Evaluation Method

- Interim and Final Report
- Attendance is not Checked, but, ...
- Questions or Comments are Mandated
  - In the quater, questions or comments with technical content must be made at least twice during lecture (may be in Japanese)
  - Good questions and comments will be awarded with points
  - Declare your name and student ID after each lecture, if you make questions or comments

Advanced Lecture on Internet Applications

1. IPv4, IPv6, UDP, DNS

Masataka Ohta

mohta@necom830.hpcl.titech.ac.jp

Structure of Lecture

- 2nd Quater
  - Advanced Lecture on Internet Infrastructure
    - Physical, Datalink and Network Layers
- 4th Quater
  - Advanced Lecture on Internet Applications
    - Transport and Application Layers

Purpose of the Lectures

- Understand the Pinciple of the Internet and Knowhow of Internet Style Protocol Design
  - The end to end principle (rfc1958)
    - principle of global connectivity
    - principle of scalability
- We are in Protocol Era
  - Protocols designed for various applications
  - APIs are of secondary importance

Reference Articles for Lecture

- RFC (Request for Comments)
- 「本当のインターネットをめざして」、情報処理学会誌、全３６回（１９９９年４月号～２００２年３月号）
- 「インターネットの真実」、週間東洋経済（２００１年１月より２００２年４月まで連載）
- Slides used in the Previous Fiscal Year (in Japanese only)
  - ftp://chacha.hpcl.titech.ac.jp/2018/appli*.ppt

Topics for the 4th Quarter (1)

1. IPv4, IPv6, UDP, DNS
2. Transport Layer: TCP, congestion control, long fat pipe, multihomine
3. File Transfer: TFTP, FTP, reliable multicast
4. Character Communication: character code and internationalization
5. Character Communication: TELNET, e-mail, SMTP, MIME

Topics for the 4th Quarter (2)

6. Character Communicaiton: Web, HTTP, HTML, GIF, Java Script
7. Character Communication: home appliance control
8. Stream Communication: RTP, time synchronization, clock synchronization
9. Stream Communication: telephone network and the Internet, internet phone

Topics for the 4th Quarter (3)

10. Internet and Society: user authentication, accounting, radius
11. Internet and Society: IPR, leagal issues
12. Internet and Society: standardization, RFC, operation, implementation, protocol design

What is Protocol?

- Procedure to communicate over networks

BTW, What is the Internet?

- Not e-mail
  - seriously thought so 20 years ago
- Not web, either
  - many still misunderstand so
- Is not applications
- The Internet is a network directly connecting terminals based on the principle of the Internet using IP (Internet Protocol)

The End to End Argument

http://web.mit.edu/saltzer/www/publications/endtoend/endtoend.pdf

- The function in question can completely and correctly be implemented only with the knowledge and help of the application standing at the end points of the communication system. Therefore, providing that questioned function as a feature of the communication system itself is not possible. (Sometimes an incomplete version of the function provided by the communication system may be useful as a performance enhancement.)

Example of E2E Argu,ent data drop

- can’t be prevented by network
  - noise, equipment down
    - buffering by network equipment is valnerable to equipment down
- to prevent data drop
  - end system must resend
- what if the end system goes down?
  - safe unless end system goes down is the ultimate reliability

E2E Argument and E2E Principle

- according to the E2E argument
  - network function can not be complete without help of end systems
  - network should have moderate functionality
    - can’t be complete, anyway
  - lacking functionality may be provided by end systems
- many functions can be provided completely only by end systems

End to End Principle Disintermediated Networking

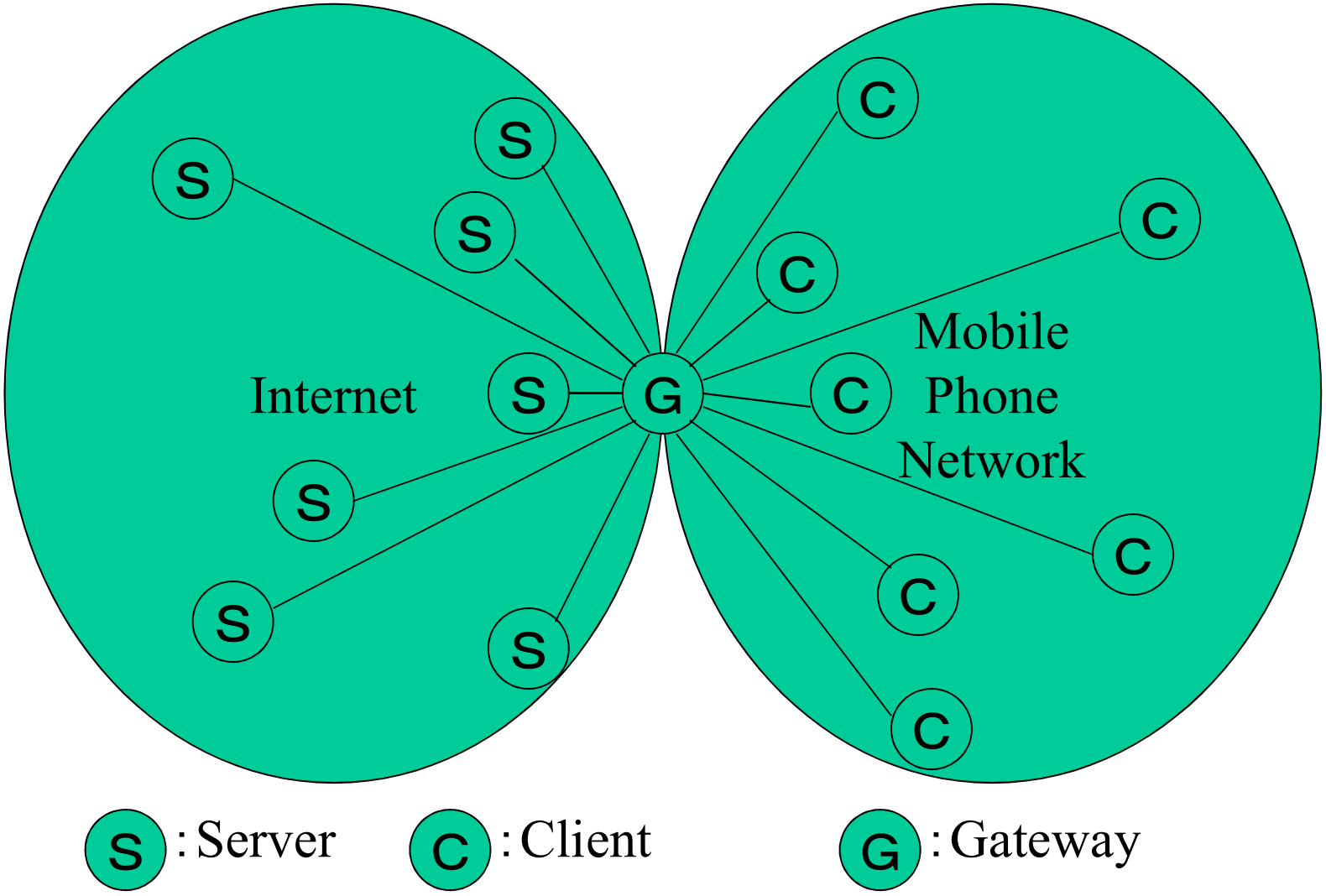
- Implement things by terminals (end) not by the network
  - network equipment has only single function (to connect terminals) and is high speed
- Implement things by directly involved terminals without involving other terminals
  - scalable (no load concentration)
  - highly reliable (system works if only terminals are working and can communicate each other over some route)

What is not the Internet (1)
e-mail

- UUNET (JUNET) was not the Internet
- Communication System for Personal Compters was not the Internet
- E-mail is an application works on the Internet
  - also works on other (phone) networks
- In the past, (oversea) e-mail was charged
  - some mail on mobile phone is still charged

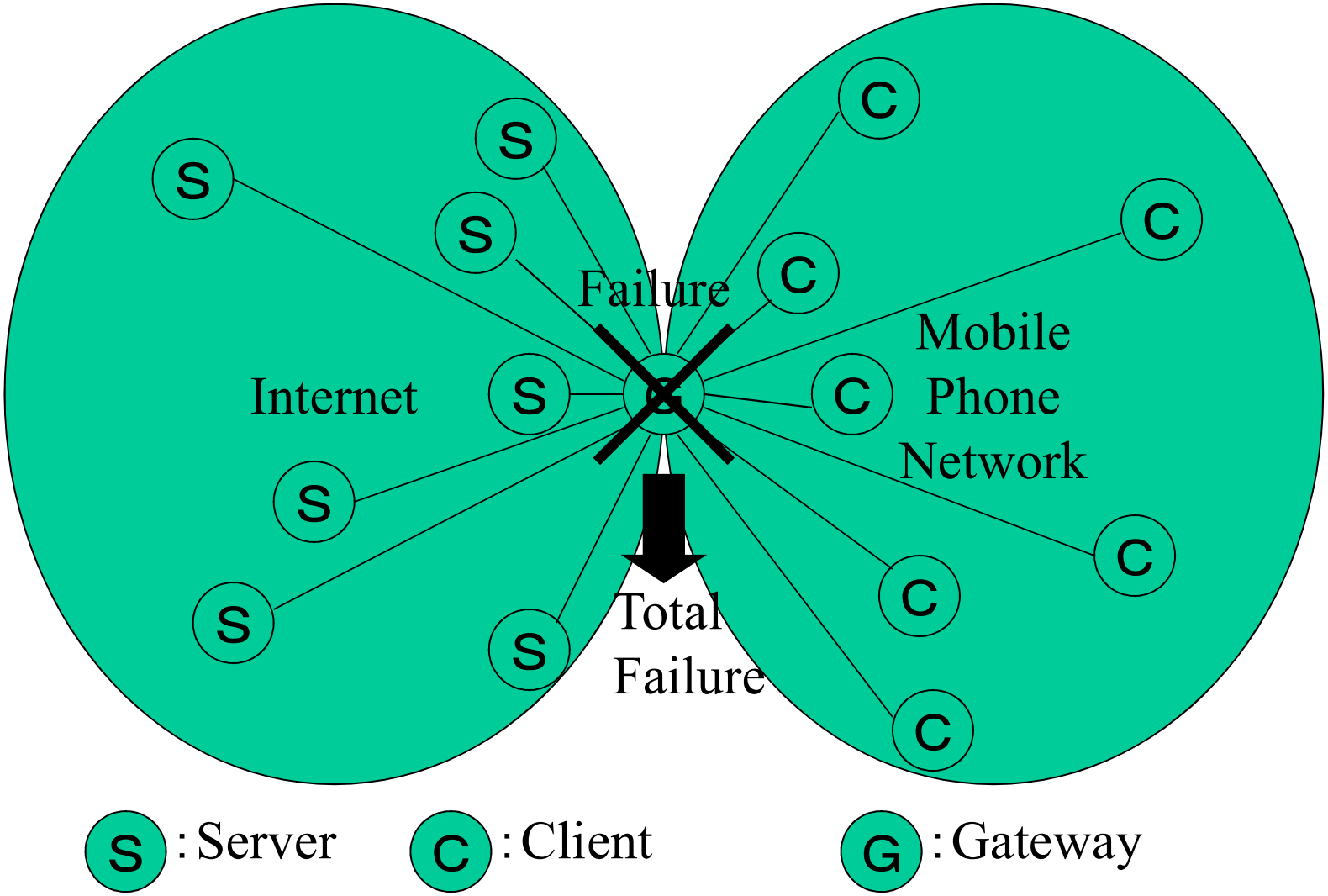
What is not the Internet (2)
Web

- Web is not the Internet
  - though Microsoft makes it obscure
- Web, too, is an application works on the Internet
  - also works on other networks
  - web browsing from mobile phone network is, in principle, charged
    - mobile phone network is not the Internet, of course



