



Chair for Network Architectures and Services – Prof. Carle
Department for Computer Science
TU München

**Master Course
Computer Networks
IN2097**

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 Technische Universität München

 **Outline**

- Project status
- Internet Structure
- Network virtualisation

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 **Talk announcement**


Mon 28 Nov, 11:00-12:00 (s.t.), Room 00.07.014
Prof. Andy Hopper, Ph.D
Head of Informatics, University of Cambridge



Computing for the Future of the Planet
Abstract: Digital technology is becoming an indispensable and crucial component of our lives, society, and environment. A framework for computing in the context of problems facing the planet will be presented. The framework has a number of goals: an optimal digital infrastructure, sensing and optimising with a global world model, reliably predicting and reacting to our environment, and digital alternatives to physical activities. Practical industrial examples will be given as well as research goals.

Andy Hopper has pursued academic and industrial careers simultaneously. In the academic career he has worked in the Computer Laboratory and the Department of Engineering at Cambridge. In the industrial context he has co-founded a dozen spin-outs and start-ups, three of which floated on stock markets. He is currently Chairman of RealVNC and Ubisense plc.

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 **First Feedback**

- Many highly appropriate project plans :)
- team00; team07; team19: please contact me.
- Interesting: Gantt charts
- Interesting: different plans for communication among team members, including mobile phone, skype, instant messaging
- Interesting: different additional tools: dropbox, git, google docs

⇒ Let us see what your final recommendations are
⇒ Let us see whether/how project plan correlates with outcome

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Internet Structure

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Internet structure: network of networks

- roughly hierarchical
- at center: “tier-1” ISPs (AT&T, Global Crossing, Level 3, NTT, Qwest, Sprint, Tata, Verizon (UUNET), Savvis, TeliaSonera), national/international coverage
 - treat each other as equals
 - can reach every other network on the Internet without purchasing IP transit or paying settlements

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Tier-1 ISP: e.g., Sprint

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Internet structure: network of networks

- “Tier-2” ISPs: smaller (often regional) ISPs
 - Connect to one or more tier-1 ISPs, possibly other tier-2 ISPs

- Tier-2 ISP pays tier-1 ISP for connectivity to rest of Internet
- tier-2 ISP is customer of tier-1 provider

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Internet structure: network of networks

- “Tier-3” ISPs and local ISPs
 - last hop (“access”) network (closest to end systems)

Local and tier-3 ISPs are customers of higher tier ISPs connecting them to rest of Internet

The diagram illustrates the Internet's network of networks. At the top is a central Tier 1 ISP (blue oval). Below it are several Tier 2 ISPs (white ovals). Further down are Tier 3 ISPs (white ovals) and local ISPs (white ovals). A red oval represents a Tier 1 ISP, and a red circle represents a Tier 3 ISP. A red arrow points from the red Tier 1 ISP to the red Tier 3 ISP, indicating a customer relationship. The text states that local and tier-3 ISPs are customers of higher tier ISPs connecting them to the rest of the Internet.

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Internet structure: network of networks

- a packet passes through many networks!

The diagram shows a packet's path through the Internet's network of networks. A blue arrow starts from a laptop on the left and passes through a local ISP, a Tier 3 ISP, a Tier 2 ISP, a Tier 1 ISP, another Tier 1 ISP, another Tier 2 ISP, and finally a local ISP on the right, ending at another laptop. This illustrates that a packet passes through many networks.

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Internet Ecosystem

- >30,000 autonomous networks
- Networks with different
 - different roles and business type
 - stub networks
 - transit networks
 - content providers
 - Influenced by traffic patterns, application popularity, economics, regulation,
- Peering
 - bilateral contracts
 - Customer-provider, settlement-free peering, or in between
- Internet Exchange Points

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Internet Exchange Point

The diagram shows an Internet Exchange Point (IXP). Six ISPs (ISP 1 through ISP 6) are connected to a central Ethernet Switch. The switch is also connected to an IXP Management Network. A cloud labeled "IXP Services: TLD DNS, Routing Registry, Looking Glass, news, etc" is connected to the switch. This illustrates how multiple ISPs can connect to a central point for exchanging traffic.

