast or multicast frames**
  - is easily possible in LANs, SMDS
  - is not necessary on physical point-to-point links
  - is a problem in NBMA networks (X.25, FR, ISDN, ATM)
- **routing in NBMA networks can be handled in two ways according to customer requirements**

Routing and NBMA 1

- **routing over a NBMA network can be done**
  - completely static
    - no routing broadcasts are required
    - static routing table entries for all remote networks pointing to next hop routers reachable over NBMA network
    - no PVC or SVC capacity used for routing
    - no SVC established for routing messages (updates, hellos, LSAs, etc.)
    - used for NBMA networks where customers must pay for payload and / or duration of a call (e.g. X.25, ISDN)

Routing and NBMA 2

- **routing over a NBMA network can be done**
  - dynamic
    - routing broadcasts will cause duplications for every virtual circuit
    - PVC or SVC capacity used for routing
    - SVC established for routing messages
- **in both cases we still need information about what circuits are present (PVC) or should be established (SVC)**
  - mapping between IP and physical address must be done in the same way as described for address resolution
  - automatic neighbor discovery is not possible without any server functionality

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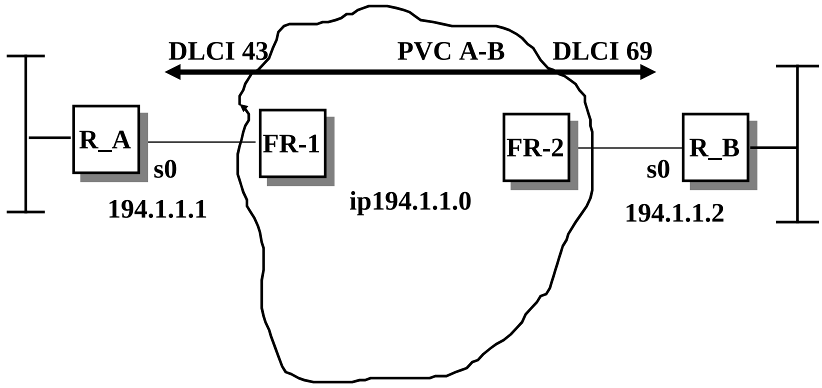
Example 1: FR-Topology



Example 1: Cisco-Configuration

Router A:
router rip
network 194.1.1.0

int s0
encapsulation frame-relay ietf
frame-relay lmi-type cisco
ip 194.1.1.1 255.255.255.0
frame-relay map ip 194.1.1.2 43 broadcast

DLCI

manual address resolution

enabling routing broadcasts
on frame relay interface

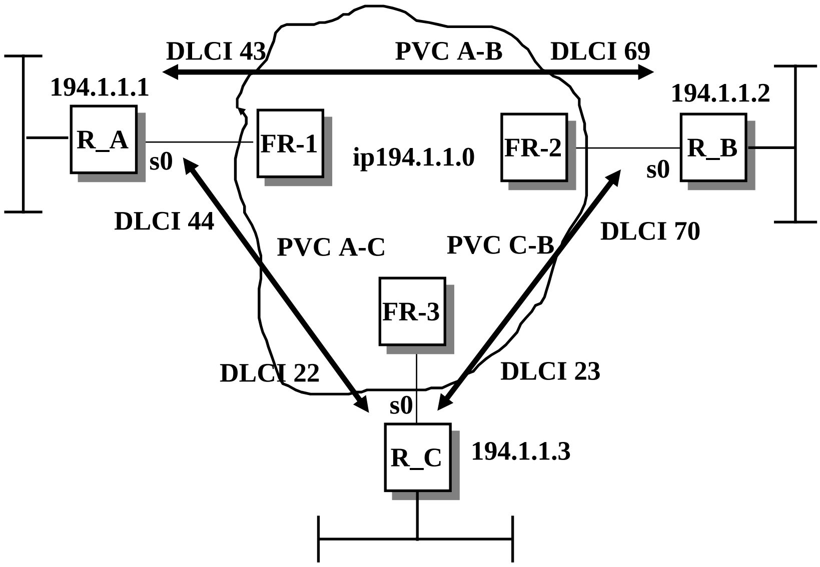
Router B:
router rip
network 194.1.1.0

int s0
encapsulation frame-relay ietf
frame-relay lmi-type cisco
ip 194.1.1.2 255.255.255.0
frame-relay map ip 194.1.1.1 69 broadcast

alternative by specifying routing neighbors

router rip
neighbor 194.1.1.2
int s0
ip 194.1.1.1 255.255.255.0
frame-relay map ip 194.1.1.2 43

Example 2: FR-Topology Full Mesh



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frame-relay map ip 194.1.1.2 43 broadcast
frame-relay map ip 194.1.1.3 44 broadcast

Router B:
router rip
network 194.1.1.0

int s0
encapsulation frame-relay ietf
frame-relay lmi-type cisco
ip 194.1.1.2 255.255.255.0

frame-relay map ip 194.1.1.1 69 broadcast
frame-relay map ip 194.1.1.3 70 broadcast

Router C:
router rip
network 194.1.1.0

int s0
encapsulation frame-relay ietf
frame-relay lmi-type cisco
ip 194.1.1.3 255.255.255.0

frame-relay map ip 194.1.1.1 22 broadcast
frame-relay map ip 194.1.1.2 23 broadcast

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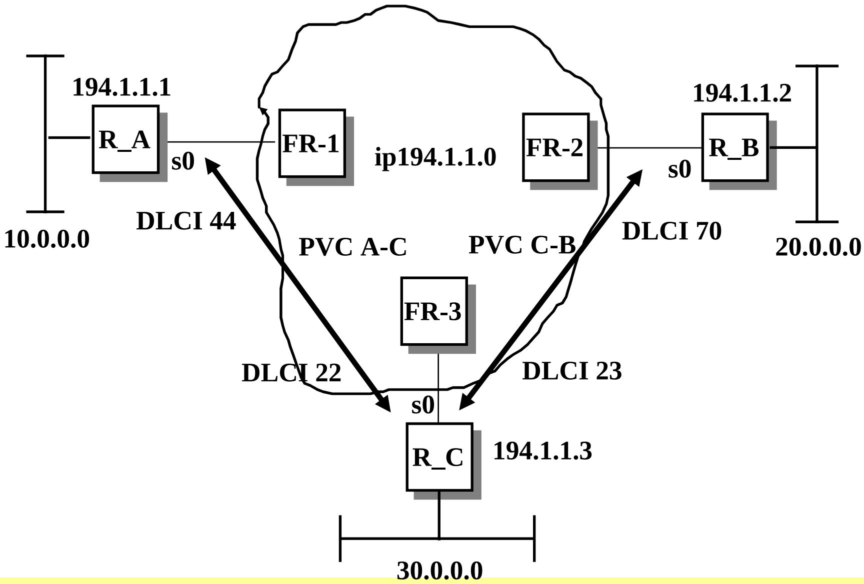
Example 3: FR-Topology Partial Mesh



Example 3: Cisco-Configuration

Router A:
router rip
network 194.1.1.0

int s0
encapsulation frame-relay ietf
frame-relay lmi-type cisco
ip 194.1.1.1 255.255.255.0
frame-relay map ip 194.1.1.3 44 broadcast

Router B:
router rip
network 194.1.1.0

int s0
encapsulation frame-relay ietf
frame-relay lmi-type cisco
ip 194.1.1.2 255.255.255.0
frame-relay map ip 194.1.1.3 70 broadcast

Router C:
router rip
network 194.1.1.0

int s0
encapsulation frame-relay ietf
frame-relay lmi-type cisco
ip 194.1.1.3 255.255.255.0
frame-relay map ip 194.1.1.1 22 broadcast
frame-relay map ip 194.1.1.2 23 broadcast

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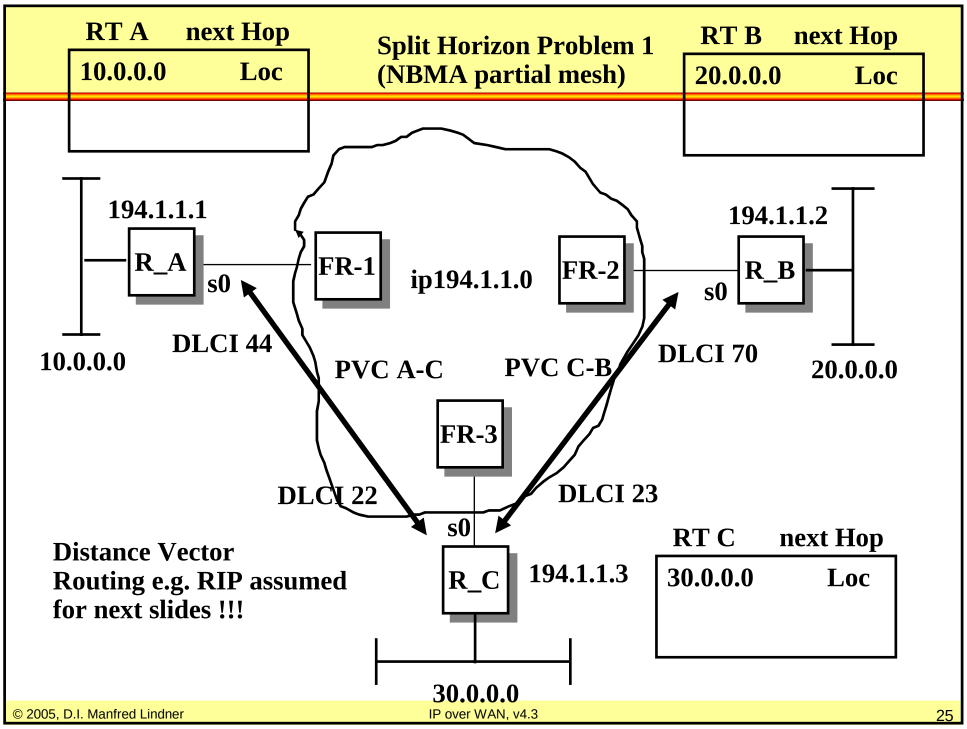