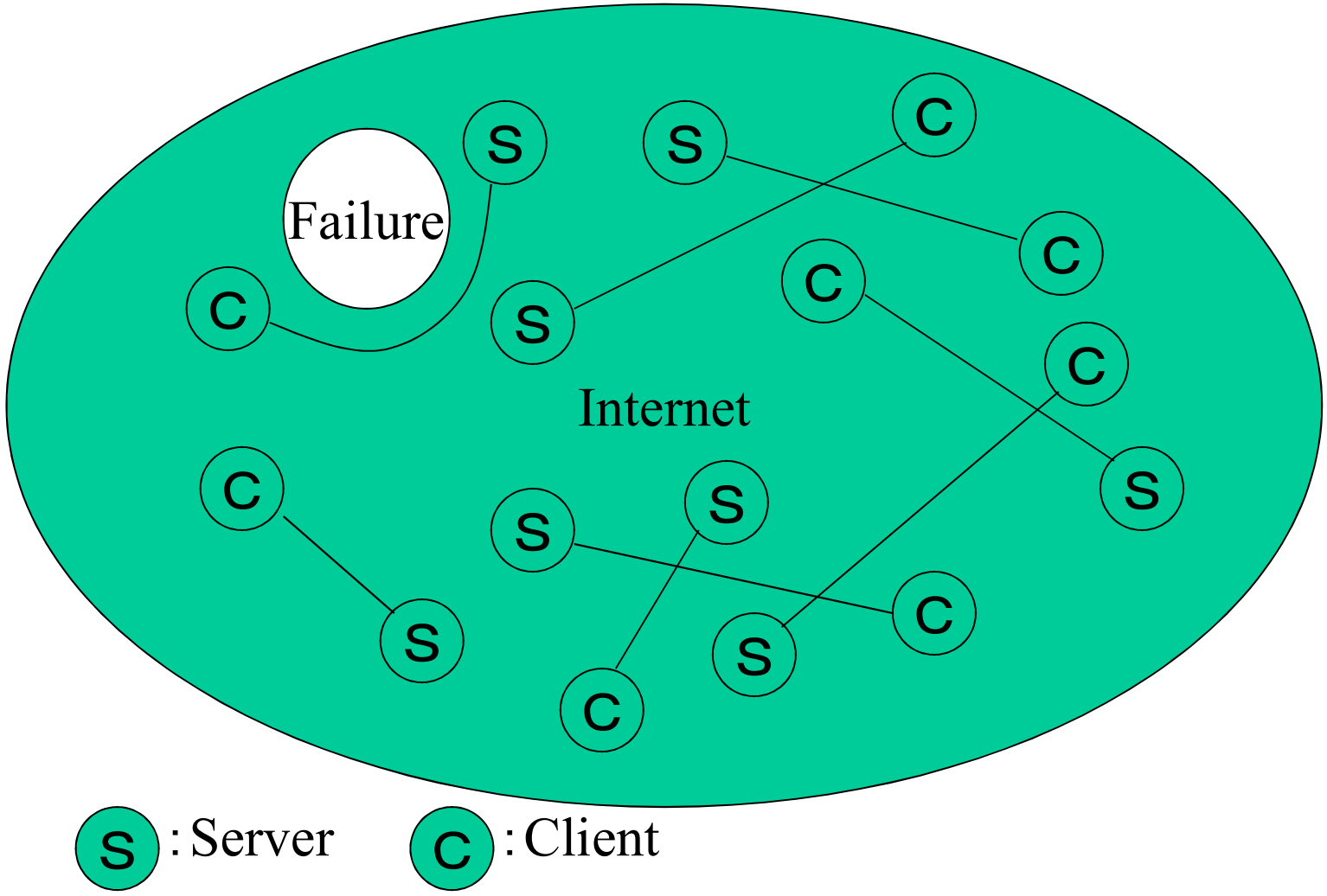
Web Browsing of i-mode from Mobile Phone Network

Servers and clients are separated and communicate through the gateway



Web Browsing from Mobile Phone Network

Servers and clients are separated and communicate through the gateway



Internet

Servers and clients are mixed and communicate with shortest pathes

What is not the Internet (3)
Phone

- Phone is not phone network
- Phone is an application works on phone networks
  - also works on other networks
  - phone over the Internet is free of charge
- Phone, today, is a promotion tool to sell Internet services
  - no need to support phone network
  - mobile phone is to sell mobile Internet services

What is not the Internet (4)
Phone Network

- Phone is not phone network
- Phone is an application works on phone networks
  - also works on other networks
  - phone over the Internet is free of charge
- We don’t need phone networks
  - neither are mobile phone networks
  - phone numbers are not necessary, either
    - IP addresses! (though alternatives may exist)

Networks

- Physical Distribution Networks
  - postal service, parcel services, convenience stores
- Information Communication Networks
  - Publishing Network (Book, News Paper, CD, Movie)
  - Financial Network
  - Phone Network
  - Broadcast Network
  - the Internet

Internet Disintermediate ICN

- Price Destruction of ICN
  - Publishing, financial, phone and broadcast networks will disappear
  - IC cost of the society decreased
    - ISP business itself is not profitable
- Publishing, financial, phone and broadcast services will:
  - remain, but, on the Internet
  - social activities increase

Publishing Network

- Mass Distribution of Same Information
- Delay of the Distribution may be Tolerated
- Protected by Copyright Act
- The First Victim of the Internet
  - Collapsing

Financial Network

- Manage Transfer of Money
- Partly, Phisical Distribution Network, but, today, mostly ICN
- Security!!!
  - Not that there is no accident
  - Who will pay the loss on accidents

Phone Network

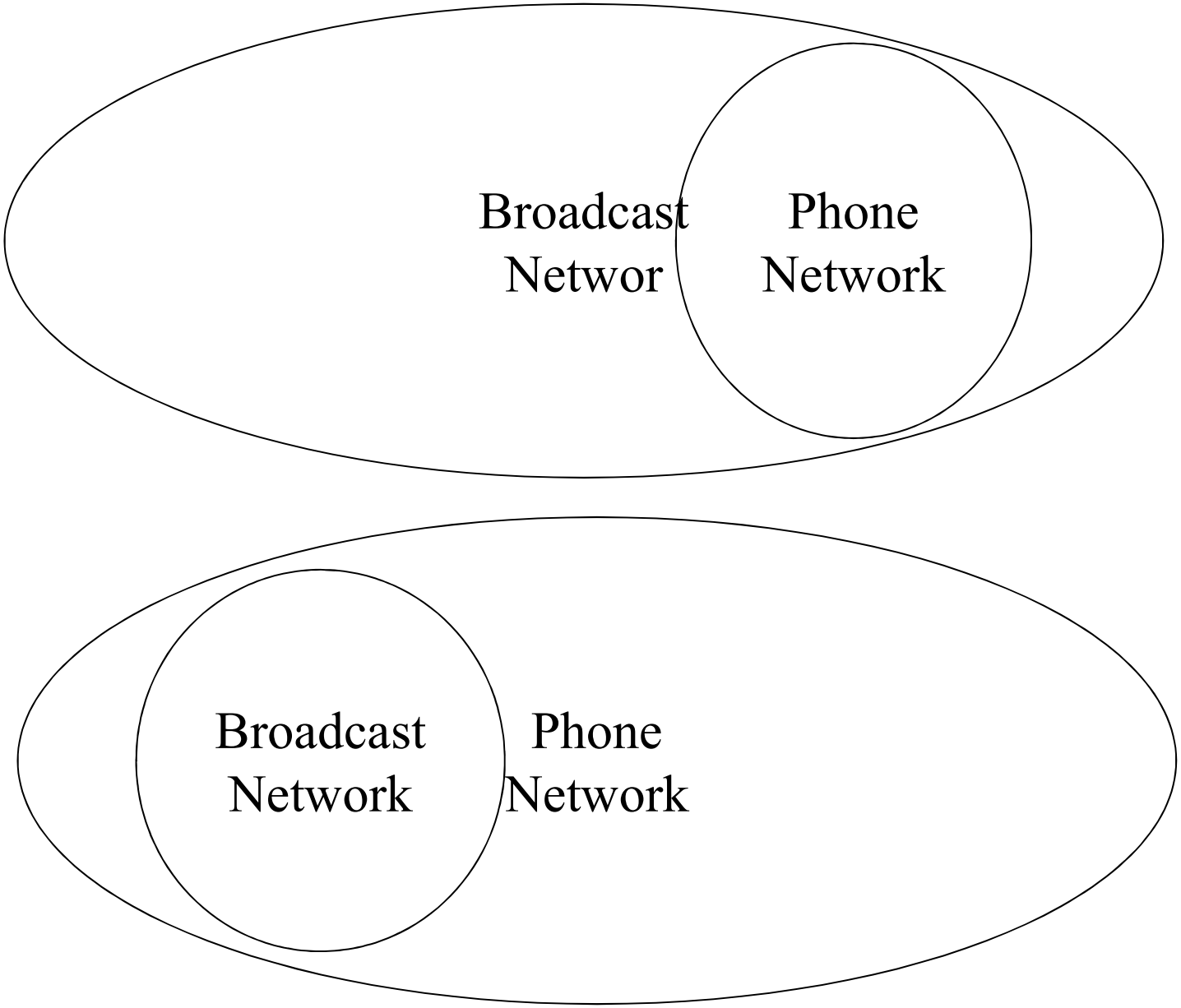
- Network for Realtime Voice Transfer
  - Allocate bandwidth for voice transfer
  - Minimize (guarantee) delay for voice transfer
- Dedicated line service may be Offerred
  - but, primary service is voice transfer
- Slow and Expensive
- Was Protected as National Company
  - Leberated by Telecommunication Business Act

Broadcast Network

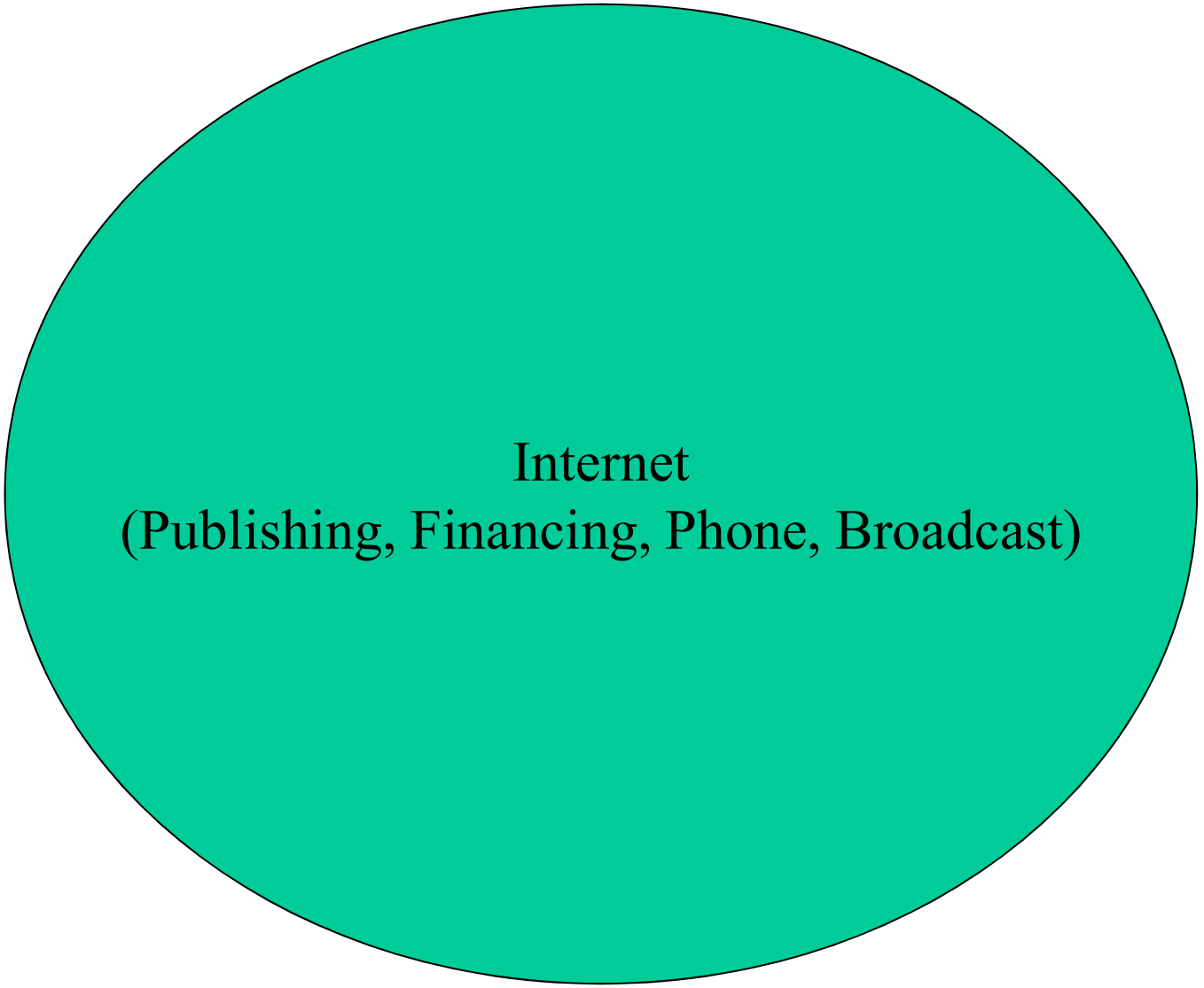
- Network to Transfer Voice/Image to Many in Realtime
  - Allocate bandwidth for the transfer
  - Minimize delay
- Wide Area One to Many Communication over Radio Waves
  - Broadcast/Multicast
- Protected by Broadcast Act

Integration of Broadcast and Telecommunication

- Viewed from Phone Network
  - one to many transfer over phone network
    - integration of broadcast network to phone network (BISDN)
- Viewed from Broadcast Network
  - receive feedback through phone network
  - one to one communication over radio wave possible?
    - integration of phone network to broadcast network
- Viewed from the Internet?