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Cost of Peering at Internet Exchange Point

Cost of Peering

source: William B. Norton, „Internet Peering“, <http://drpeering.net/>

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ISP Peering Relations

source: <http://www.skitter.net/>

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IPv4 vs. IPv6 Graphs

source: caida.org

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AS Connectivity

INTERNET as seen from EASYPNET Switzerland

© 2002 Philippe Bourcier - SYSCTL Lab


NETGEO db copyright CAIDA
map copyright Dave Pope

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Network Architectures

Link virtualization: ATM, MPLS



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Virtualization of networks

- Virtualization of resources
 - powerful abstraction in systems engineering
- Computing examples of virtualisation popular for long time
 - virtual memory
 - virtual devices
 - Virtual machines: e.g., Java
 - IBM VM operation system (1960's/70's)
- Layering of abstractions
 - don't bother with details of the lower layer, only deal with lower layers abstractly

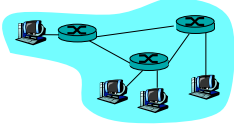
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The Internet: Virtualizing Networks

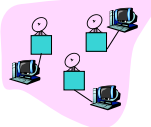
- 1974: multiple unconnected networks
 - ARPAnet
 - data-over-cable networks
 - packet satellite network (Aloha protocol)
 - packet radio network

... differing in:

- addressing conventions
- packet formats
- error recovery
- routing



ARPAnet



satellite net

"A Protocol for Packet Network Intercommunication",
V. Cerf, R. Kahn, IEEE Transactions on Communications,
May, 1974, pp. 637-648.

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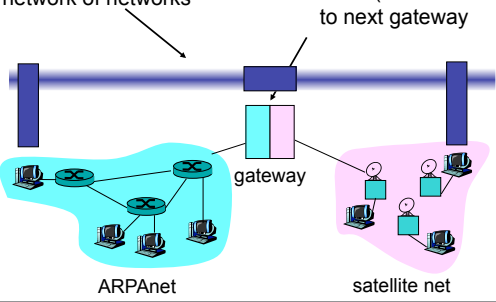
The Internet: Virtualizing networks

Internetwork layer (IP):

- addressing: internetwork appears as single, uniform entity, despite underlying local network heterogeneity
- network of networks

Gateway:

- "embed internetwork packets in local packet format or extract them"
- route (at internetwork level) to next gateway



gateway

ARPAnet satellite net

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Cerf & Kahn's Internetwork Architecture

- What is virtualized?
- two layers of addressing: internetwork and local network
- new layer (IP) makes everything homogeneous at internetwork layer
- underlying local network technology
 - cable
 - satellite
 - 56K telephone modem
 - today: ATM, MPLS
- ... "invisible" at internetwork layer.
Looks like a link layer technology to IP!



ATM and MPLS

- ATM, MPLS separate networks in their own right
 - different service models, addressing, routing from Internet
- Viewed by Internet as logical link connecting IP routers
 - just like dialup link is really part of separate network (telephone network)
- ATM, MPLS: of technical interest in their own right



Asynchronous Transfer Mode: ATM

- 1990's/00 standard for high-speed networking
 - 155Mbps to 622 Mbps and higher
 - *Broadband Integrated Service Digital Network* architecture
- *Goal: integrated, end-end transport of carry voice, video, data*
 - meeting timing/QoS requirements of voice, video versus Internet best-effort model
 - "next generation" telephony: technical roots in telephone world
 - packet-switching (fixed length packets, called "cells") using virtual circuits, and label swapping



Datagram or VC network: why?

- | | |
|---|--|
| <p>Internet</p> <ul style="list-style-type: none"> □ data exchange among computers <ul style="list-style-type: none"> ▪ "elastic" service, no strict timing requirements □ "smart" end systems (computers) <ul style="list-style-type: none"> ▪ can adapt, perform control, error recovery ▪ simple inside network, complexity at "edge" □ many link types <ul style="list-style-type: none"> ▪ different characteristics ▪ uniform service difficult | <p>ATM</p> <ul style="list-style-type: none"> □ evolved from telephony □ human conversation: <ul style="list-style-type: none"> ▪ strict timing, reliability requirements ▪ need for guaranteed service □ "dumb" end systems <ul style="list-style-type: none"> ▪ telephones ▪ complexity inside network |
|---|--|

ATM architecture

The diagram shows a sequence of four boxes representing network elements: end system, switch, switch, and end system. Each box is divided into three horizontal layers: AAL (Adaptation Layer) at the top, ATM in the middle, and physical at the bottom. Vertical lines connect the layers between adjacent elements, showing that AAL is only present in the end systems, while ATM and physical layers are present in all elements.

