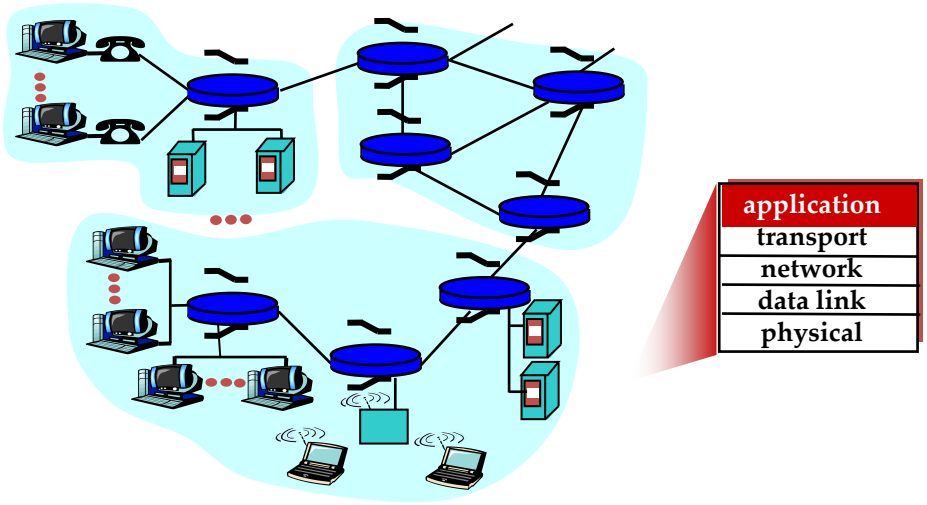
CS 4390
Computer Networks



History and Some Fundamental Concepts

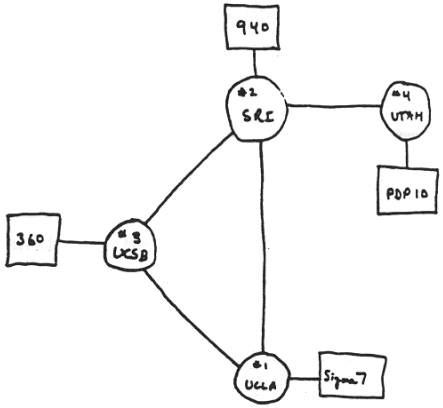
Adapted from "Computer Networking – a Top-Down Approach"

Internet History

1961-1972: Early packet-switching principles

- 1961: *Kleinrock* - queueing theory shows effectiveness of packet-switching
- 1964: *Baran* - packet-switching in military nets
- 1967: ARPAnet conceived by Advanced Research Projects Agency
- 1969: first ARPAnet node operational

- 1972:
  - ARPAnet public demo
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes



THE ARPA NETWORK

Internet History – cont'd

1972-1980: internetworking, new and proprietary nets

- 1970: *ALOHAnet* satellite network in Hawaii
- 1974: Cerf and Kahn - architecture for interconnecting networks
- 1976: *Ethernet* at Xerox PARC
- late70's: proprietary architectures: *DECnet, SNA, XNA*
- late 70's: switching fixed length packets (ATM precursor)
- 1979: ARPAnet has 200 nodes

Cerf and Kahn's internetworking principles:

- *minimalism, autonomy - no internal changes required to interconnect networks*
- *best effort service model*
- *stateless routers*
- *decentralized control*

define today's Internet architecture

Internet History – cont'd

1980-1990: new protocols, a proliferation of networks

- 1983: deployment of TCP/IP
- 1982: SMTP e-mail protocol defined
- 1983: DNS defined for name-to-IP-address translation
- 1985: FTP protocol defined
- 1988: TCP congestion control

- new national networks: Csnet, BITnet, NSFnet, Minitel
- 100,000 hosts connected to confederation of networks

Internet History – cont'd

1990, 2000's: commercialization, the Web, new apps

- early 1990's: ARPAnet decommissioned
- 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)
- early 1990s: Web
  - hypertext [Bush 1945, Nelson 1960's]
  - HTML, HTTP: Berners-Lee
  - 1994: Mosaic, later Netscape
  - late 1990's: commercialization of the Web

late 1990's – 2000's:

- more killer apps: instant messaging, P2P file sharing
- network security to forefront
- est. 50 million host, 100 million+ users
- backbone links running at Gbps

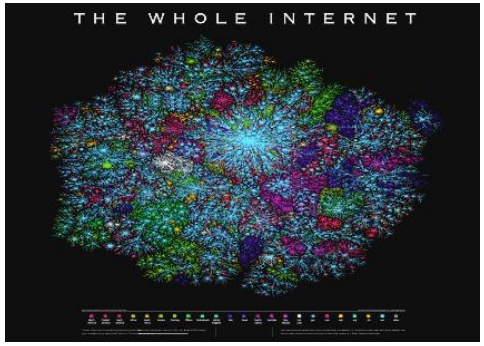
Internet History – cont'd

2005-present

- Billions of hosts
  - Smartphones
  - Tablets
- Aggressive deployment of broadband access
- Increasing ubiquity of high-speed wireless access
- Emergence of online social networks:
  - Facebook, Twitter, LinkedIn
- Service providers (Google, Microsoft) create their own networks
  - Bypass Internet, providing "instantaneous" access to search, email, etc.
- E-commerce, universities, enterprises running their services in "cloud" (e.g., Amazon EC2)
  - Cloud computing

Computer Networking – What?