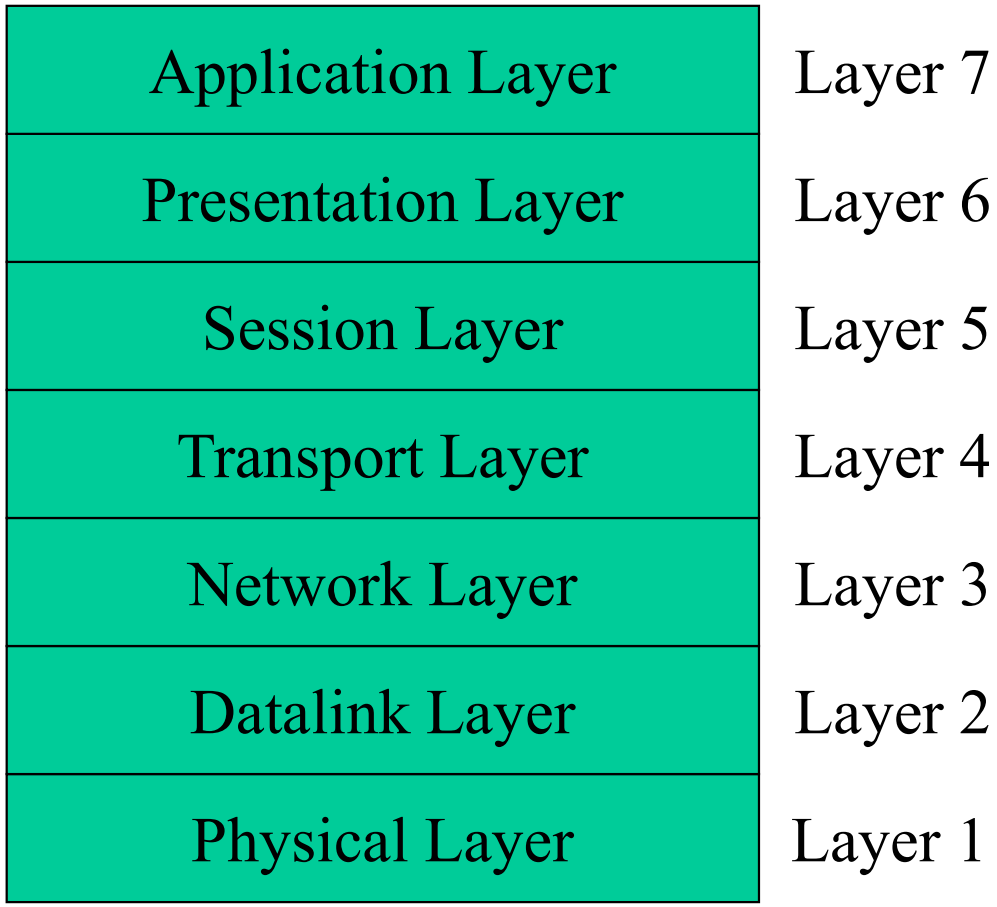
Two Visions on “Integration of Broadcast and Telecommnication



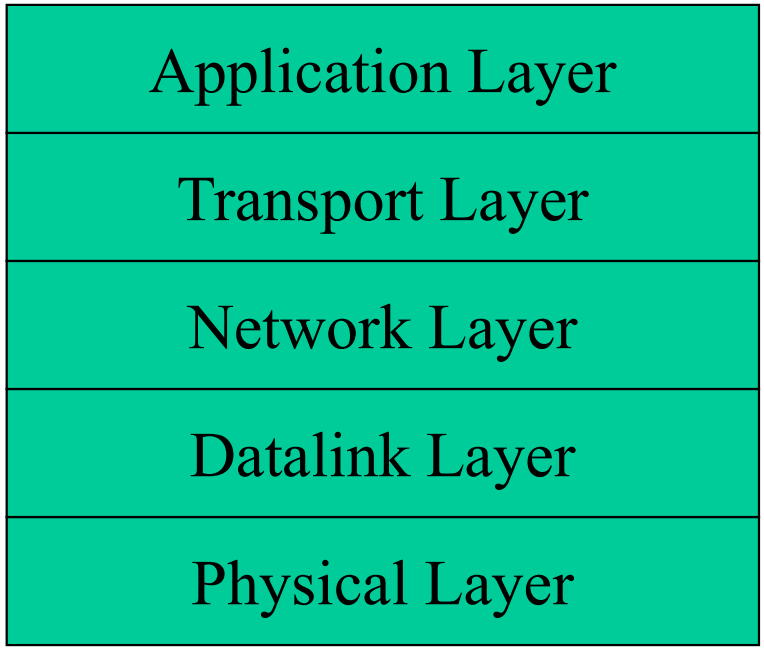
Integration of IC Services by the Internet

Layering of Protocols

- Have Layers based on Level of Abstraction
  - 7 layer model of OSI (Open Systems Interconnection)
  - 5 layer model of the Internet
- Corresponds to Subroutines (Structuring) in Programming



Layering Structure of OSI



Layering Structure of the Internet

Physical Layer

- Map Physical Phenomena and Information
  - Voltage high/low <-> 0/1
  - Lignt on/off <-> 0/1
  - Amplitude and Phase <-> 0/1/.../63
- Multiple Similar Physical Layers may be Integrated (Repeaters)
- Corresponds to Control Firmware in Peripheral Devices in

Datalink Layer

- Joint between Network and Physical Layers
- If Physical Layer have more than 2 devices
  - distinction between them is necessary
- Multiple Dissimilar Physical Layers may be Integrated
  - Local Relays (Bridges)
- Corresponds to Device Drivers in Programming

Network Layer
Internetworking Layer

- Integrate Many Datalink Layers to form a Global Network
- Global Relaying (Routers, Gateways)
- Corresponds to File Manager and Inter-process Commnication in Programming

Transport Layer

- Network Layer Identify Terminals
- Transport Layer Identify Communications
  - Multiple communications may exists between a pair of terminals
    - different communication is processed by different process
    - may require different bandwidth etc.
      - unimportant in the current best effort Internet
- Corresponds to Process Manager in Programming

Sesssion, Presentation and Application Layers

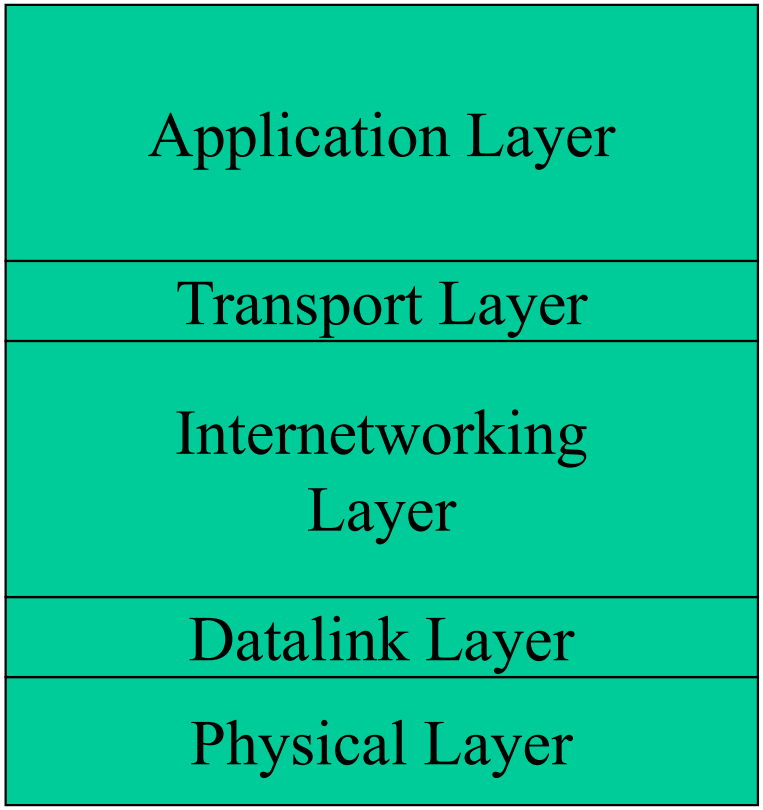
- Corresponds to Internal Structure of each Process in Programming
- Corresponds to Internal Structure of each Process in Terminals
- Without Interworking, there is no Point to have 3 Layers
  - Layering of the Internet has the Application Layer only

Transport and Application Layers

- With Best Effort Network, Distinction is within Each Terminal
- Assigning Packets of Each Communication to Corresponding Process is Transport
- Further Distinctions is not Meaningful
  - Protocols shared by many applications (e.g. TCP (assure reliability and manage bandwidth)) are, traditionally, classified as Transport

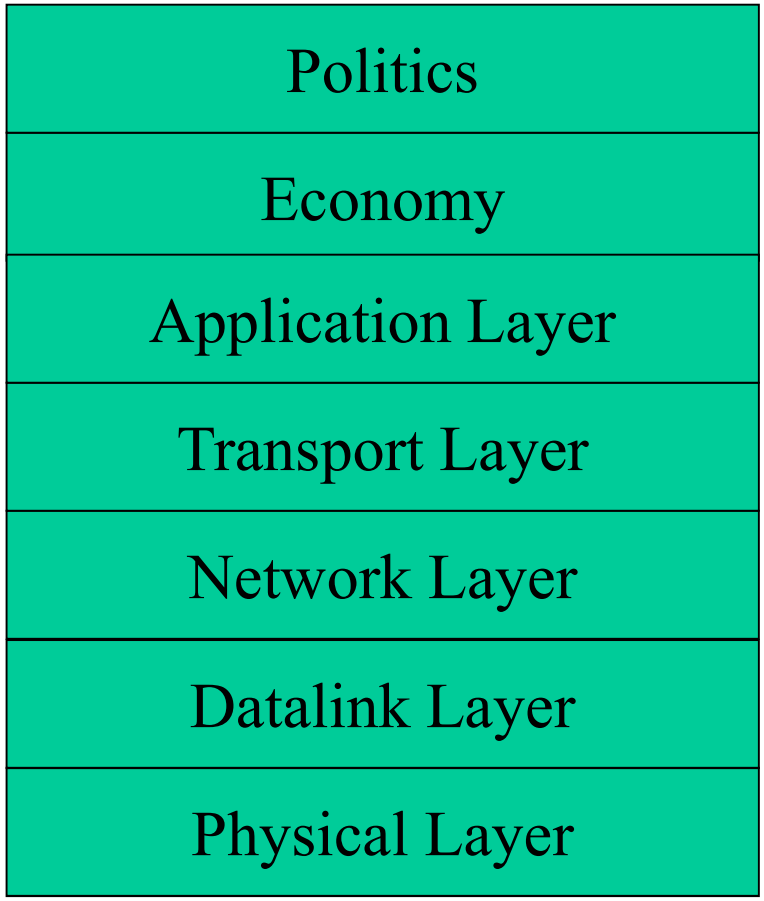
Layering of the Internet

- Physical and Application Layers are Essential
- The Internetworking Layer does as Much Things as Possible
- Datalink and Transport Layers should Avoid to do Thing