- **adaptation layer:** only at edge of ATM network
 - data segmentation/reassembly
 - roughly analogous to Internet transport layer
- **ATM layer:** “network” layer
 - cell switching, routing
- **physical layer**

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ATM: Network or Link layer?

Vision: end-to-end transport:
 “ATM from desktop to desktop”

- ATM is a network technology

Reality: used to connect IP backbone routers

- “IP over ATM”
- ATM as switched link layer, connecting IP routers

The diagram illustrates an IP network (represented by a cloud) connected to an ATM network (represented by a cloud). IP routers are shown connecting to ATM routers, which in turn connect to end systems (desktops).

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ATM Adaptation Layer (AAL)

- ATM **Adaptation Layer (AAL):** “adapts” upper layers (IP or native ATM applications) to ATM layer below
- AAL present **only in end systems**, not in switches
- AAL layer segment (header/trailer fields, data) fragmented across multiple ATM cells
 - analogy: TCP segment in many IP packets

This diagram is identical to the one in slide 25, showing the ATM architecture with AAL, ATM, and physical layers across end systems and switches.

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ATM Adaptation Layer (AAL) [more]

Different versions of AAL layers, depending on ATM service class:

- **AAL1:** for CBR (Constant Bit Rate) services, e.g. circuit emulation
- **AAL2:** for VBR (Variable Bit Rate) services, e.g., MPEG video
- **AAL5:** for data (e.g., IP datagrams)

The diagram shows the structure of an ATM cell. At the top is a box for 'User Data'. Below it is the 'AAL PDU' (Adaptation Layer Protocol Data Unit), which consists of a 'CPCS Header' and a 'CPCS Trailer'. Below the AAL PDU is the 'ATM cell', which consists of an 'ATM Cell Header', an 'AAL Header', 'Payload Data (<=48 bytes)', and an 'AAL Trailer'. The 'ATM Cell' is shown to be composed of multiple 'ATM cells' (indicated by a bracket). The 'AAL PDU' and 'ATM cell' are shown to be part of the 'SAR sublayer' (Segmentation and Reassembly sublayer), while the 'User Data' is part of the 'Convergence sublayer'.

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ATM Layer

Service: transport cells across ATM network

- analogous to IP network layer
- very different services than IP network layer
- possible Quality of Service (QoS) Guarantees

Network Architecture	Service Model	Guarantees ?				Congestion feedback
		Bandwidth	Loss	Order	Timing	
Internet	best effort	none	no	no	no	no (inferred via loss)
ATM	CBR	constant rate	yes	yes	yes	no congestion
ATM	VBR	guaranteed rate	yes	yes	yes	no congestion
ATM	ABR	guaranteed minimum	no	yes	no	yes
ATM	UBR	none	no	yes	no	no

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ATM Layer: Virtual Circuits

- **VC transport:** cells carried on VC from source to destination
 - call setup, teardown for each call *before* data can flow
 - addressing of destination e.g. by E.164 number
 - each packet carries VC identifier (*not* destination ID)
 - label swapping: VC identifier may change along path
 - *every* switch on source-destination path maintains “state” for each passing connection
 - link, switch resources (bandwidth, buffers) may be *allocated* to VC: to get circuit-like perf.
- **Permanent VCs (PVCs)**
 - long lasting connections
 - typically: “permanent” route between to IP routers
- **Switched VCs (SVC):**
 - dynamically set up on per-call basis

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ATM VCs

- **Advantages of ATM VC approach:**
 - QoS performance guarantee for connection mapped to VC (bandwidth, delay, delay jitter)
- **Drawbacks of ATM VC approach:**
 - Inefficient support of datagram traffic
 - one PVC between each source/destination pair does not scale
 - SVC introduces call setup latency, processing overhead for short lived connections

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ATM Layer: ATM cell

- 5-byte ATM cell header
- 48-byte payload (Why?)
 - small payload ⇒ short cell-creation delay for digitized voice
 - halfway between 32 and 64 (compromise!)