- Infrastructure that provides applications running on different hosts (end systems) with the ability to exchange data
  - Networked applications
- Important driver of the Information Revolution
  - Along with computing technology
  - Make cheap and ubiquitous information access possible
- Enabler of innovation & education
- Economic engine!



Computer Networking – Why?

- Resource sharing
  - Printers, super computers, hosts, etc…
- Distributed processing
  - Data can be anywhere (data centers)
  - Processing capacity can be distributed and used in parallel
- Innovative applications
  - Social networking
  - E-commerce
  - Entertainment
  - Smart home, smart TV, smart …everything!!! ☺

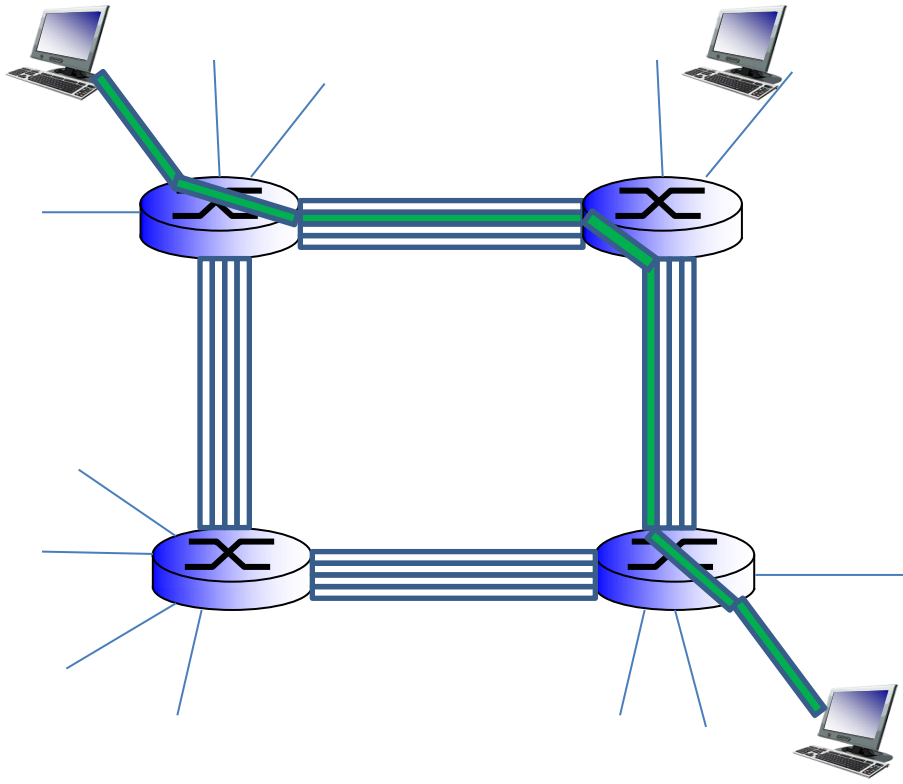
Computer Networking – How?

- Data communications
  - Circuit switching
  - **Packet switching**
  - Transmission medium
- Network architecture
  - **Protocols**
  - **Layering**
  - **Abstraction**
- Application paradigms
  - Client-server
  - Peer-to-peer
  - Broadcast
- …

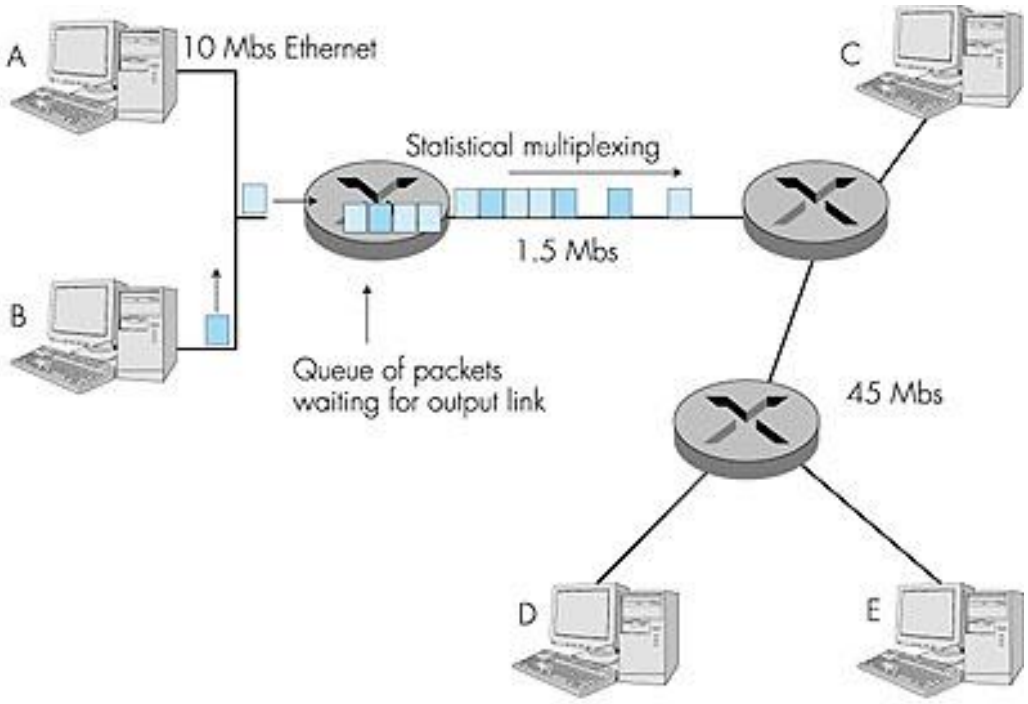
Data Communication
Circuit Switching

end-end resources allocated to, reserved for "call" between source & destination:

- In diagram, each link has four circuits.
  - call gets 2nd circuit in top link and 1st circuit in right link.
- dedicated resources: no sharing
  - circuit-like (guaranteed) performance
- circuit segment idle if not used by call *(no sharing)*
- Commonly used in traditional telephone networks



Data Communication
Packet Switching



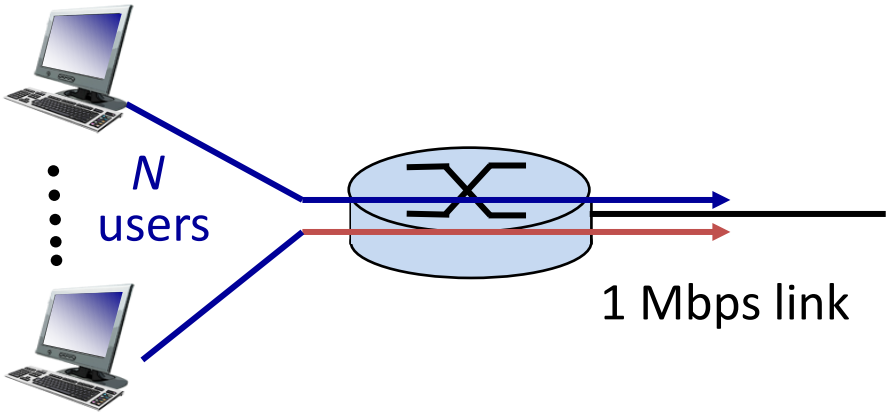
- Store and forward
  - The network nodes between source host and destination host store and forward a chunk of data
  - Packets is the unit for storing and forwarding

Packet Switching v.s. Circuit Switching

packet switching allows more users to use network!

example:

- 1 Mb/s link
- each user:
  - 100 kb/s when "active"
  - active 10% of time



- *circuit-switching:*
  - 10 users
- *packet switching:*
  - 35 users, probability > 10 active at same time is less than .0004

Packet Switching – Characteristics

- Efficient
  - Resources used on demand (v.s. dedicated path of circuit switching)
  - ***Statistical multiplexing***
- Generic – can be used for many types of applications
- Out-of-order delivery
  - Path is not guaranteed to be the same for different packets
- Contention
  - Due to shared resources: switch, links, bandwidth
- Delay
  - Packets may be queued

Physical Media

- signal: propagates between transmitter/receiver pairs
- physical link: what lies between transmitter & receiver
- guided media:
  - signals propagate in solid media: copper, fiber, coax
- unguided media:
  - signals propagate freely, e.g., radio

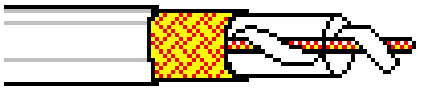
twisted pair (TP)

- two insulated copper wires
  - Category 5: 100 Mbps, 1 Gpbs Ethernet
  - Category 6: 10Gbps

Physical Media: coax, fiber

coaxial cable:

- two concentric copper conductors
- bidirectional
- broadband:
  - multiple channels on cable
  - HFC



fiber optic cable:

- glass fiber carrying light pulses, each pulse a bit
- high-speed operation:
  - high-speed point-to-point transmission (e.g., 10's-100's Gpbs transmission rate)
- low error rate:
  - repeaters spaced far apart
  - immune to electromagnetic noise

Physical Media: Radio Frequency (RF)

- signal carried in electromagnetic spectrum
- no physical "wire"
- bidirectional
- propagation environment effects:
  - reflection
  - obstruction by objects
  - interference

radio link types:

- terrestrial microwave
  - e.g. up to 45 Mbps channels
- LAN (e.g., WiFi)
  - 11Mbps, 54Mbps, 300Mbps
- wide-area (e.g., cellular)
  - 3G cellular: ~ few Mbps
- satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low altitude

What is a Protocol?

human protocols:

- "what's the time?"
- "I have a question"
- introductions

… specific msgs sent

… specific actions taken when msgs received, or other events

network protocols:

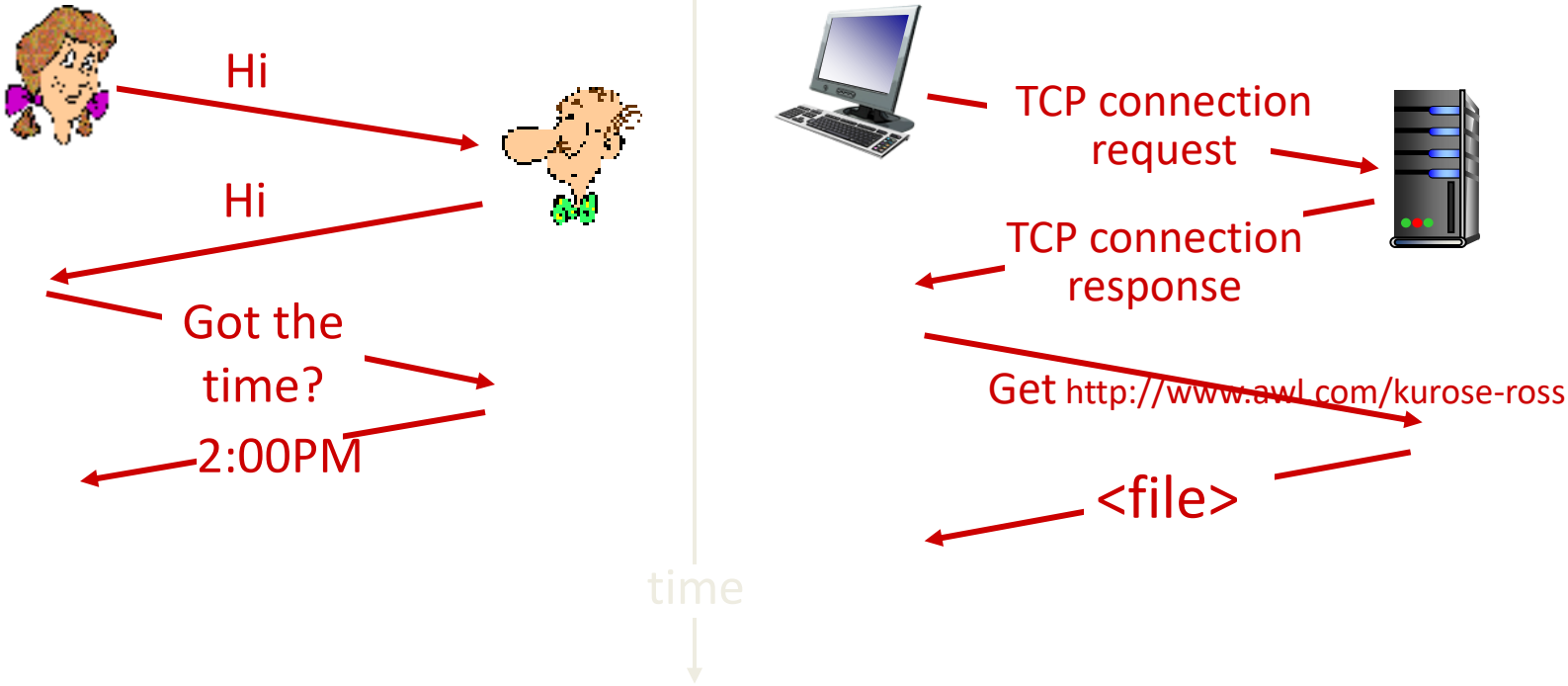
- machines rather than humans
- all communication activity in Internet governed by a suite of protocols

protocols define format, order of messages sent and received among network entities, and actions taken on message transmission, receipt

Message Syntax and Semantic

What is a Protocol?

a human protocol and a computer network protocol:



Q: other human protocols?

Layering

Computer networks are complex, with many "pieces":

- hosts
- routers
- links of various media
- applications
- protocols
- hardware, software
- interfaces
- …

that provide many functionalities

- routing and forwarding
- framing
- error control
- …

Question:

is there any hope of *organizing and discussing* functionalities and structure of networks?

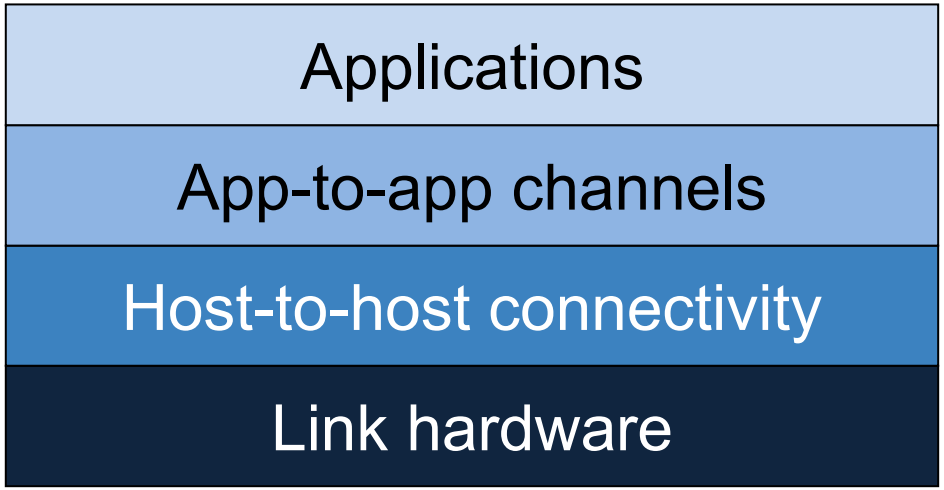
Answer:

The key is ***layering***!