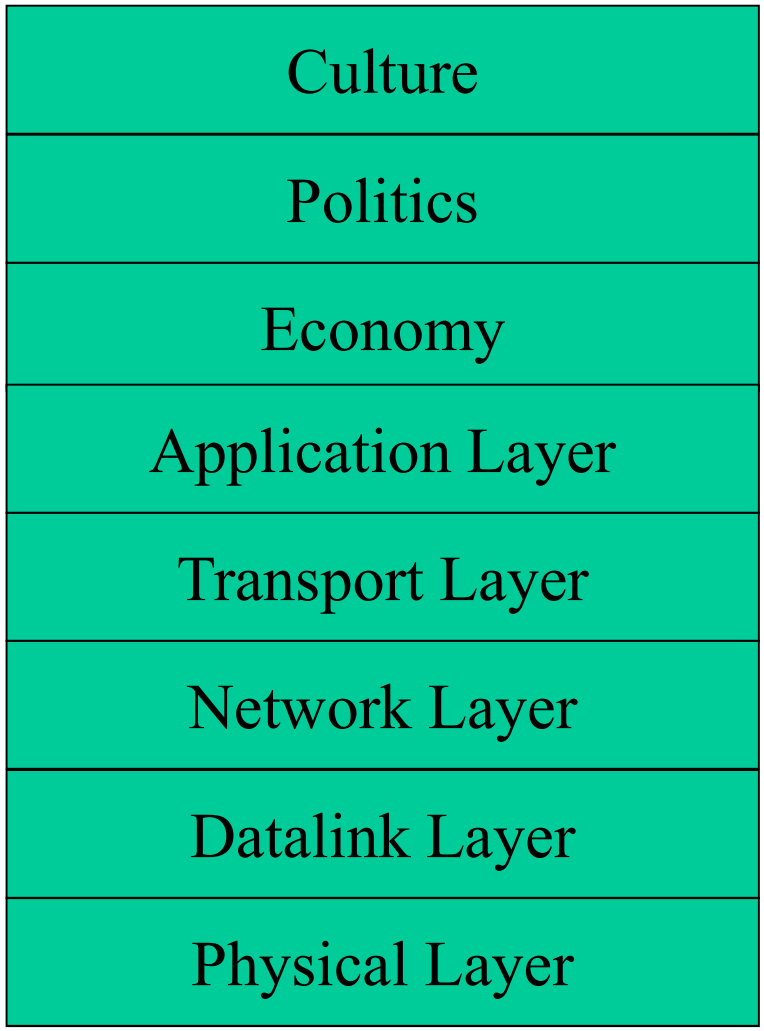


Here is the Essence of the Internet

Layering Structure of the Internet



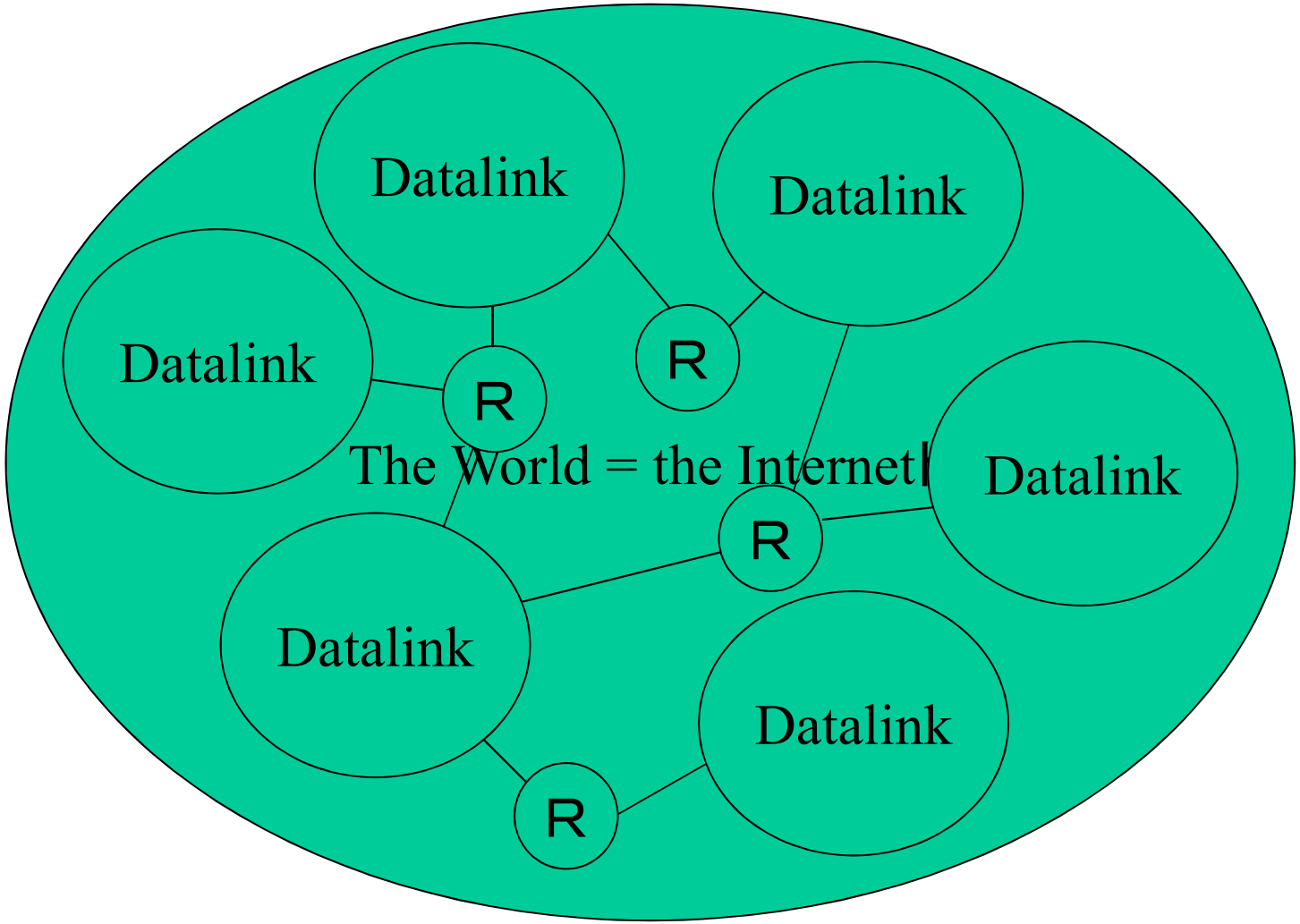
Layering Structure over the Internet?



Layering Structure over the Internet!

Structure of the Internet

- CATENET Model
  - Many small (w.r.t. # of devices) datalinks interconnected by IP (Internet Protocol) routers

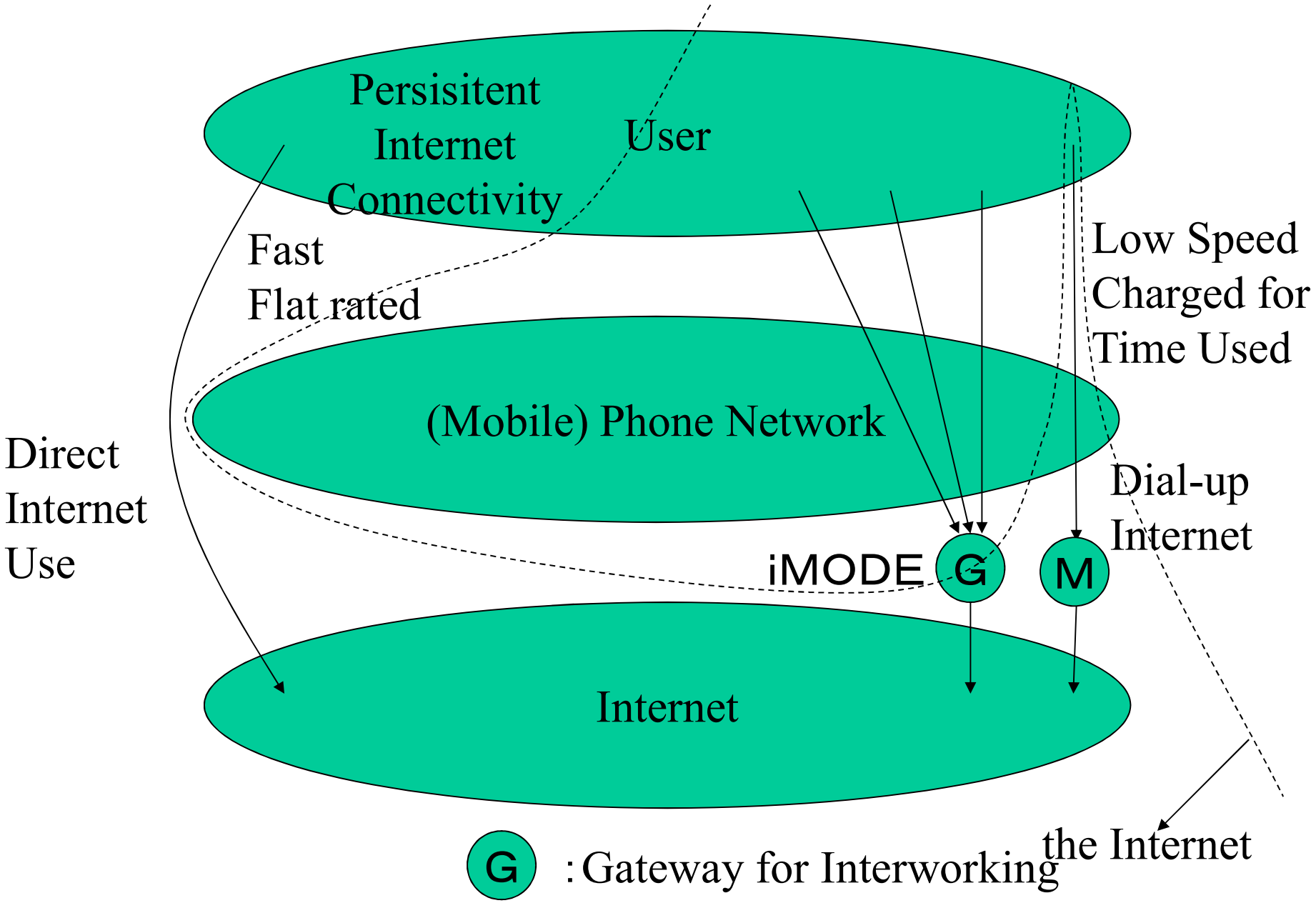


R : Router

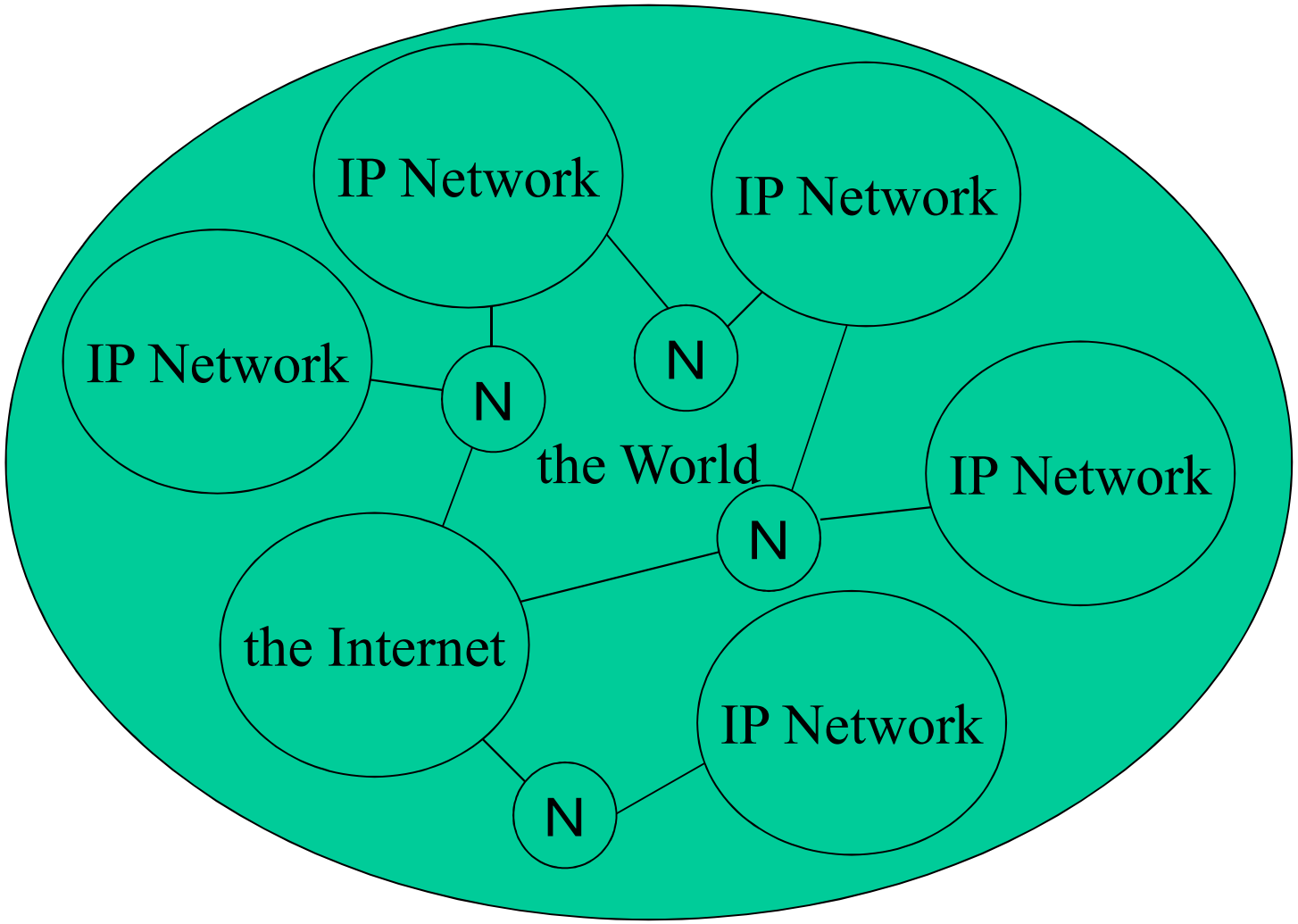
CATENET Model

The Internet and Structure of Networks

- Example of Internet
  - Dial-up Internet
- Example of non Internet
  - i-mode
    - IP, but, relaying at transport layer
  - Legacy NAT
    - IP, but, addresses etc. are modified, which is not visible to terminals
      - Interworking at the transport layer and above