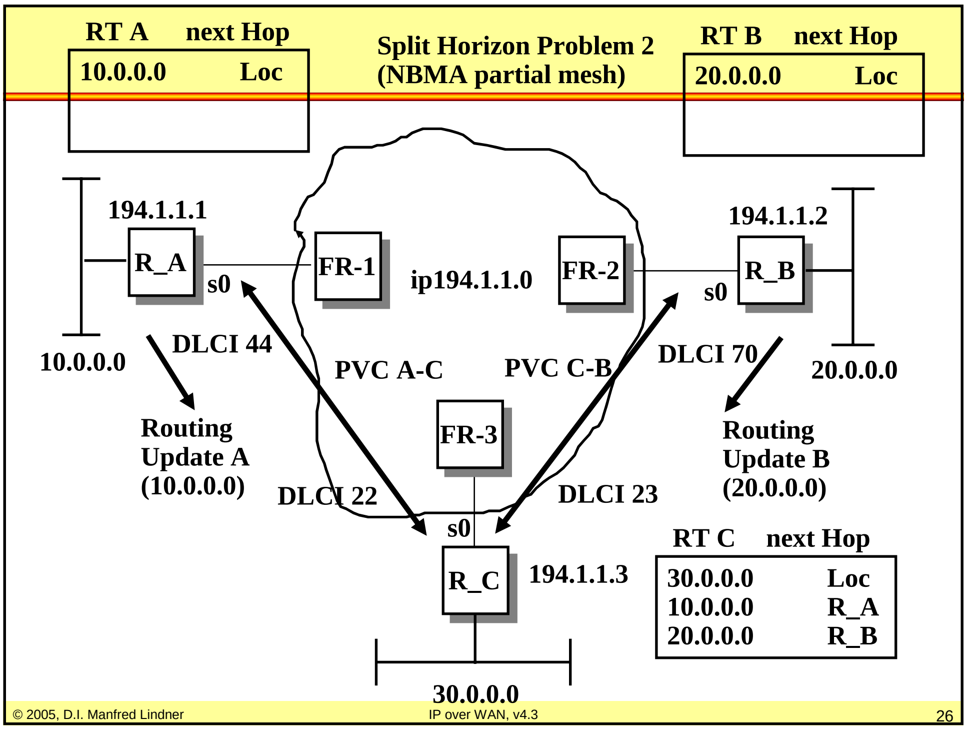

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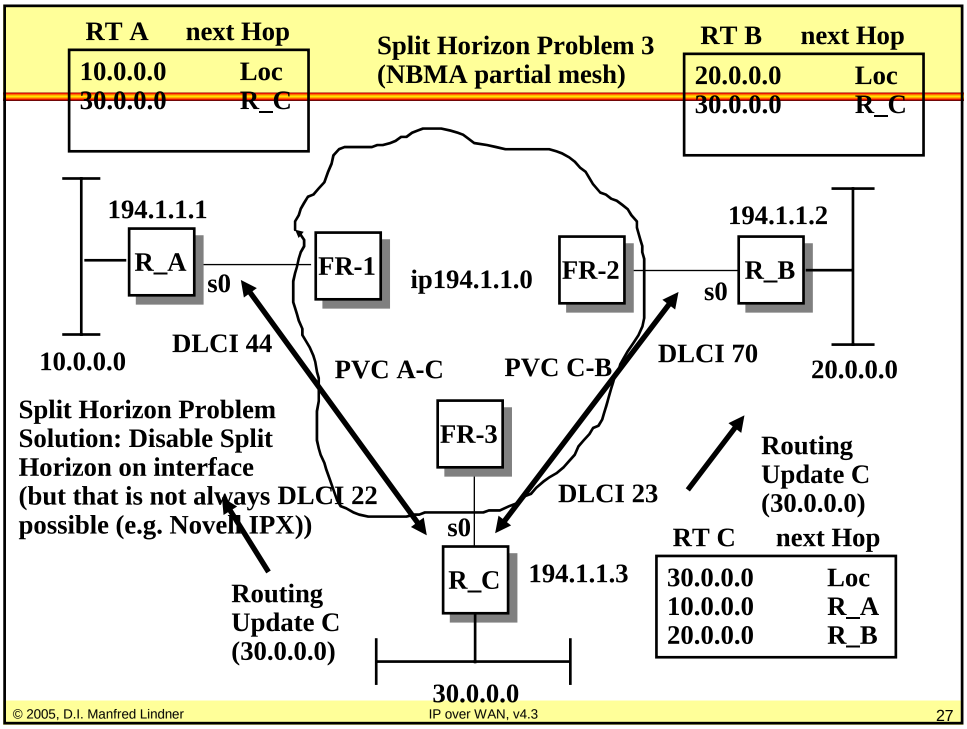

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Summary of NBMA Issues 1

- **broadcasts can not be used for address resolution**
  - static mapping of next hop to LCN / DLCI / VPI-VCI number in case of PVC service
  - static mapping of next hop to X.121 / ISDN / ATM number in case of SVC service
  - administrative overhead
- **broadcasts can not be used for neighbor discovery done usually by the routing protocol**
  - manual configuration of neighbors for dynamic routing or static routing only
  - administrative overhead in either cases

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Summary of NBMA Issues 2

- **broadcasts can not be used for routing updates (periodic or incremental)**
  - static routing
    - administrative overhead
  - or duplication of routing messages for every outgoing virtual circuit
    - router performance- and bandwidth-issue
- **dynamic routing overhead**
  - may be too expensive in case of SVC service
  - may be acceptable in case of PVC service

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Summary of NBMA Issues 3

- **for routing protocols where split horizon can not be disabled**
  - full mesh of virtual circuits is necessary
- **for routing protocols where split horizon can be disabled**
  - partial mesh of virtual circuits is necessary, but traffic between leaf-networks of partial mesh will be forwarded by the central router of the partial mesh
    - drawback: traffic goes twice through the NBMA cloud

Solutions for some NBMA Problems

- **inverse ARP**
  - solves address resolution problem for Frame Relay PVC´s or ATM PVC´s
- **turn split horizon off**
  - in case of dynamic routing and partial mesh
- **use of subinterfaces**
  - to change NBMA behavior to a bundle of point-to-point links (full or partial mesh)
    - hence no address resolution is necessary
    - but in case of dynamic routing the problem caused by duplication of routing messages still remains
  - can be used if split horizon can not be disabled in case of partial mesh

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IP over Serial Line

- **dynamic address resolution**
  - not necessary
- **encapsulation**
  - proprietary format
    - between routers or IP hosts of same vendor
  - or PPP (RFC 1661)
    - for interoperability between routers or IP hosts of different vendors
- **routing**
  - static routing to save bandwidth and / or for security
  - dynamic routing for ease of administration

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Reasons for Point-to-Point Protocol (PPP)

- **Communication between router of different vendors on a LAN was possible**
  - From the very beginning
    - Remember: Ethernet V2 Protocol Type field or LLC-DSAP/SSAP fields carry information about the protocol stack (e.g. IP or IPX or SAN or NetBEUI or AppleTalk)
- **Communication between router of different vendors on a serial line was not possible**
    - Because of the proprietary "kind of HDLC" encapsulation method used by different vendors
- **PPP standardizes multiprotocol encapsulation on a serial line**
    - hence interoperability is the main focus

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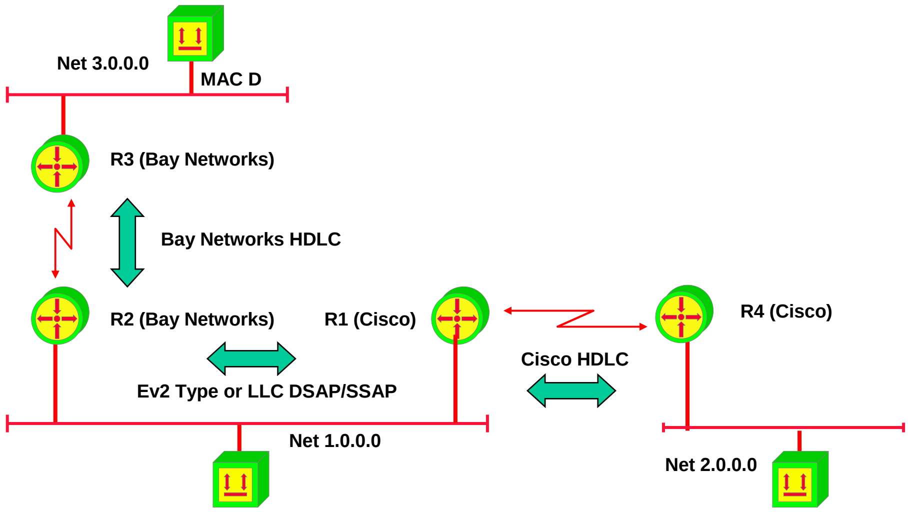
Interoperability without PPP



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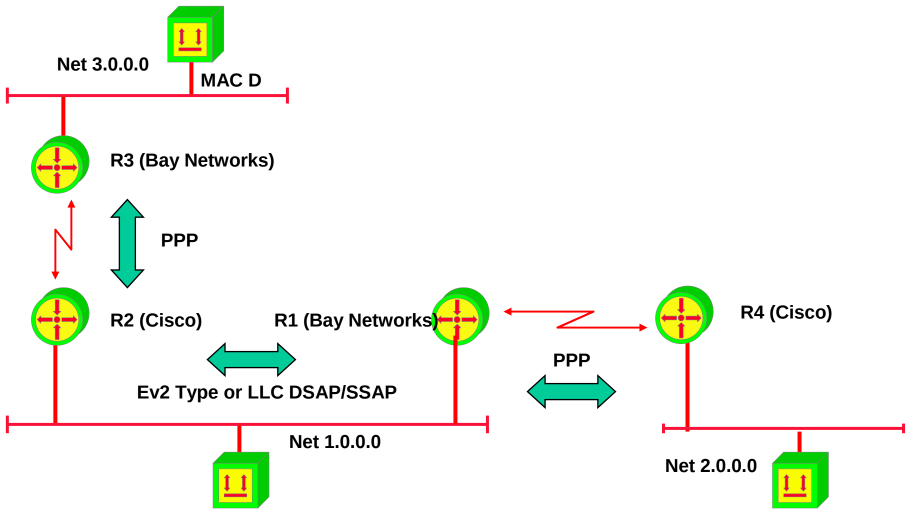
Interoperability with PPP