Cell header

Cell format

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ATM cell header

- VCI:** virtual channel ID
 - may *change* from link to link through network
- PT:** Payload type: RM (resource management) vs. data cell
- CLP:** Cell Loss Priority bit
 - CLP = 1 implies low priority cell, can be discarded if congestion
- HEC:** Header Error Checksum
 - cyclic redundancy check

40 bits

VCI PT CLP HEC

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Virtual Circuit Switching

Incoming		Outgoing	
Port	VCI	Port	VCI
1	14	3	22
1	77	2	41

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Multiplexing of Variable vs. Fixed Size Packets

- Multiplexing of variable size packets**
- ATM Multiplexing**

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ATM Identifiers

- ATM Cell**
- Virtual Path Identifiers and Virtual Channel Identifiers**
 - a. VPI and VCI in a UNI**
 - b. VPI and VCI in an NNI**

(UNI: User-to-Network-Interface
NNI: Network-to-Network-Interface)

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ATM Virtual Connections

The diagram shows a central pipe representing an ATM virtual connection. On the left, three connections enter with VPI values of 14 and 18. On the right, three connections exit with VPI values of 14 and 18. A yellow callout box states: "This virtual connection is uniquely defined using the pair: (14, 21)", with arrows pointing to VPI=14 and VCI=21. The VCI values for the connections are: VCI=21, 32, 45 for VPI=14; and VCI=70, 74, 45 for VPI=18.

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ATM Physical Layer

Physical Medium Dependent (PMD) sublayer

- **SONET/SDH:** transmission frame structure (like a container carrying bits);
 - bit synchronization;
 - bandwidth partitions (TDM);
 - several speeds:
 - OC3 = 155.52 Mbps
 - OC12 = 622.08 Mbps
 - OC48 = 2.45 Gbps
 - OC192 = 9.6 Gbps
- **T1/T3:** transmission frame structure (old telephone hierarchy): 1.5 Mbps/ 45 Mbps
- **unstructured:** just cells (busy/idle)
 - transmission of **idle cells** when no data cells to send

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IP-Over-ATM

Classic IP only

- 3 "networks" (e.g., LAN segments)
- MAC (802.3) and IP addresses

Ethernet LANs

IP over ATM

- replace "network" (e.g., LAN segment) with ATM network
- ATM addresses, IP addresses

Ethernet LANs ATM network

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IP-Over-ATM

The diagram shows a network topology with three protocol stacks:

- Left stack (Ethernet):** app, transport, IP, Eth, phy
- Middle stack (IP over ATM):** IP, AAL, ATM, phy
- Right stack (ATM):** app, transport, IP, AAL, ATM, phy

The network consists of a central router connected to three LANs. The connections between the router and LANs are labeled as ATM phy.

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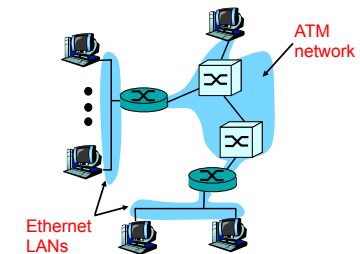
Datagram Journey in IP-over-ATM Network

- **at Source Host:**
 - IP layer maps between IP, ATM destination address (using ARP)
 - passes datagram to AAL5
 - AAL5 encapsulates data, segments cells, passes to ATM layer
- **ATM network:** moves cell along VC to destination
- **at Destination Host:**
 - AAL5 reassembles cells into original datagram
 - if CRC OK, datagram is passed to IP

IP-Over-ATM

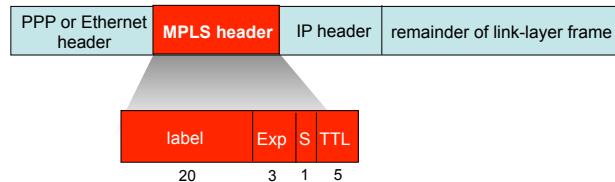
Issues:

- IP datagrams into ATM AAL5 PDUs
- from IP addresses to ATM addresses
 - just like IP addresses to 802.3 MAC addresses!
 - ARP server



Multiprotocol label switching (MPLS)

- initial goal: speed up IP forwarding by using fixed length label (instead of IP address) to do forwarding
 - borrowing ideas from Virtual Circuit (VC) approach
 - but IP datagram still keeps IP address!