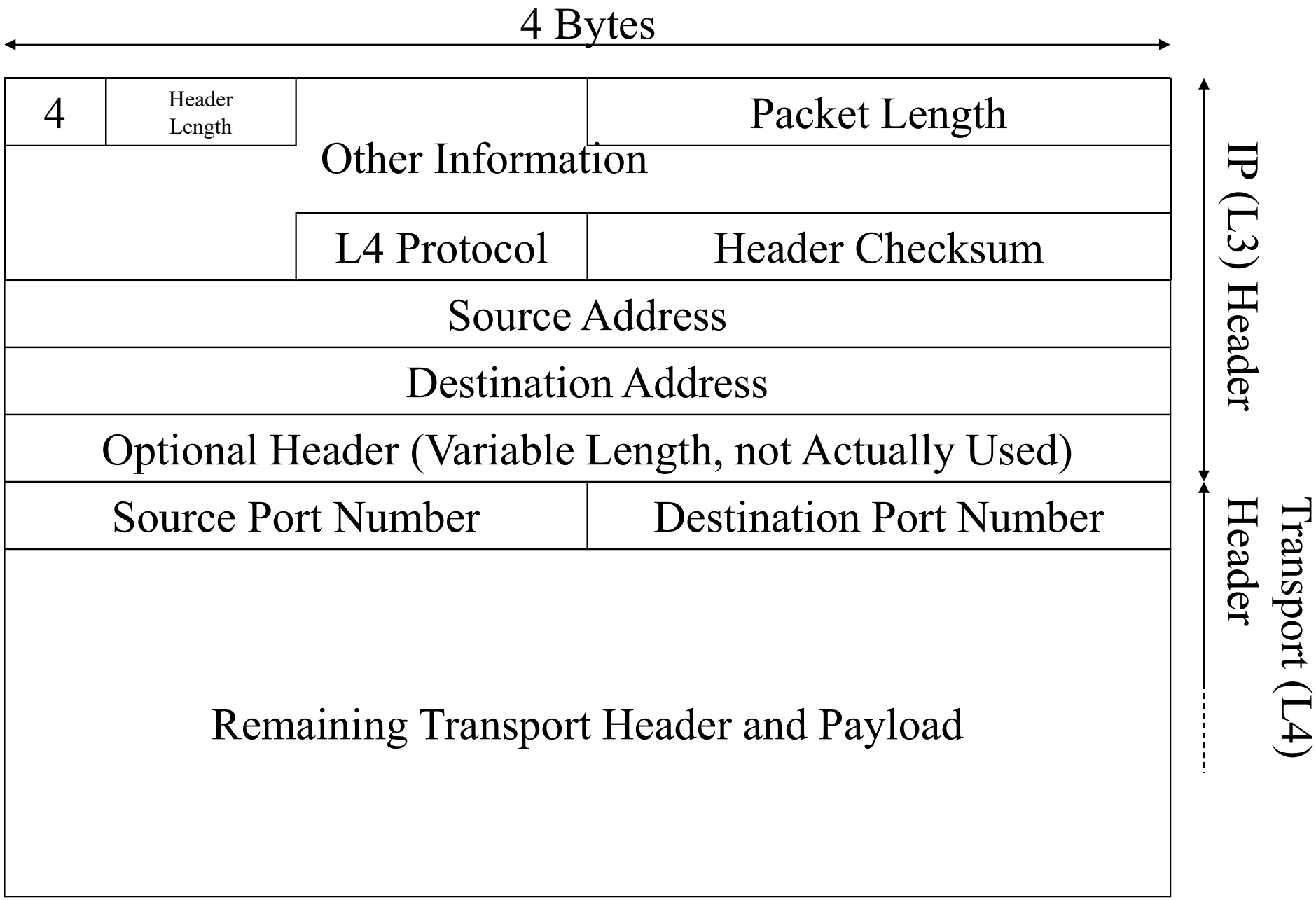
Phone Network and the Internet



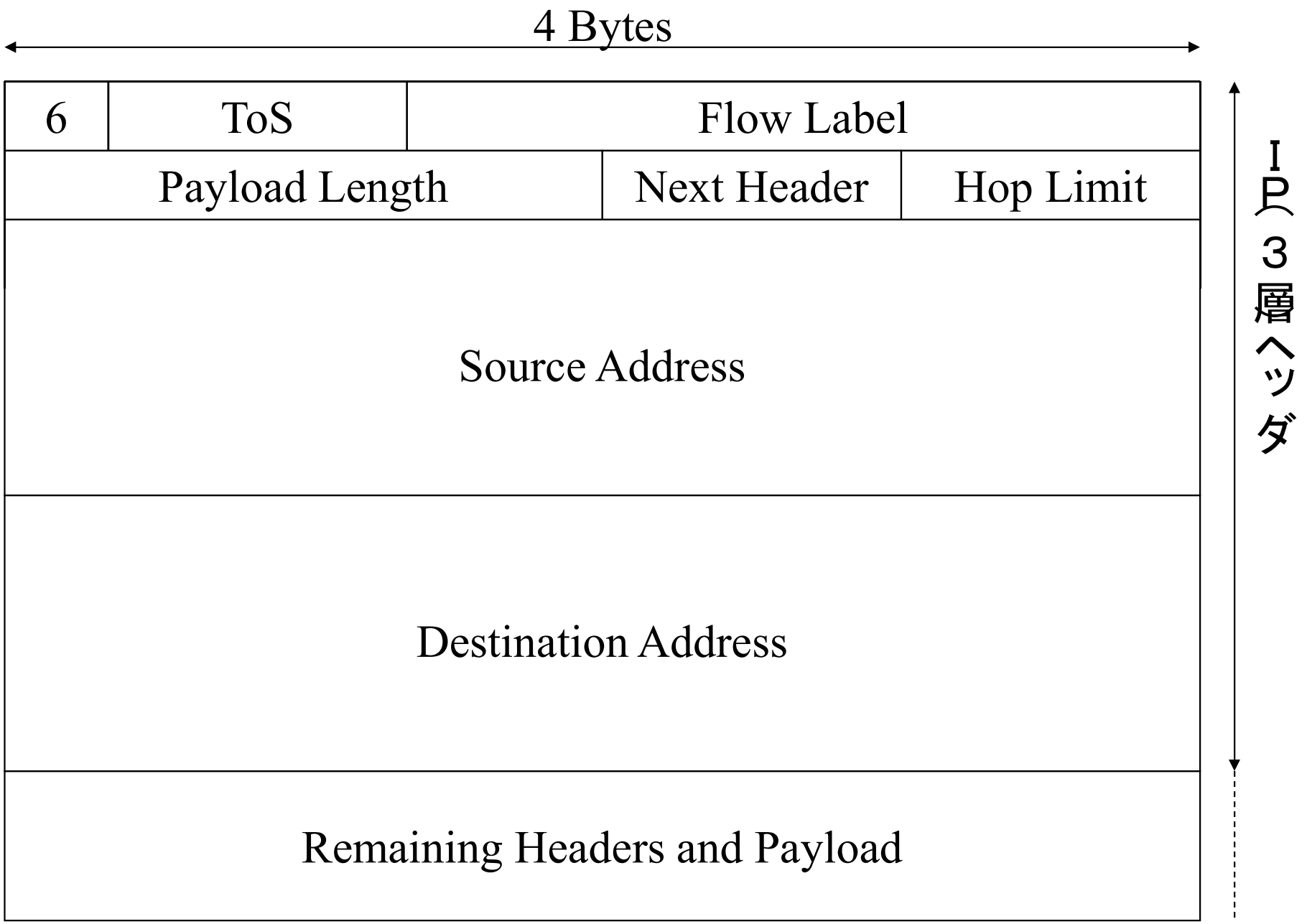
NAT and the Internet

Data Format of the Internet

- Data are Assembled to Form Packets
- Each Packet has its Own Destination
  - datagram, not virtual circuit
- With IPv4, 20B Internetworking Layer Header is Attached
- In Addition to a Transport Layer Header