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Today's Main Focus of PPP

- **Providing dial-in possibilities for IP systems**
  - using modems and Plain Old Telephone Network (POTS)
  - using ISDN
  - using ADSL (Asymmetric Digital Subscriber Line)
    - PPPoE (PPP over Ethernet), PPPoA (PPP over ATM)
- **Dial-in:**
  - Into a corporate network (Intranet) of a company
    - Here the term RAS (remote access server) is commonly used to describe the point for accessing the dial-in service
  - Into the Internet by having an dial-in account with an Internet Service Provider (ISP)
    - Here the term POP (point-of-presence) is used to describe the point for accessing the service

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PPP Overview

- **data link protocol**
- **used to encapsulate network layer datagram's or bridged packets (multiprotocol traffic)**
  - over serial communication links in a well defined manner
- **connectionless service**
- **symmetric point-to-point protocol**
- **industry standard for dial-in service**
  - used for interoperability, even over leased lines
  - finally displacing SLIP (serial line IP) in the field
- **supports the simultaneous use of network protocols**

PPP Components

- **three major components**
  - HDLC framing and encapsulation (RFC 1662)
    - bitstuffing for synchronous serial lines
    - modified bytestuffing for asynchronous serial
  - Link Control Protocol (LCP, RFC 1661)
    - establishes and closes the link
    - tests the link for quality of service features
    - negotiation of parameters
    - configures the link
  - family of Network Control Protocols (NCP, div. RFCs)
    - configures and maintains network layer protocols.
    - NCP´s exist for IP, OSI, DECnet, AppleTalk, Novell
    - NCPs are started after link establishment through LCP.

PPP Frame Format

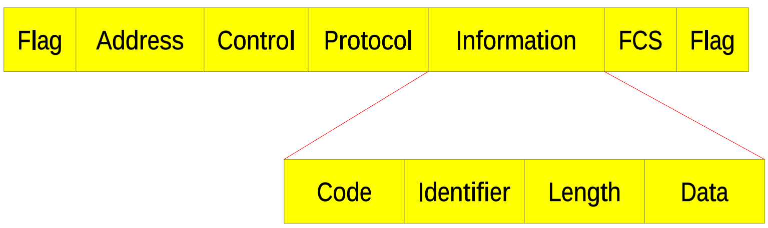
Flag	Address	Control	Protocol	Information	FCS	Flag

Flag = 01111110
Address = 11111111
Control = 00000011 (UI frame)

Protocol = see RFC 1700 (assigned numbers)
Information= Network Layer PDU
FCS = 16 bit

- **some protocol fields**
  - 0021 Internet Protocol
  - 0029 AppleTalk
  - 8021 IP Control Protocol
  - 8029 AppleTalk Control Prot.
  - C021 Link Control Protocol
  - C223 Authentication CHAP
  - 0027 DECnet Phase 4
  - 002B Novell IPX
  - 8027 DECnet Control Protocol
  - 802B IPX Control Protocol
  - C023 Authentication PAP

Link Control Protocol (LCP) Frame Format



- **carried in PPP information field**
  - protocol field has to be 0xC021
  - code field indicates type of LCP packet
  - identifier field is used to match requests and replies
  - data field values are determined by the code field (e.g. contains options to be negotiated)

Types of LCP Packets

- **There are three classes of LCP packets:**
  - class 1: Link Configuration packets used to establish and configure a link
    - Configure-Request (code 1, details in option field), Configure-Ack (code 2), Configure-Nak (code 3, not supported option) and Configure-Reject (code 4, not supported option)
  - class 2: Link Termination packets used to terminate a link
    - Terminate-Request (code 5) and Terminate-Ack (code 6)
  - class 3: Link Maintenance packets used to manage and debug a link
    - Code-Reject (code 7, unknown LCP code field), Protocol-Reject (code 8, unknown PPP protocol field), Echo-Request (code 9), Echo-Reply (code 10) and Discard-Request (code 11)

LCP and PPP Connection

- **LCP**
  - supports the establishment of the connection and allows certain configuration options to be negotiated
- **PPP connection is established in four phases**
  - phase 1: link establishment and configuration negotiation
    - Done by LCP (note: deals only with link operations, does not negotiate the implementation of network layer protocols)
  - phase 2: optional procedures that were agreed during negotiation of phase 1 (e.g. CHAP)
  - phase 3: network layer protocol configuration negotiation done by corresponding NCPs
    - E.g. IPCP, IPXCP, ...
  - phase 4: link termination

PPP Phases

- **task of phase 1**
  - LCP is used to automatically
    - agree upon the encapsulation format options
    - handle varying limits on sizes of packets
    - detect a looped-back link and other common configuration errors (magic number for loopback detection)
  - options which may be negotiated
    - maximum receive unit
    - authentication protocol
    - quality protocol
    - Protocol-Field-Compression
    - Address-and-Control-Field-Compression
    - these options are described in RFC 1661 (except authentication protocols)

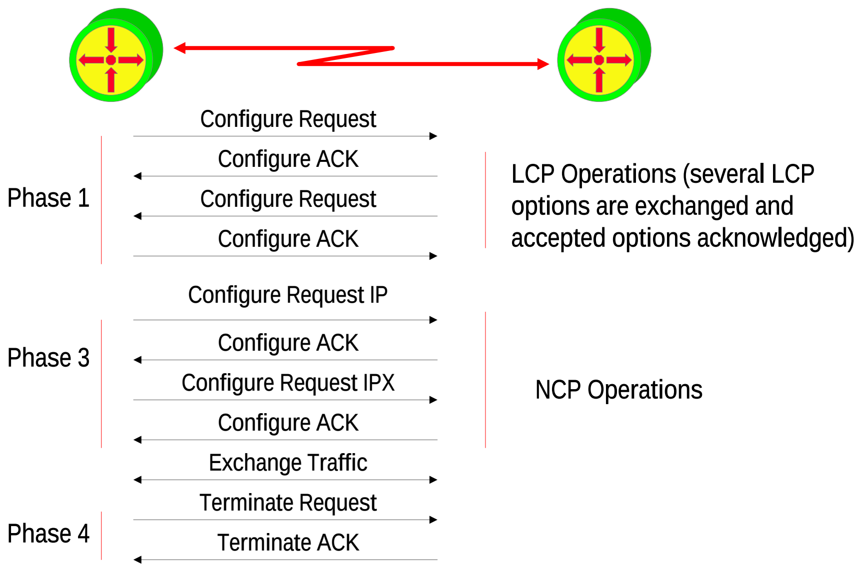
PPP Phases

- **task of phase 1 (cont.)**
  - options which may be negotiated but implementations are specified in other RFCs
    - PPP link quality protocol (RFC 1989)
    - PPP compression control protocol (RFC 1962)
    - PPP compression STAC (RFC 1974)
    - PPP compression PREDICTOR (RFC 1978)
    - PPP multilink (RFC 1990)
    - PPP callback (draft-ietf-pppext-callback-ds-01.txt)
    - PPP authentication CHAP (RFC 1994)
    - PPP authentication PAP (RFC 1334)
    - PPP Extensible Authentication Protocol (EAP), RFC 2284

PPP Phases

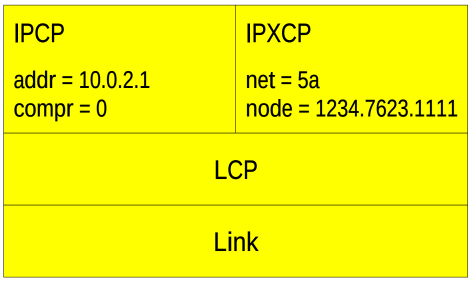
- **task of phase 2**
  - providing of optional facilities
    - authentication, compression initialization, multilink, etc.
- **task of phase 3**
  - network layer protocol configuration negotiation
    - after link establishment, stations negotiate/configure the protocols that will be used at the network layer; performed by the appropriate network control protocol
    - particular protocol used depends on which family of NCPs is implemented
- **task of phase 4**
  - link termination
    - responsibility of LCP, usually triggered by an upper layer protocol of a specific event

PPP Link Operation Example



Network Control Protocol

- one per upper layer protocol (IP, IPX…)
- each NCP negotiates parameters appropriate for that protocol
- IP - IP address, Def. Gateway, DNS Server, TTL, TCP header compression…
- IPX - network/node address, compression, router name



PAP Authentication (RFC 1334)

- **Password Authentication Protocol**
- **simple two way handshake**
- **passwords are sent in clear text**
- **snooping gets you the password**
- **not compatible with bi-directional authorization**

CHAP Authentication RFC 1994

- **Challenge Authentication Protocol**
- **follows establishment of LCP**
- **identifies user**
- **three way handshake**
- **one way authentication only**
  - station which starts (authenticator) the three way handshake proofs authentication of the other station
  - must be configured on both sides if two way authentication is necessary
- **snooping does not discover password**

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CHAP Operation

- **three way handshake**
  - PPP link successfully installed by LCP
  - local station sends a challenge message to remote station
  - challenge contain random number and own user-id
  - remote station replies with value using one way hash function based on crypto negotiated for this user-id
  - response is compared with stations own calculation of random number with same crypto
  - if equal success messages is sent to remote station
  - if unequal failure message is sent