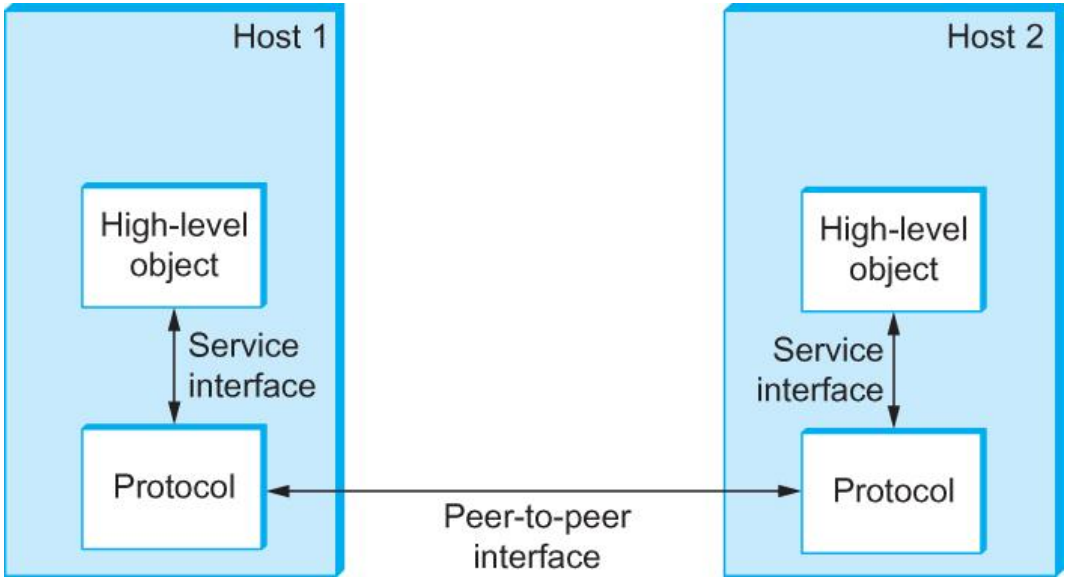
It uses the power of ***abstraction***

Layering and Power of Abstraction

- Divide the (complex) functionality of a system into manageable chunks (layers) – divide-and-conquer principle!
  - Each layer relies on functions of the layer below
  - Each layer exports functions to the one above
  - A layer 'sees' the immediate lower layer as an abstraction
- Power of abstraction
  - Implementation details are hidden
  - Functions in a layer can be changed without disturbing other layers
- *Interface* between layers defines interaction between them