Format of IPv4 Packets



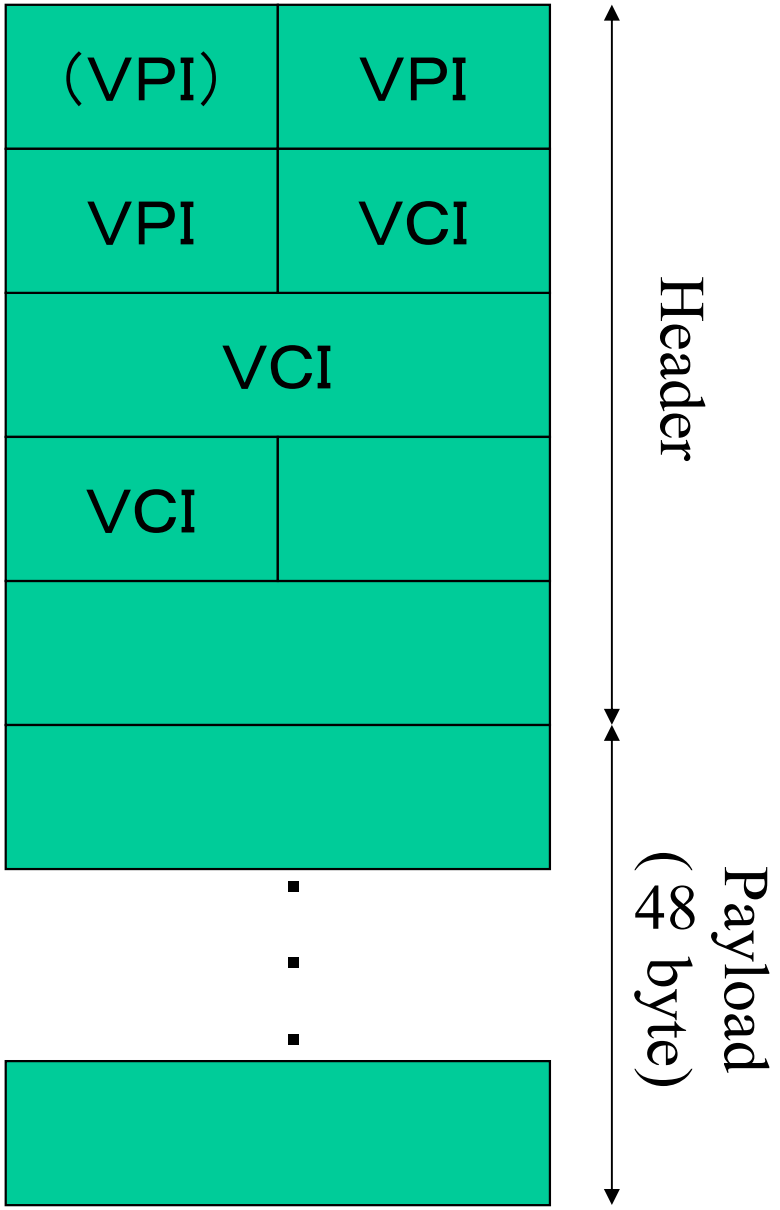
IPv6 Packet Format

Function of IP Routers

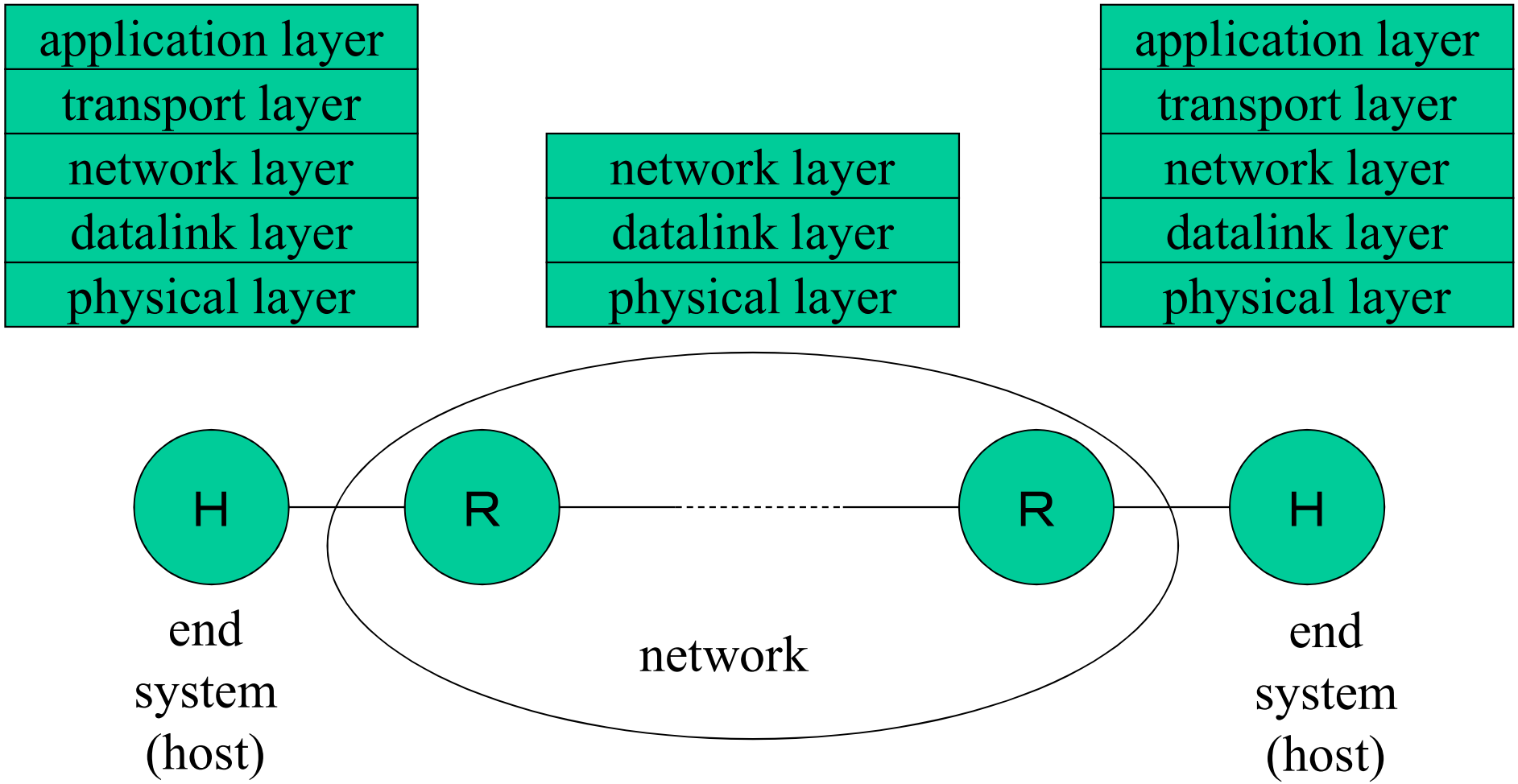
- decrement TTL and forward packet based on destination address
  - routing table is constructed in advance by routing protocols
  - no advance signaling, no BW guarantee
- with IPv4, may divide packets for datalinks with small MTU (fragmentation)

ATM (Asynchronous Transfer Mode)

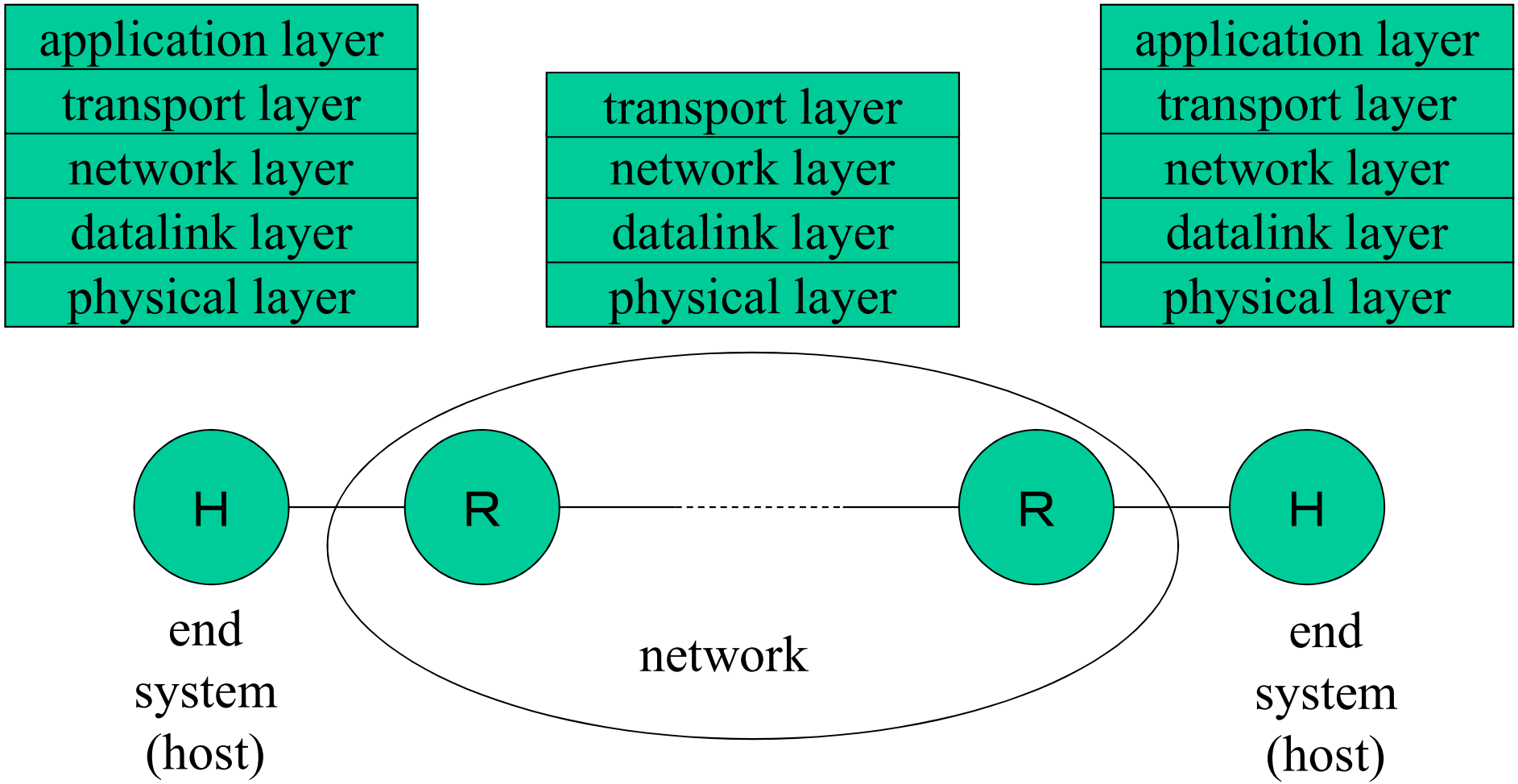
- packet (cell) network of phone companies
- data is divided into fixed length 48B cells and 5B simple header is attached
  - faster than processing complex header?
- cell header contains ID (VPI/VCI)
  - ID is obtained from network, in advance, by telling destination to the network (signaling)
    - overhead in time (even several seconds) and processing
    - in theory, can provide QoS guarantee
    - Virtual Circuit