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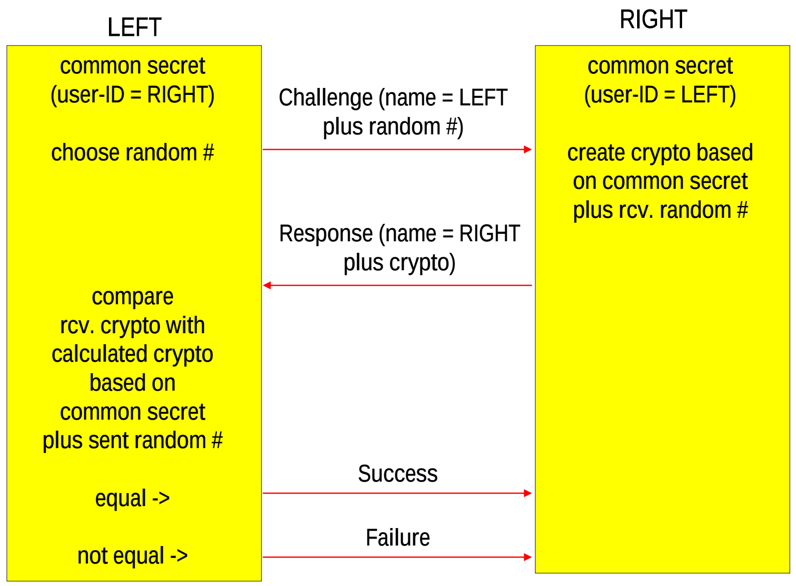
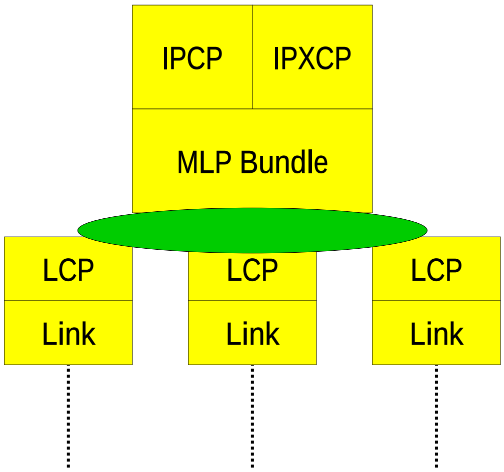
CHAP Authentication Procedure



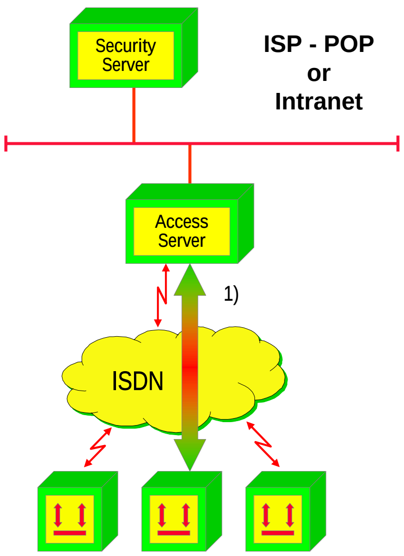
Multilink PPP (RFC 1990)

- **“bundles” bandwidth of multiple interfaces**
  - based on LAPB Multilink procedures (ISO 7776)
- **enabled by LCP negotiation**
- **inactive until authentication**
- **protocol-id 0x003D**
- **single NCP across all links in bundle**
- **large packets are fragmented and sent across links in balanced way**
  - fragments carry sequence number and are tagged with begin and end flags
- **better granularity than packet-level switching**

Multilink PPP

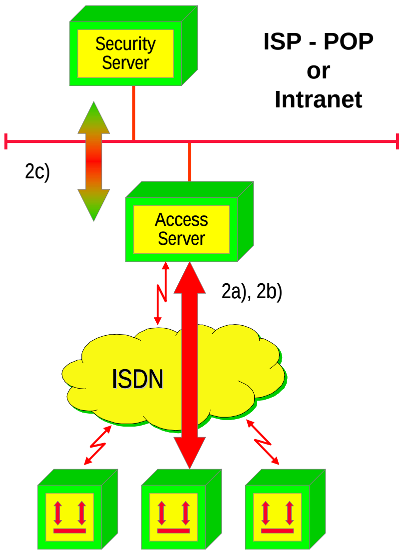


RAS Operation 1



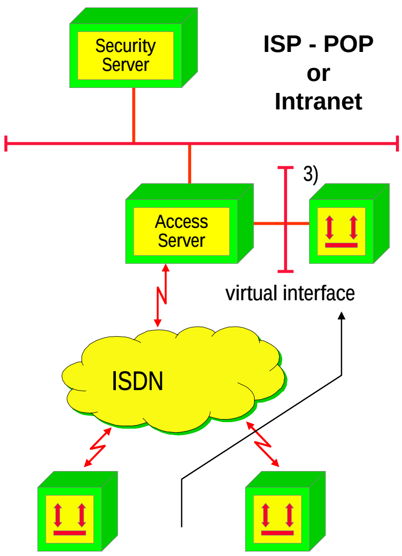
- remote PC places ISDN call to access server, ISDN link is established (1)

RAS Operation 2



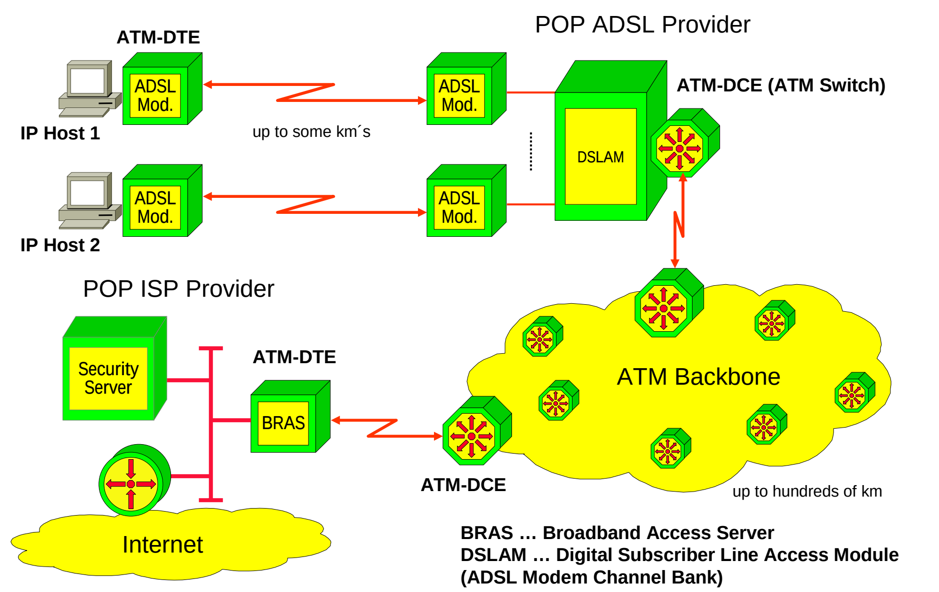
- **PPP link (multiprotocol over serial line) is established**
  - LCP Link Control Protocol (2a)
    - establishes PPP link plus negotiates parameters like authentication CHAP
  - authentication
    - CHAP Challenge Authentication Protocol to transport passwords (2b)
    - verification maybe done by central security server (2c) -> Radius, TACACS, TACACS+

RAS Operation 3



- **PPP NCP (Network Control Protocol) IPCP**
  - assigns IP address, Def. GW, DNS to remote PC
- **remote PC appears as**
  - device reachable via virtual interface (3), IP host Route
- **optionally**
  - filter could be established on that virtual interface
    - authorization
  - accounting can be performed
    - actually done by security server (AAA server)
    - TACACS, Radius

ADSL: Physical Topology



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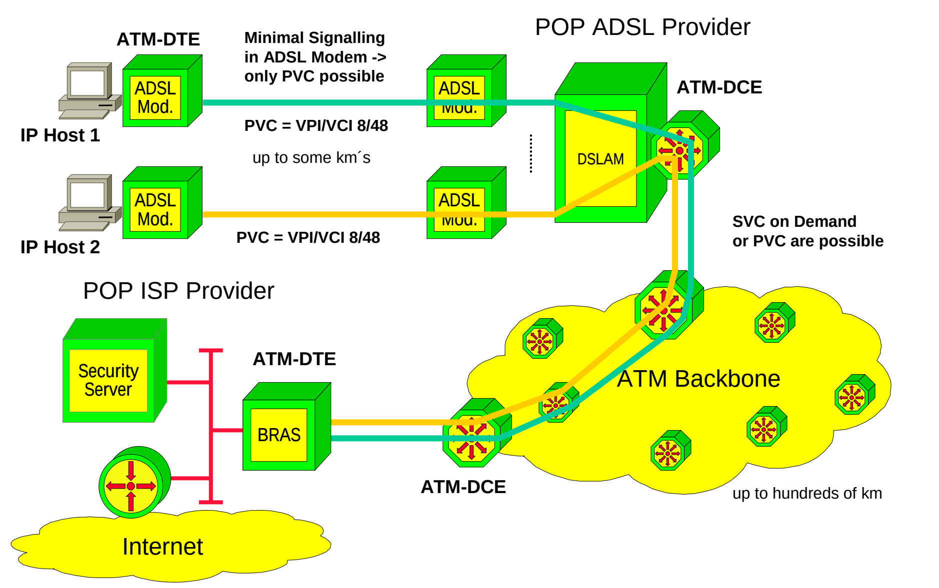
ADSL: ATM Virtual Circuits



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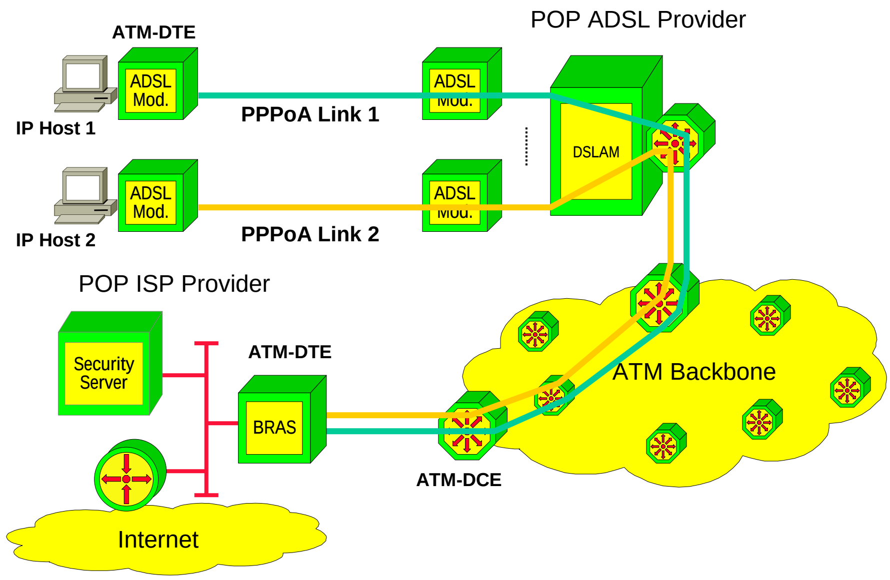
ADSL: PPP over ATM (PPPoA)