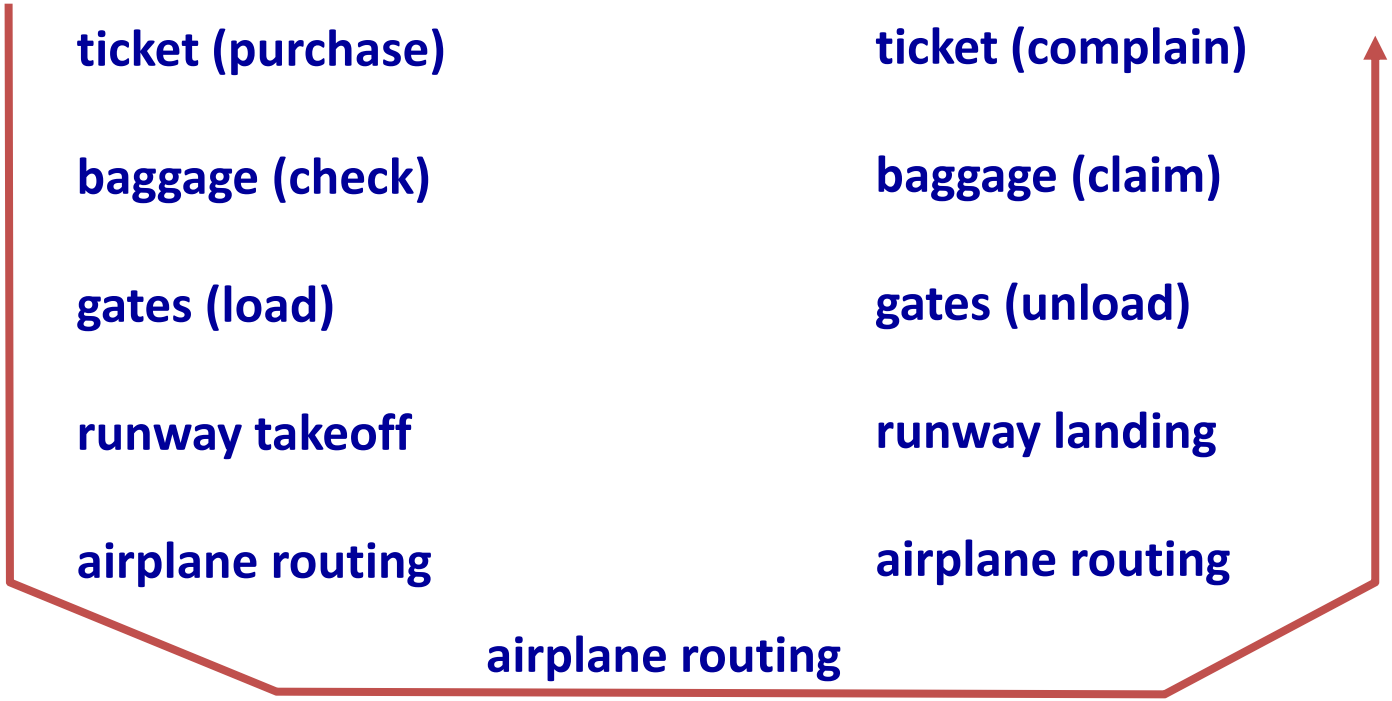
Interfaces



- Inter-layer
  - Service interface
- Inter-host
  - Peer-to-peer interface

Analogy: Organization of Air Travel

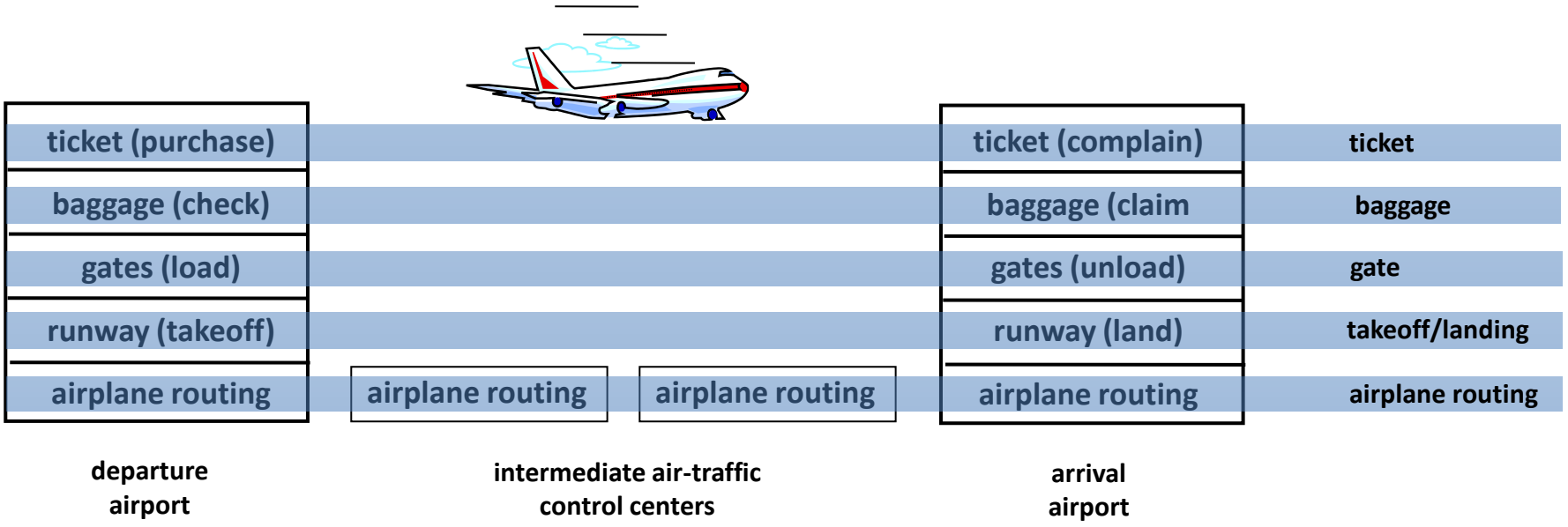
- a series of steps



Layering of Airline Functionality

layers: each layer implements a service

- via its own internal-layer actions
- relying on services provided by layer below

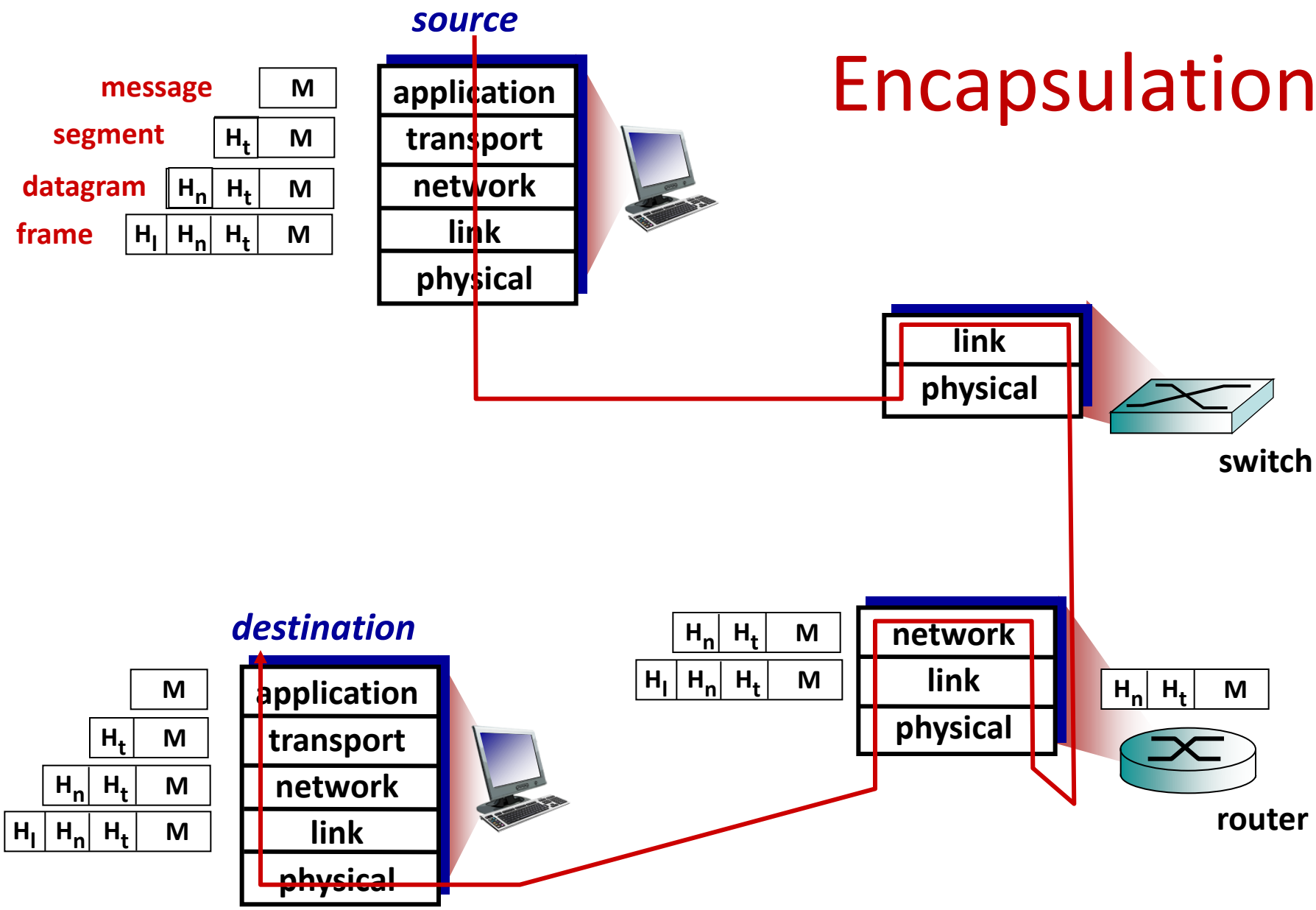


Why Layering?