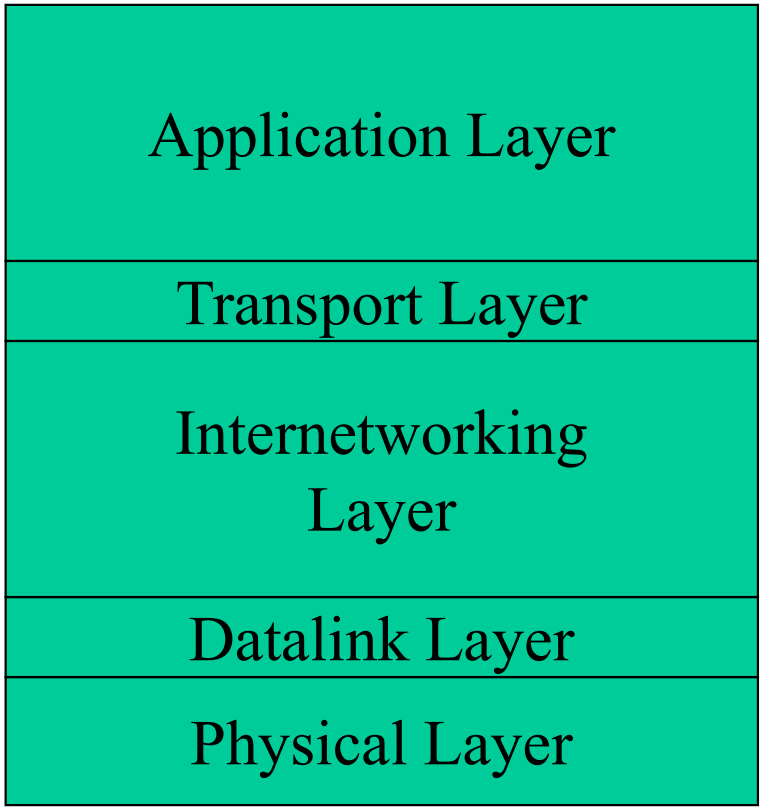
A cell of ATM



best effort internet



internet with QoS guarantee



TCP, UDP

Here is the Essence of the Internet

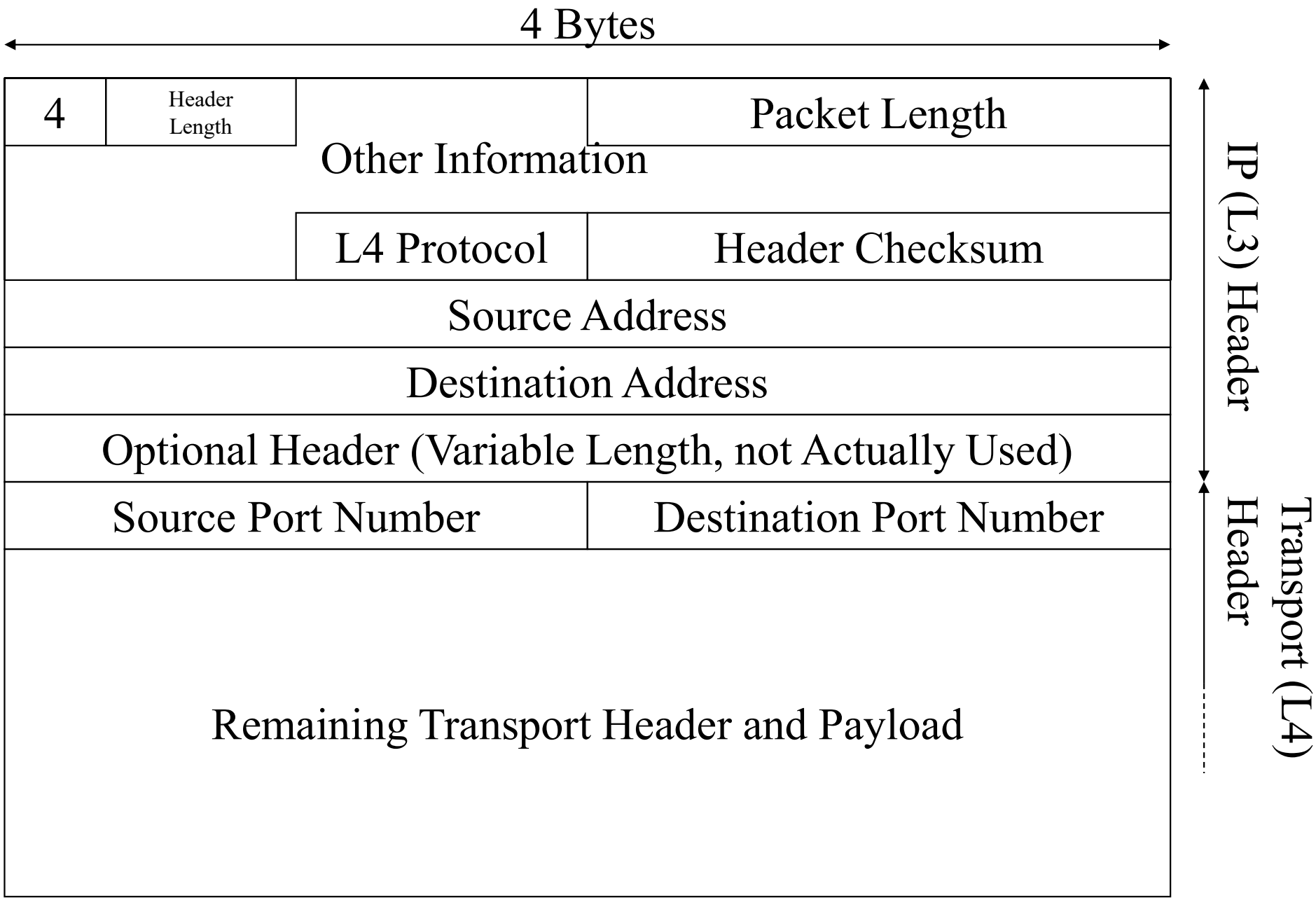
Layering Structure of the Internet

TCP and UDP

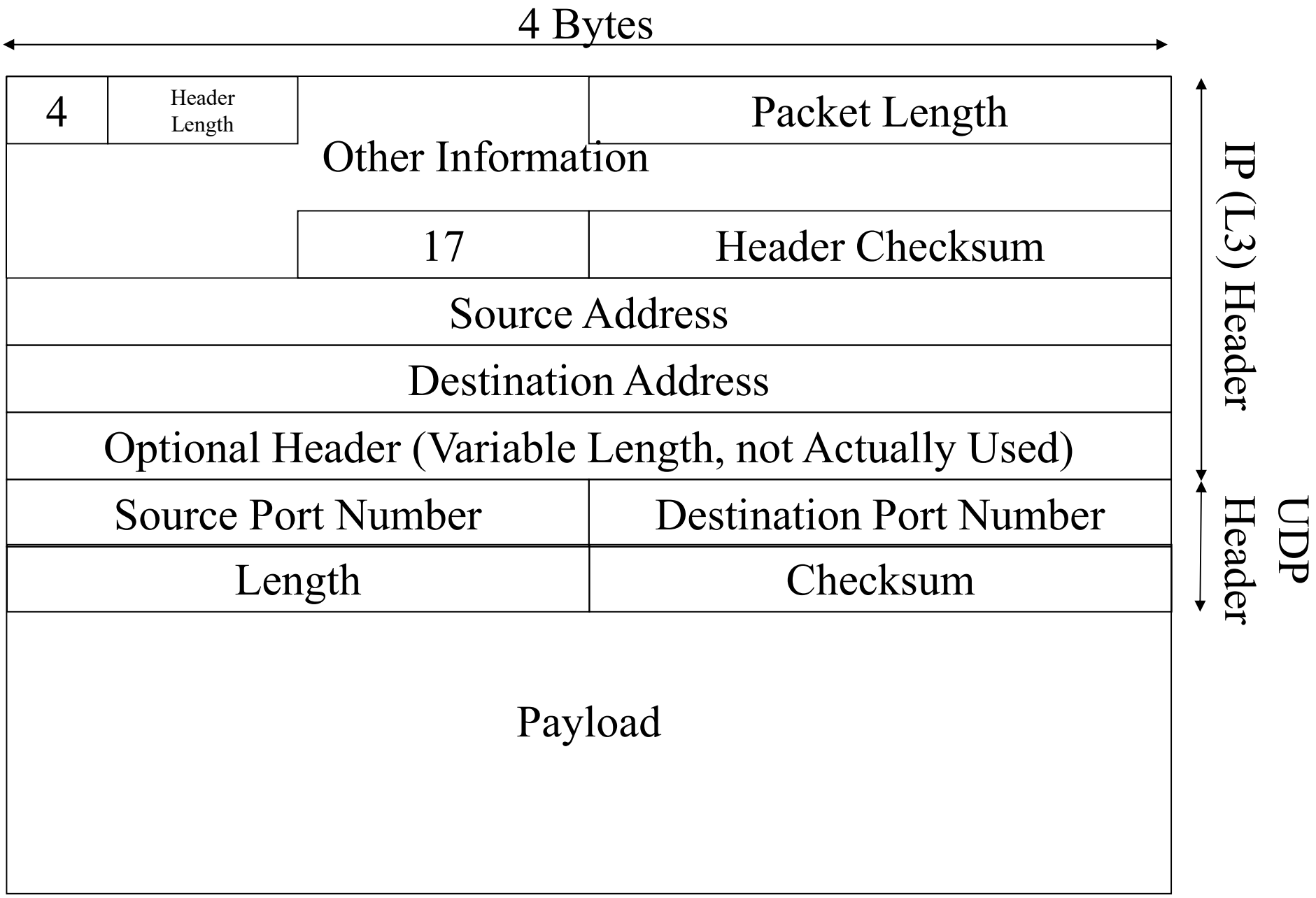
- TCP (rfc793)
  - Transmission Control Protocol
  - retransmit when data error or drop is detected
  - adjust transmission rate
- UDP (rfc768)
  - User Datagram Protocol
  - do nothing (let applications do something)
    - nothing except for delivery to applications

UDP

- simple and, by itself, light weight
  - complex functions may be performed by applications
- connectionless at transport layer
- may be used by light weight applications
- must be used for communication not suitable for TCP (1:1 bidirectional)
  - unidirectional communication
  - multicast, broadcast



Format of IPv4 Packets



Format of IPv4 UDP Packets

Destination Port Number

- destination host deliver packets to application processes based on port numbers
- source host can know port numbers from, say, URLs
- default port number may be assigned for well know services
  - 53 for DNS

Source Port Number

- may be used as destination port number for reply or ICMP error (error generated by intermediate routers)
- may be omitted (0)

Length

- length of UDP header and payload in byte
- unnecessary?
  - IP header already have length
  - an IP packet can’t hold multiple UDP packets

Checksum

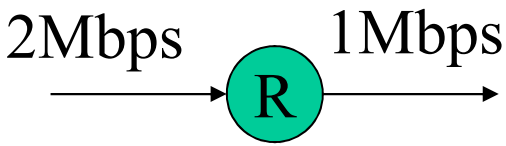
- one’s complement
  - 0 has two representations (0...0, 1...1)
- may be omitted for IPv4
  - 0...0 means omition
- may not be omitted for IPv6
  - 0...0 is not allowed

Phone Network vs the Internet

- which is more error prone?

Reason of Packet Drop

- packet is lost upon transmission error
  - not so common
- routers must drop packet if buffer is full
  - primary reason of packet drop in the Internet



Congestion Control

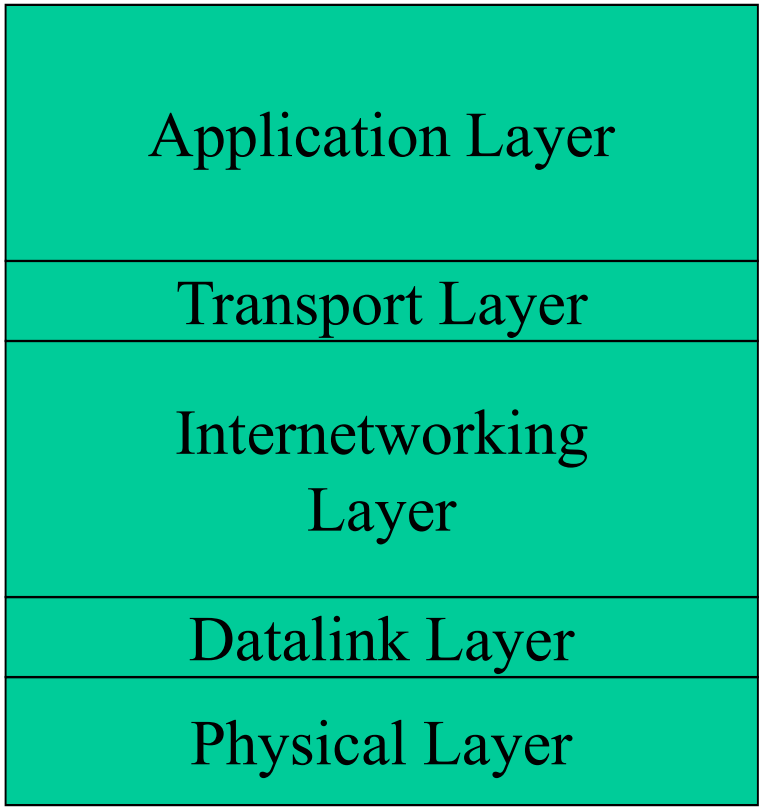
- BW is not managed in the Internet
- if everyone send packet at will, large amount of packet loss may occur
- everyone will be happy if packets are sent at rate a little below link BW
- though merely gentlemen's agreement
  - combined with TCP, widely spread
  - can not break the agreement unless both sides cooperate

Practice of Congestion Control by TCP

- control TCP rate according to congestion situation of the Internet
  - if congested, reduce transmitter's window size
- what is congestion?
  - packet drop
- packet drop is detected by timeout or acknowledge number not increasing

Congestion Avoidance with UDP

- no general theory
  - basically impossible for streaming
- how to detect packet drop
  - timeout? depends on application protocol
- how to act against packet drops?
  - retransmit the packets
    - increase retransmission interval if packet drops are frequent



DNS (domain name),
RTP (streaming), ...

UDP

Here is the Essence of the Internet

Layering Structure of the Internet

DNS (Domain Name System) (rfc1034, 1035)

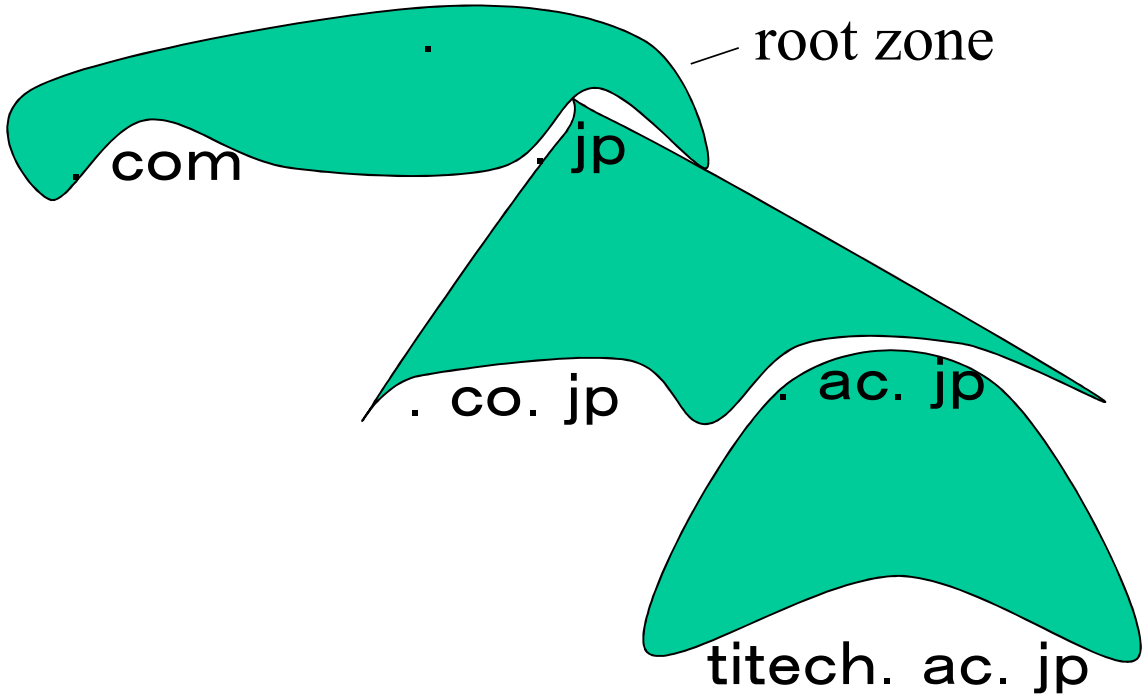
- loosely coupled distributed database to map domain name to its value (IP address etc.)
  - domain name consists with labels separated by "." representing hierarchy
    - necom830.hpcl.titech.ac.jp
- one of the most important application (?) of the Internet
- mainly use UDP (TCP is sometimes used)
  - at port number 53

Domain Name and Name Servers

- domain name forms tree with “.” as root
  - the last “.” may be omitted
- delegate authority through tree structure
  - necom830.hpcl.titech.ac.jp
  - IANA, JPNIC, TIT, Ohta lab.
- each part of tree under authority (zone) is served by multiple name servers
  - loosely coupled distributed database

Order of Name Servers

- parent zone offer name server information of child zones
- primary server (only one)
  - have master information of a zone
- secondary server (at least one)
  - obtain zone information from other servers
  - periodically check zone information of other servers
    - if updated, perform zone transfer (TCP)