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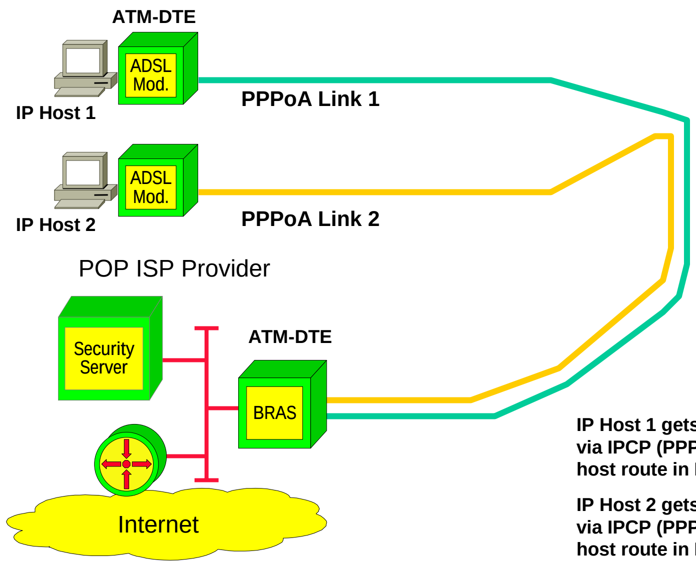
ADSL: PPP over ATM (PPPoA), IPCP



IP Host 1 gets global IP address via IPCP (PPP-NCP), appears as host route in BRAS

IP Host 2 gets global IP address via IPCP (PPP-NCP), appears as host route in BRAS

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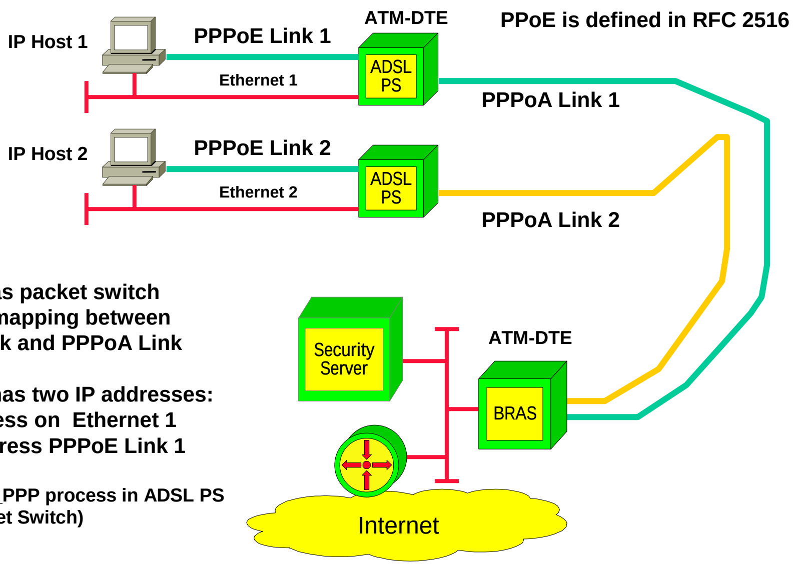
ADSL: PPP over Ethernet (PPPoE)

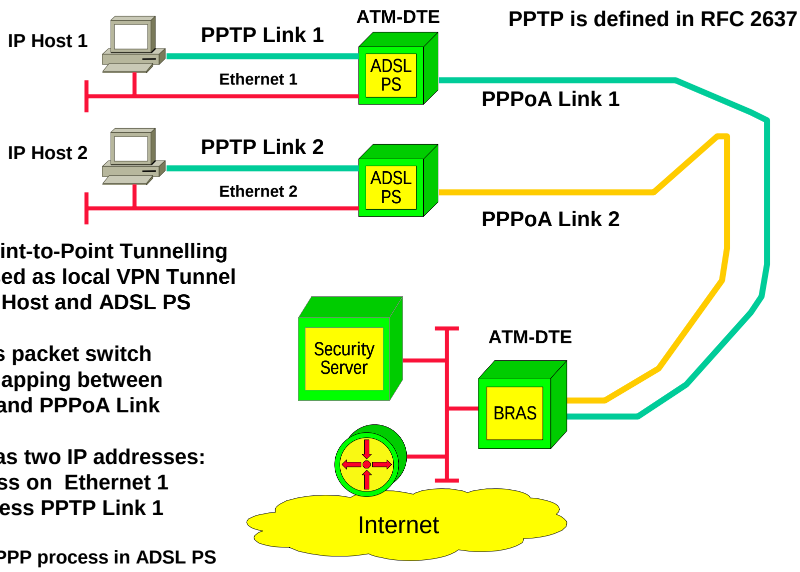


ADSL PS as packet switch performs mapping between PPPoE Link and PPPoA Link

IP Host 1 has two IP addresses:
local address on Ethernet 1
global address PPPoE Link 1

note: Relay_PPP process in ADSL PS
(PS … Packet Switch)

ADSL: PPTP over Ethernet (Microsoft VPN)



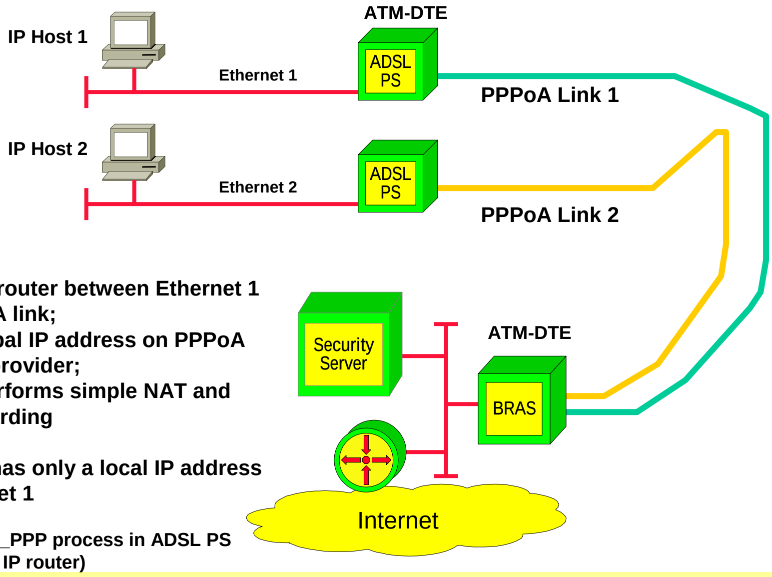
PPTP … Point-to-Point Tunnelling Protocol used as local VPN Tunnel between IP Host and ADSL PS

ADSL PS as packet switch performs mapping between PPTP Link and PPPoA Link

IP Host 1 has two IP addresses:
local address on Ethernet 1
global address PPTP Link 1

note: Relay_PPP process in ADSL PS

ADSL: Routed PPPoA

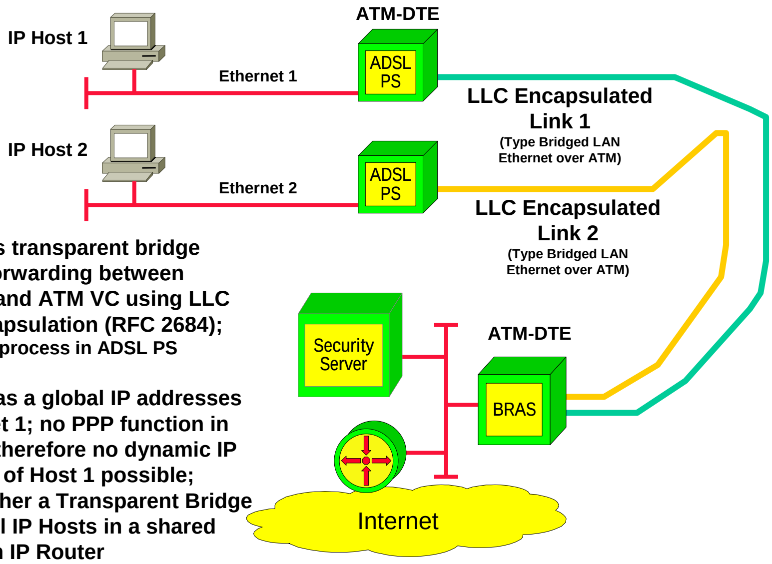


ADSL PS :
acts as IP router between Ethernet 1 and PPPoA link;
gets a global IP address on PPPoA link from provider;
usually performs simple NAT and DNS forwarding

IP Host 1 has only a local IP address on Ethernet 1

note: Dialup_PPP process in ADSL PS (PS is a real IP router)

ADSL: Ethernet Approach



ADSL PS as transparent bridge performs forwarding between Ethernet 1 and ATM VC using LLC bridge encapsulation (RFC 2684);
note: Bridge process in ADSL PS

IP Host 1 has a global IP addresses on Ethernet 1; no PPP function in BRAS and therefore no dynamic IP addressing of Host 1 possible;
BRAS is either a Transparent Bridge grouping all IP Hosts in a shared media or an IP Router

Agenda

- **IP and Network Technologies**
  - Address Resolution Aspects
  - Routing Aspects
  - Examples
  - NBMA Summary
- **IP over WAN**
  - IP over Serial Line / PPP / ADSL
  - IP over X.25
  - IP over Frame Relay
  - IP over ISDN
  - IP over SMDS
  - IP over ATM

IP over X.25

- **address resolution**
  - dynamic ARP not possible
  - must be done by static mapping between IP addresses and LCN (PVC) or X.25 address (SVC)
- **encapsulation**
  - RFC 1356 (former RFC 877) for interoperability between routers or IP hosts of different vendors
- **routing**
  - static routing to save costs (normal case)
  - dynamic routing in case of PVCs and network under own cost control for ease of administration