dealing with complex systems:

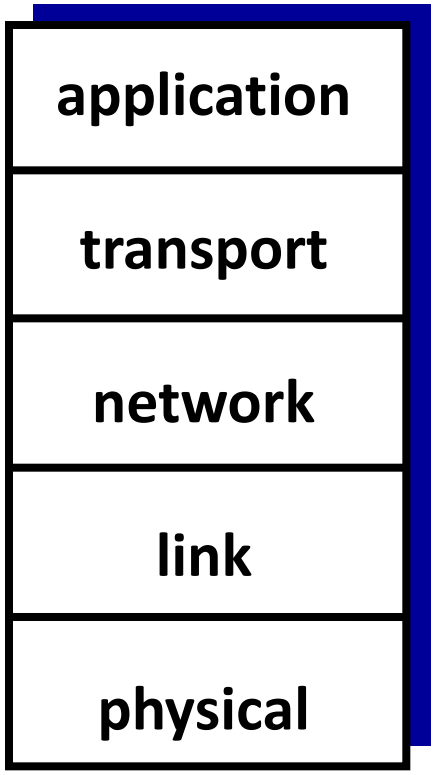
- explicit structure allows identification, relationship of complex systems pieces
  - layered *reference model* for discussion
- modularization eases maintenance, updating of system
  - change of implementation of layer's service transparent to rest of system
  - e.g., change in gate procedure does not affect rest of system
- layering considered harmful?

Encapsulation



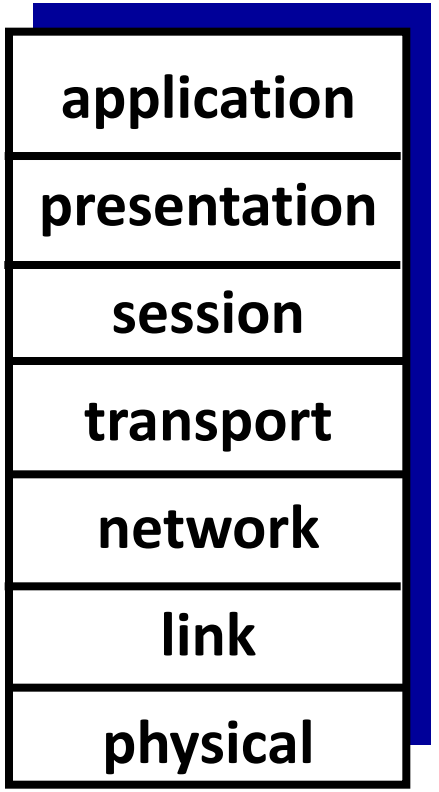
Internet (TCP/IP) Protocol Stack

- *application:* supporting network applications
  - FTP, SMTP, HTTP
- *transport:* process-process data transfer
  - TCP, UDP
- *network:* routing of datagrams from source to destination
  - IP, routing protocols
- *link:* data transfer between neighboring network elements
  - Ethernet, 802.11 (WiFi), PPP
- *physical:* bits "on the wire"