MPLS capable routers

- a.k.a. label-switched router
- forwards packets to outgoing interface based only on label value (don't inspect IP address)
 - MPLS forwarding table distinct from IP forwarding tables
- signaling protocol needed to set up forwarding
 - Label Distribution Protocol (LDP)
 - RSVP-TE
- forwarding possible along paths that IP alone would not allow (e.g., source-specific routing)
- MPLS supports traffic engineering
- must co-exist with IP-only routers

MPLS forwarding tables

in label	out label	dest	out interface
10	A	A	0
12	D	D	0
8	A	A	1

in label	out label	dest	out interface
10	6	A	1
12	9	D	0

in label	out label	dest	out interface
8	6	A	0

in label	out label	dest	out interface
6	-	A	0

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Virtual Private Networks

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Virtual Private Networks (VPN)

VPNs

Networks perceived as being private networks by customers using them, but built over shared infrastructure owned by service provider (SP)

- Service provider infrastructure:
 - backbone
 - provider edge devices
- Customer:
 - customer edge devices (communicating over shared backbone)

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VPN Reference Architecture

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VPNs: Why?

- Privacy
- Security
- Works well with mobility (looks like you are always at home)
- Cost
 - many forms of newer VPNs are cheaper than leased line VPNs
 - ability to share at lower layers even though logically separate means lower cost
 - exploit multiple paths, redundancy, fault-recovery in lower layers
 - need isolation mechanisms to ensure resources shared appropriately
- Abstraction and manageability
 - all machines with addresses that are “in” are trusted no matter where they are

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VPN: logical view

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Leased-Line VPN

customer sites interconnected via static virtual channels (e.g., ATM VCs), leased lines

customer site connects to provider edge

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Customer Premise VPN

- all VPN functions implemented by customer

customer sites interconnected via tunnels

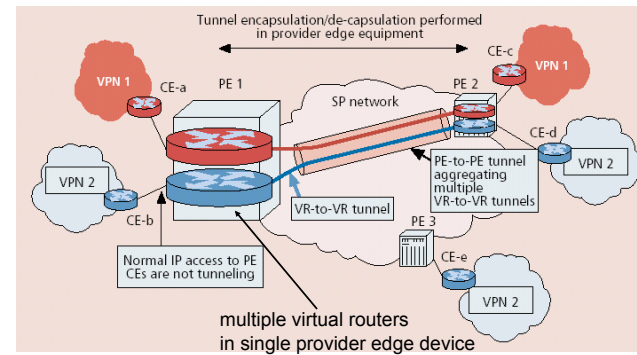
- tunnels typically encrypted
- Service provider treats VPN packets like all other packets

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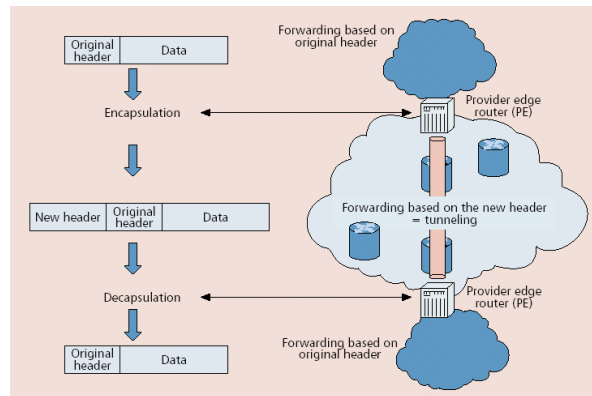
Variants of VPNs

- Leased-line VPN
 - configuration costs and maintenance by service provider: long time to set up, manpower
- CPE-based VPN
 - expertise by customer to acquire, configure, manage VPN
- Network-based VPN
 - Customer routers connect to service provider routers
 - Service provider routers maintain separate (independent) IP contexts for each VPN
 - sites can use private addressing
 - traffic from one VPN cannot be injected into another

Network-based Layer 3 VPNs



Tunneling



MPLS-based VPN