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IP over Frame Relay

- **address resolution**
  - can be done by inverse ARP (RFC 2390) together with LMI in case of PVC and NBMA topology
  - must be done by static mapping between IP addresses and X.121/E.164 address (SVC)
  - static mapping for PVC can be made easier by usage of subinterfaces
    - definition of several logical network interfaces on one physical network interface
    - mapping of every virtual circuit to a corresponding subinterface, every subinterface belonging to a different IP subnet
    - reduction of NBMA topology to a star of point-to-point links
    - mapping is done using DLCI and IP subnet only (remote IP address is not necessary)

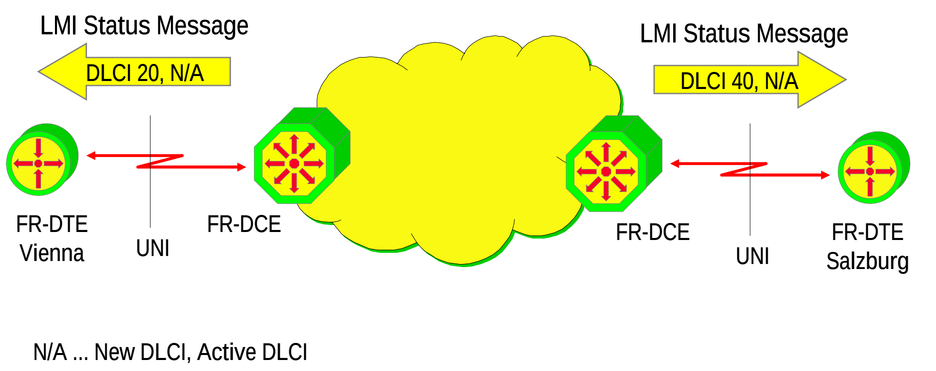
Inverse ARP

- in case of PVC service with the presence of a LMI protocol
  - new DLCIs are reported as soon as they are established
    - unfortunately layer 3 addressing is not included in LMI PVC Status announcements
  - although a new DLCI is reported by LMI
    - additional configuration of an FR-DTE is necessary for mapping layer 3 addresses to this DLCI
  - in large environments with many PVC's
    - high administrative / configuration overhead
  - improvement with inverse ARP

RFC 2390 Inverse ARP

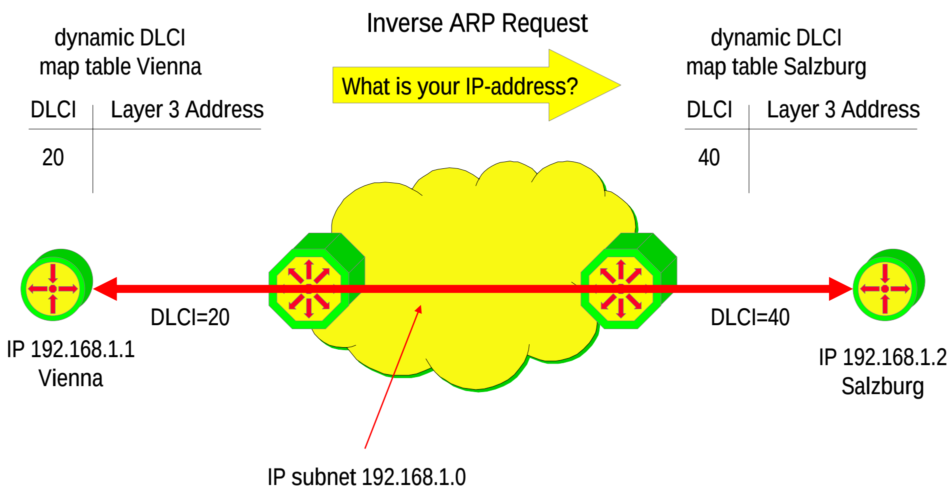
- RFC 2390 specifies Inverse ARP method
  - for an automated discovery and mapping of layer 3 addresses to a DLCI
  - expansion of original ARP protocol defined for LAN´s
- Inverse ARP protocol allows a FR-DTE
  - to discover layer 3 addresses of a station located at the other side of a virtual circuit
- Inverse ARP also specified for ATM
  - help of ILMI to announce ATM-PVC´s

Inverse ARP Operation 1



 IP over WAN, v4.3 73

Inverse ARP Operation 2



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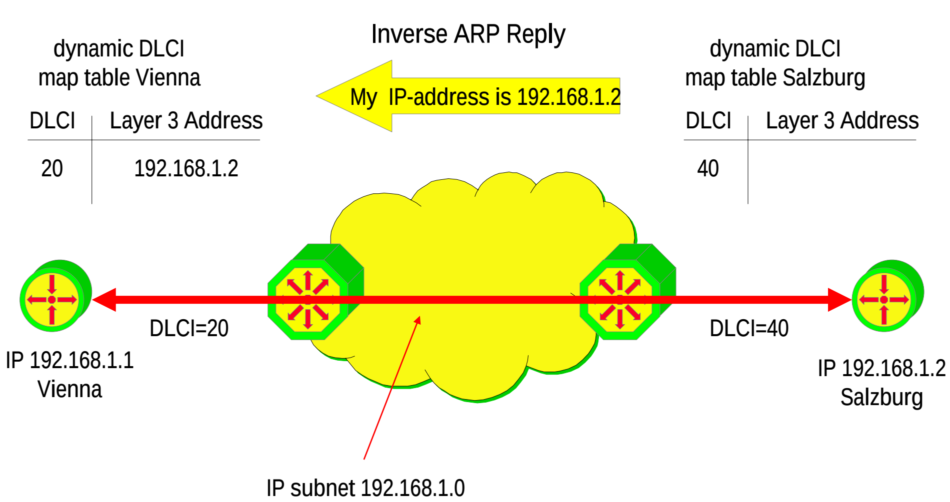
Inverse ARP Operation 3



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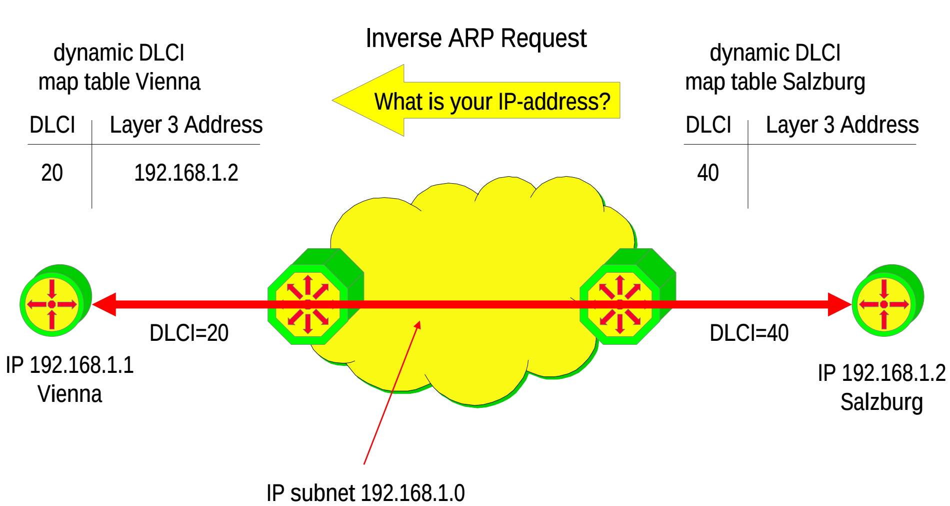
Inverse ARP Operation 4



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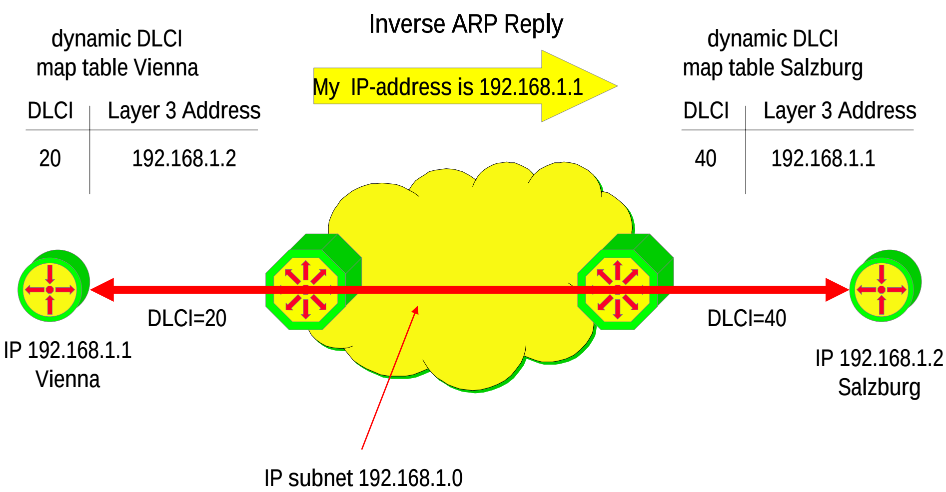
Inverse ARP Operation 5



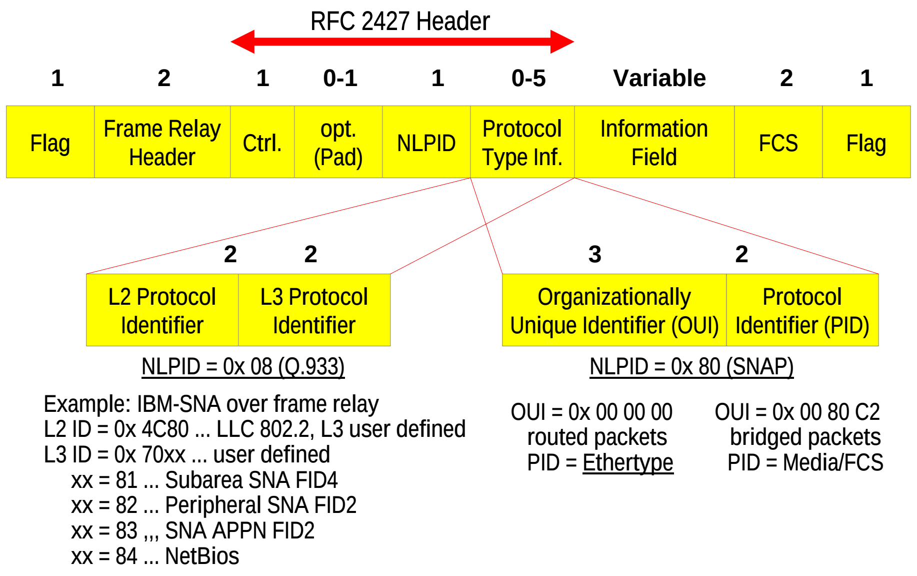
IP Encapsulation over Frame Relay

- **encapsulation**
  - for interoperability reasons between routers or IP hosts of different vendors a defined encapsulation of higher protocols is necessary
    - FR-DTEs of different vendors must recognize protocol type of received packet in order to proceed with processing
  - RFC 2427 defines encapsulation of multiprotocol traffic over frame relay
    - like PPP for serial links between routers
    - RFC 2427 is former RFC 1490
    - fragmentation described in RFC 1490 not longer defined in RFC 2427