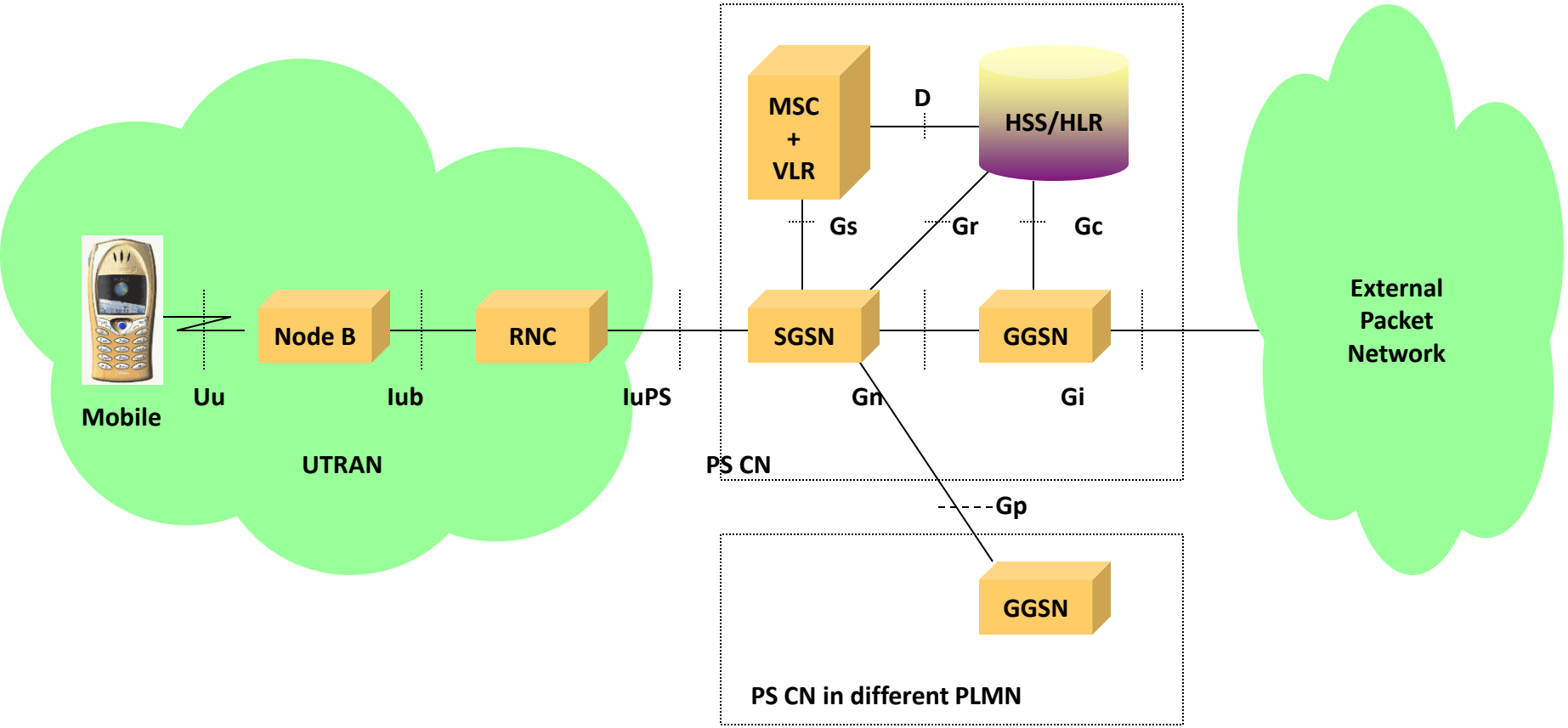


ISO/OSI Reference Model

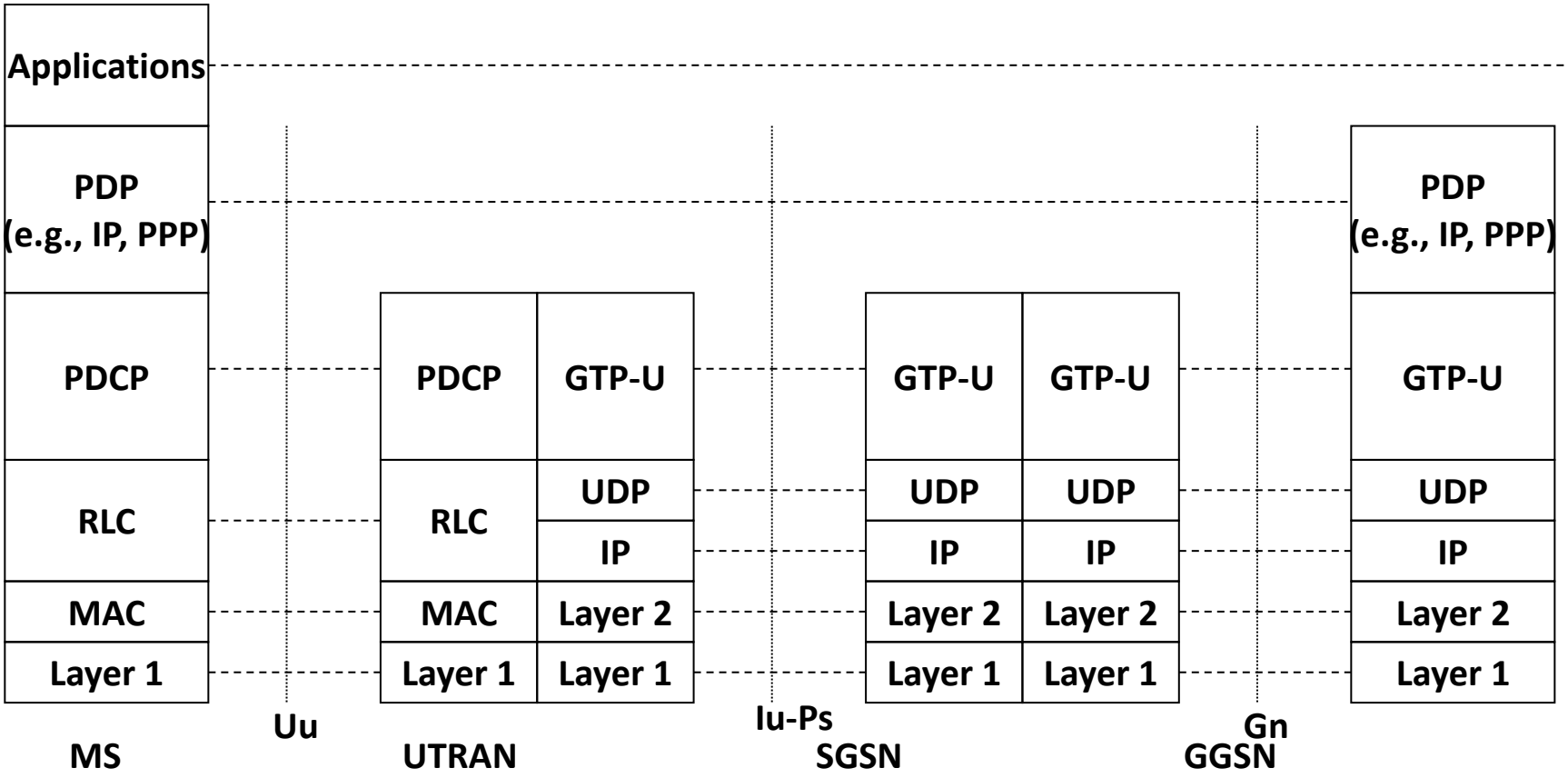
- *presentation:* allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions
- *session:* synchronization, check-pointing, recovery of data exchange
- Internet stack "missing" these layers!
  - these services, *if needed,* must be implemented in application
  - needed?



Protocol Reference Model for 3GPP Packet Switching Domain



3GPP User-plane Protocol Stack between Mobile and GGSN



3GPP Control-plane Protocol Stack between Mobile and SGSN