RFC 2427

- **basic multiprotocol encapsulation**
  - normal Q.922 Annex A frame relay header & trailer
- **RFC 2427 Header**
  - Q.922 Control (Crt)
    - 0x 03 ... UI unnumbered information)
  - PAD (optional)
    - padding octet (all zeros) to align frame on a convenient boundary
  - Network Level Protocol Identifier (NLPID)
    - values defined by ISO/IEC TR 9577
    - 0x 08 ... user defined format using Q.933 (e.g. ISO 8208, SNA)
    - 0x 80 ... SNAP format
    - 0x 81 ... ISO CNLP, 0x 82 ... ISO ES-IS, 0x 83 ... ISO IS-IS
    - 0x CC ... Internet IP

RFC 2427



Bridging over Frame Relay

NLPID = SNAP OUI = 0x 00 80 c2

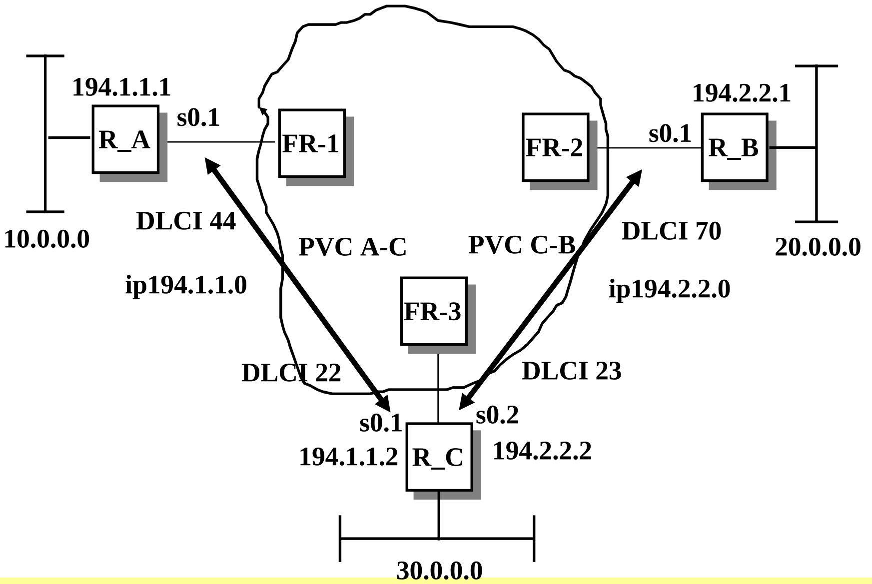
PID values

media	without preserved FCS	with preserved FCS
802.3	0x 00 07	0x 00 01
802.4	0x 00 08	0x 00 02
802.5	0x 00 09	0x 00 03
FDDI	0x 00 0A	0x 00 04
802.6	0x 00 0B	
Fragments	0x 00 0D	
802.1 (d, g) BPDU´s	0x 00 0E	
Source Routing BPDU´s	0x 00 0F	

IP over Frame Relay

- **routing**
  - static routing to save bandwidth (PVC)
  - dynamic routing for ease of administration (PVC)
  - philosophy may change with deployment of frame relay SVC service

Example 4: FR-Topology with Subinterfaces



Example 4: Cisco-Configuration

Router A:
router rip
network 194.1.1.0

int s0
encapsulation frame-relay ietf
frame-relay lmi-type cisco
int s0.1 point-to-point
ip 194.1.1.1 255.255.255.0
frame-relay interface dlci 44

Router B:
router rip
network 194.2.2.0

int s0
encapsulation frame-relay ietf
frame-relay lmi-type cisco
int s0.1 point-to-point
ip 194.2.2.1 255.255.255.0
frame-relay interface dlci 70

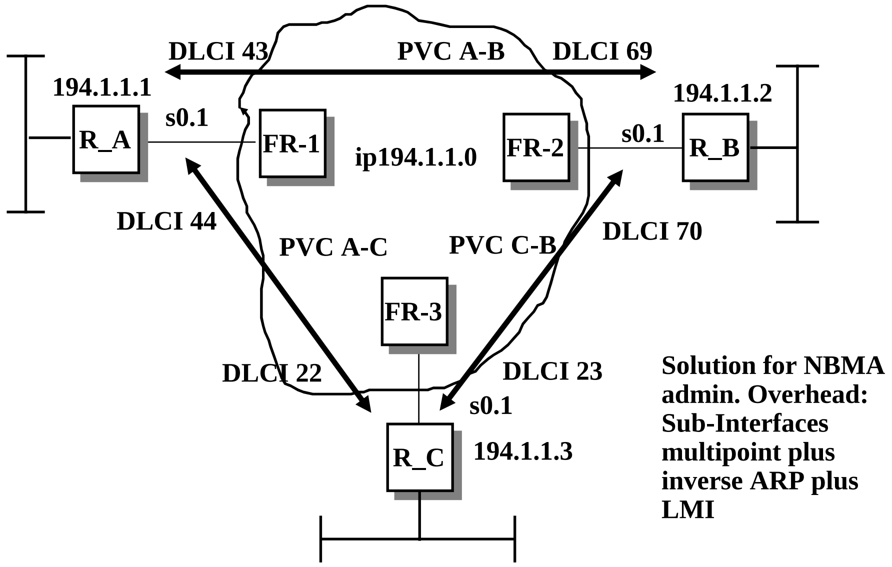
Router C:
router rip
network 194.1.1.0
network 194.2.2.0

int s0
encapsulation frame-relay ietf
frame-relay lmi-type cisco
int s0.1 point-to-point
ip 194.1.1.2 255.255.255.0
frame-relay interface dlci 22
int s0.2 point-to-point
ip 194.2.2.2 255.255.255.0
frame-relay interface dlci 23

Point-to-Point Subinterface::

no frame-relay map command is necessary (connection to a IP subnet on a ptp interface means other side is accessible);
no inverse ARP is enabled on a ptp subinterface

Example 5: FR-Topology with Subinterfaces



Solution for NBMA admin. Overhead: Sub-Interfaces multipoint plus inverse ARP plus LMI

Example 5: Cisco-Configuration

Router A:
router rip
network 194.1.1.0

int s0
encapsulation frame-relay ietf
frame-relay lmi-type cisco
int s0.1 multipoint
ip 194.1.1.1 255.255.255.0
frame-relay interface dlci 43
frame-relay interface dlci 44

Router B:
router rip
network 194.1.1.0

int s0
encapsulation frame-relay ietf
frame-relay lmi-type cisco
int s0.1 multipoint
ip 194.1.1.2 255.255.255.0
frame-relay interface dlci 69
frame-relay interface dlci 70

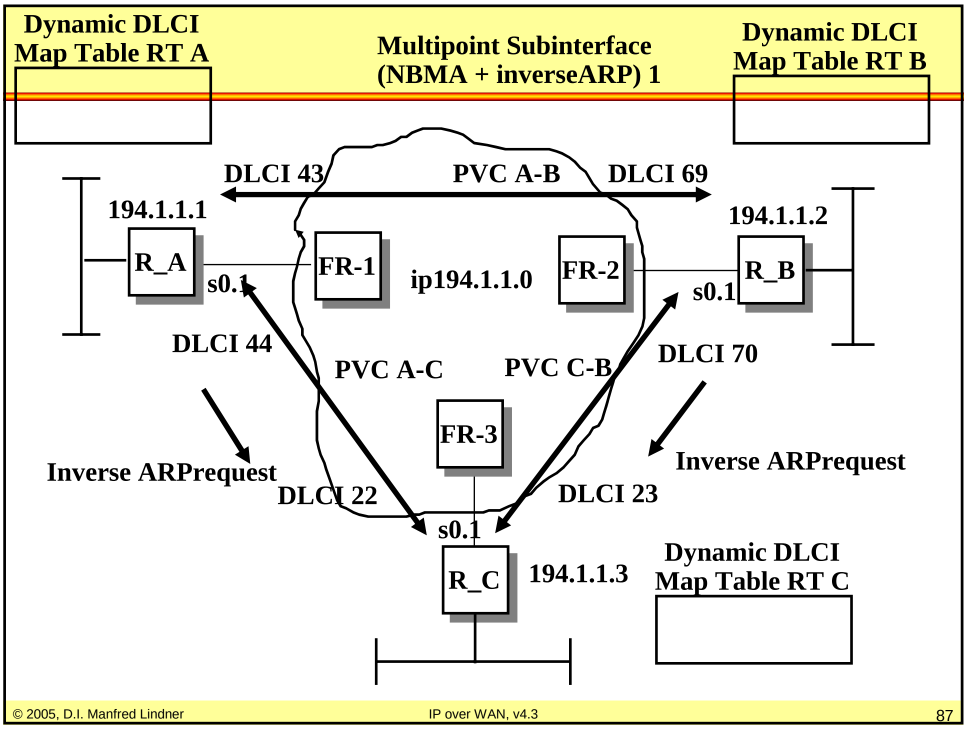
Router C:
router rip
network 194.1.1.0

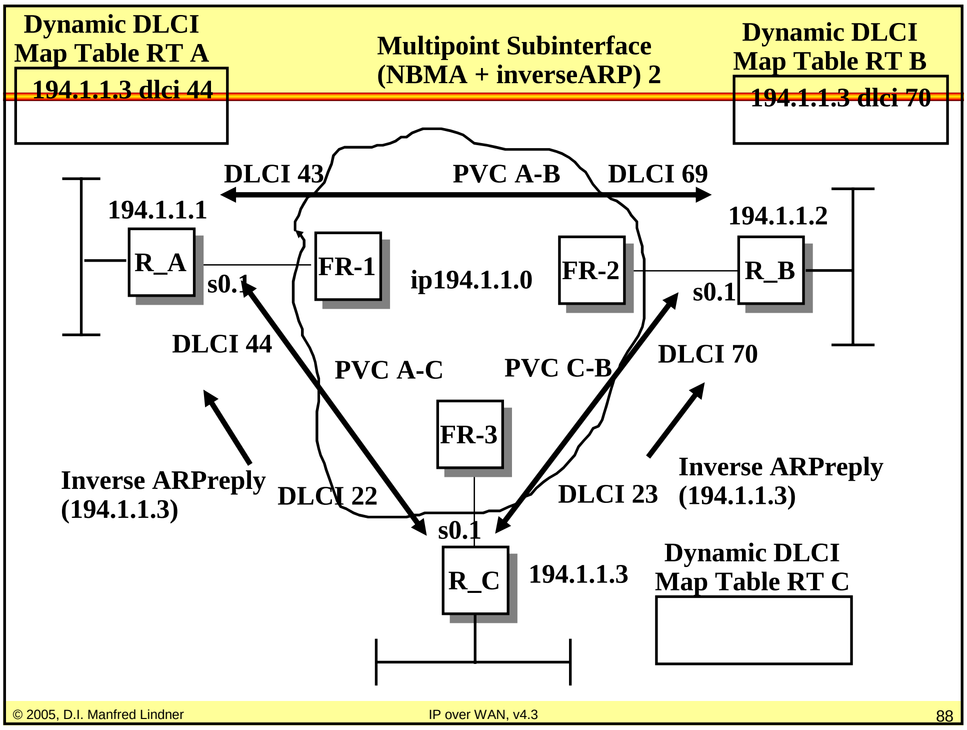
int s0
encapsulation frame-relay ietf
frame-relay lmi-type cisco
int s0.1 multipoint
ip 194.1.1.3 255.255.255.0
frame-relay interface dlci 22
frame-relay interface dlci 23

Multipoint Subinterface:

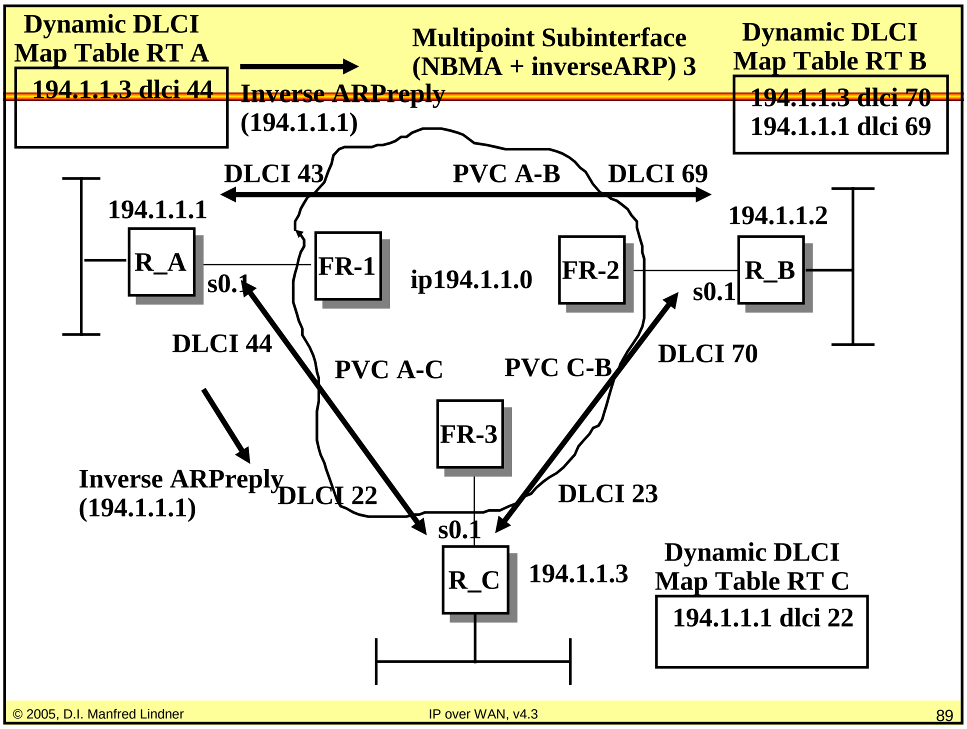
allows to put all routers again in a NBMA environment;
no frame-relay map command is necessary because inverse ARP is enabled by default!!!
no frame-relay interface dlci commands are necessary, if LMI signals presence of PVC-DLCI´s

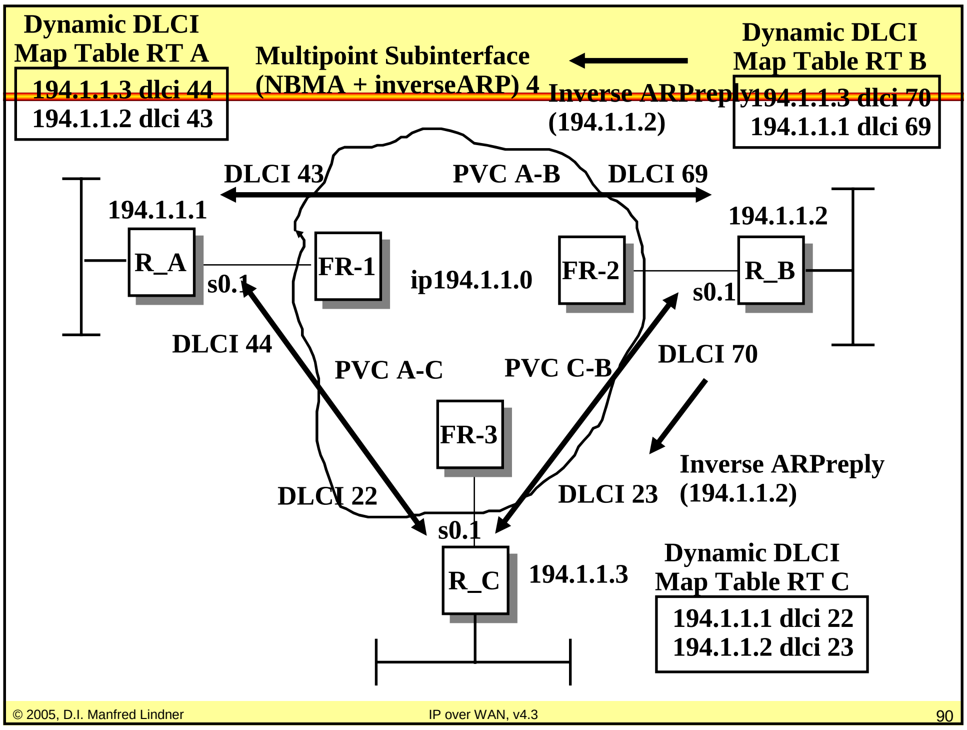
L81 - IP over WAN





L81 - IP over WAN





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  - IP over SMDS
  - IP over ATM

IP over ISDN

- **address resolution**
  - dynamic ARP not possible
  - must be done by static mapping between IP addresses and ISDN telephone number
- **encapsulation**
  - proprietary format
    - between routers or IP hosts of same vendor
  - or PPP (RFC 1661)
    - for interoperability between routers or IP hosts of different vendors

IP over ISDN

- **routing**
  - static routing to save costs (normal case)
  - dynamic routing only in case of ISDN leased line

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IP over DQDB/SMDS

- **address resolution**
  - dynamic ARP possible using DQDB group addresses as destination of broadcasts
- **encapsulation**
  - RFC 1209 (SNAP header)
- **routing**
  - static routing to save costs
  - dynamic routing for ease of administration

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IP over ATM

- **ATM is connection-oriented**
  - assumes connection-oriented applications
- **IP is connection-less**
  - assumes connection-less network
- **significant mismatch**
- **how to solve the problem**
  - interface layer between IP and ATM
    - connection-less behavior towards IP
    - connection-oriented behavior towards ATM
  - several methods
    - IETF approach
    - ATM Forum approach

IP over ATM : Solving the Problem I.

- **encapsulation**
  - if IP is transmitted over any type of media, an appropriate encapsulation has to be defined
  - IETF RFC 2684 (former 1483) (ATM - PPP)
- **address resolution**
  - IP and ATM addresses are different
  - IETF RFC 2225 (former 1577) (ATM-ARP Server)
  - *ATM Forum Name Services*
  - *ATM Forum LAN Emulation*

IP over ATM: Solving the Problem II.

- **connection-setup**
  - ATM requires connections
  - IETF RFC 1755
- **transmission unit**
  - a maximum transmission unit has to be defined
  - IETF RFC 2225 (former 1626)
- **broadcast and multicast support**
  - ATM does not inherently support broadcasts
  - IETF MARS (RFC 2022, Multicast Address Resolution Server)
  - IETF MCS (RFC 2149, Multicast Server)
  - *ATM Forum LAN Emulation*

IP over ATM: Solving the Problem III.

- **path determination**
  - ATM has it´s own routing
  - ATM is treated as NBMA
    - Non Broadcast Multi Access
  - hop-by-hop IP routing not appropriate for ATM networks
  - IETF Next Hop Resolution Protocol (NHRP, RFC 2332)
  - IETF Multi Protocol Label Switching (MPLS, RFC 3031)
  - *ATM Forum Multi Protocol over ATM (MPOA)*
  - *ATM Forum Integrated PNNI*

Summary

- **for transport of IP over WAN three points must be covered**
  - encapsulation
  - address resolution
  - routing
- **straight forward for LAN and point-to-point links**
- **special care must be taken in case of NBMA networks**