.
root zone
. com
. jp
. co. jp
. ac. jp
titech. ac. jp

Resolver and Name Server

- resolver
  - mechanism to look up DNS database upon request from upper layer applications
    - may be included in applications
  - exchange packets with name servers and resolvers
  - may cache data
- the first server to ask is statically configured

Recursive Resolvers

- resolvers to send several queries if the first query does not result in full final response
- NS, CNAME etc. makes additional queries necessary
- non-recursive resolvers are stub resolvers
  - stub resolvers are statically configured with addresses of recursive resolvers
    - stub resolvers can share concentrated cache of a recursive resolver

Information Held by Nodes RR (Resource Record)

- RR have fields of
  - class
    - not used
  - type
    - IP address, mail server, etc.
  - TTL
    - time to live for cache
  - data
    - data depending on type

RR Types for DNS itself

- SOA (start of authority)
  - zone management information
- NS (name server)
  - domain name of name server
- CNAME (canonical name)
  - alias
- (glue) A (address) or AAAA (IPv6)
  - IP address of name server

SOA (Start of Authority) RR (1)

- specified at a root of a zone
  - primary name server
    - domain name of the primary NS of the zone
  - mail address of zone administrator
    - converting “@” to “.”
  - serial number
    - serial number of zone information

SOA (Start of Authority) RR (2)

- refresh interval
  - interaval to check serial numer by secondaries
- refresh retry
  - retry interval after refresh zone transfer failure
- expire
  - secondaries zone information is valid until “expire” even if refresh zone transfer keep failing
- minimum TTL
  - minimum TTL of RRs in zone (default)

Zone Transfer

- transfer zone information from primary to secondaries
  - over TCP
- may also be used between secondaries
  - secondaries are statically configured which servers to check
  - first, check serial number
    - if serial number is updated, perform zone transfer

NS (Name Server) RR

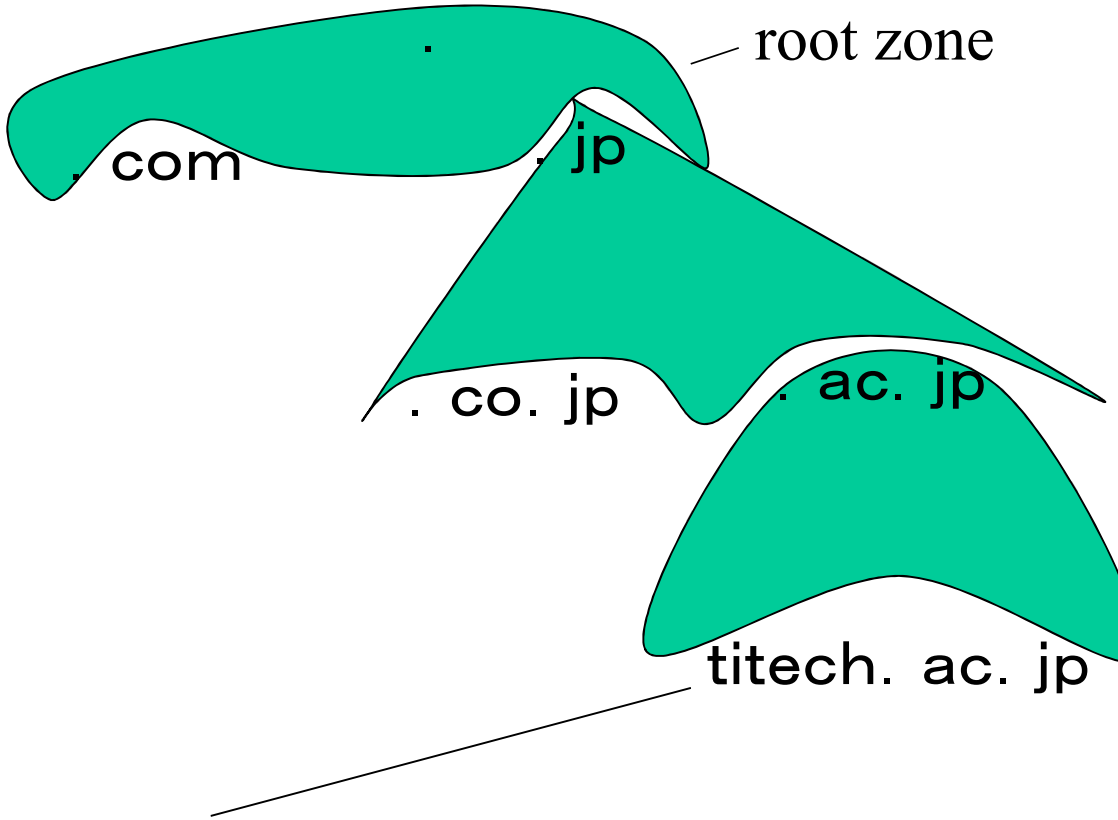
- specify domain name of NS
- at root of a zone
  - specify NSes of the zone
- at lower edges of a zone
  - specify NSes of child zones
  - glue A (AAAA) may also be specified

CNAME (Canonical Name) RR

- specify canonical name
  - used at leaf node as alias

Glue A (Addrees) RR

- if NS of a child zone is in or below the child zone
  - address of NS of the child zone can be resolved by asking NS of the child zone
    - loop!
- address of NS of the child zone may also be specified in parent zone



titech. ac. jp NS ns1. noc. titech. ac. jp

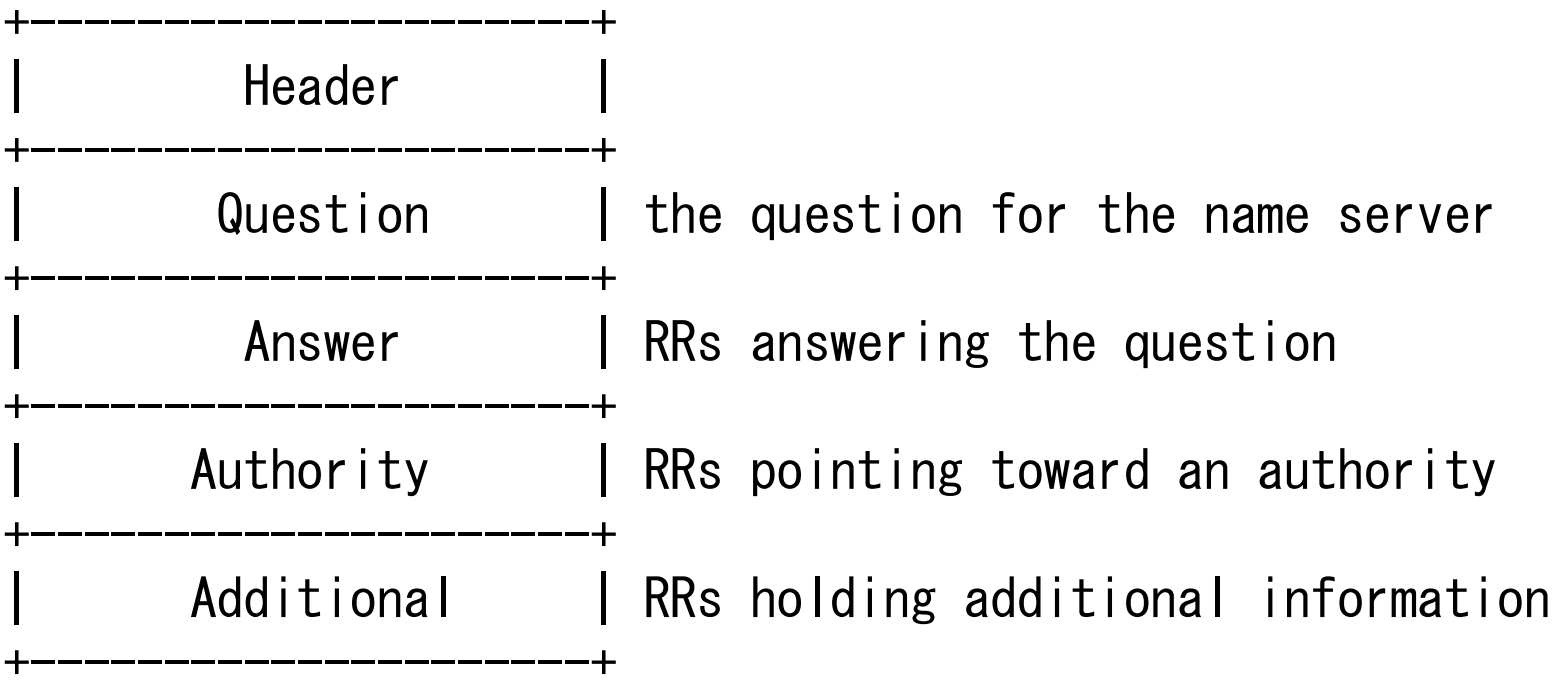
ns1. noc. titech. ac. jp A 131. 112. 125. 4

name server and glue A

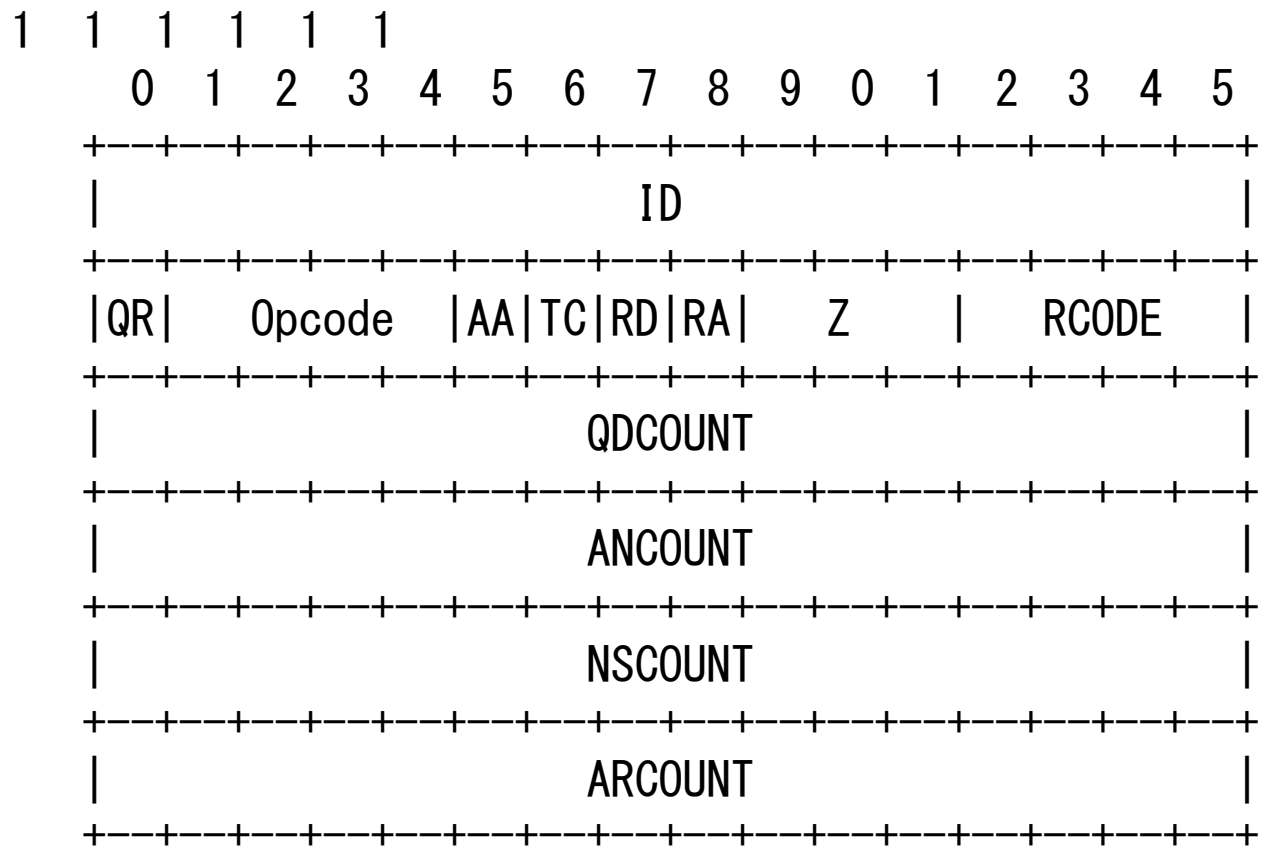
RR Types for Applications

- A
  - IPv4 Address
- AAAA
  - IPv6 address
- MX
  - priority and domain name of a mail server
- PTR
  - reverse lookup from IP address to host name

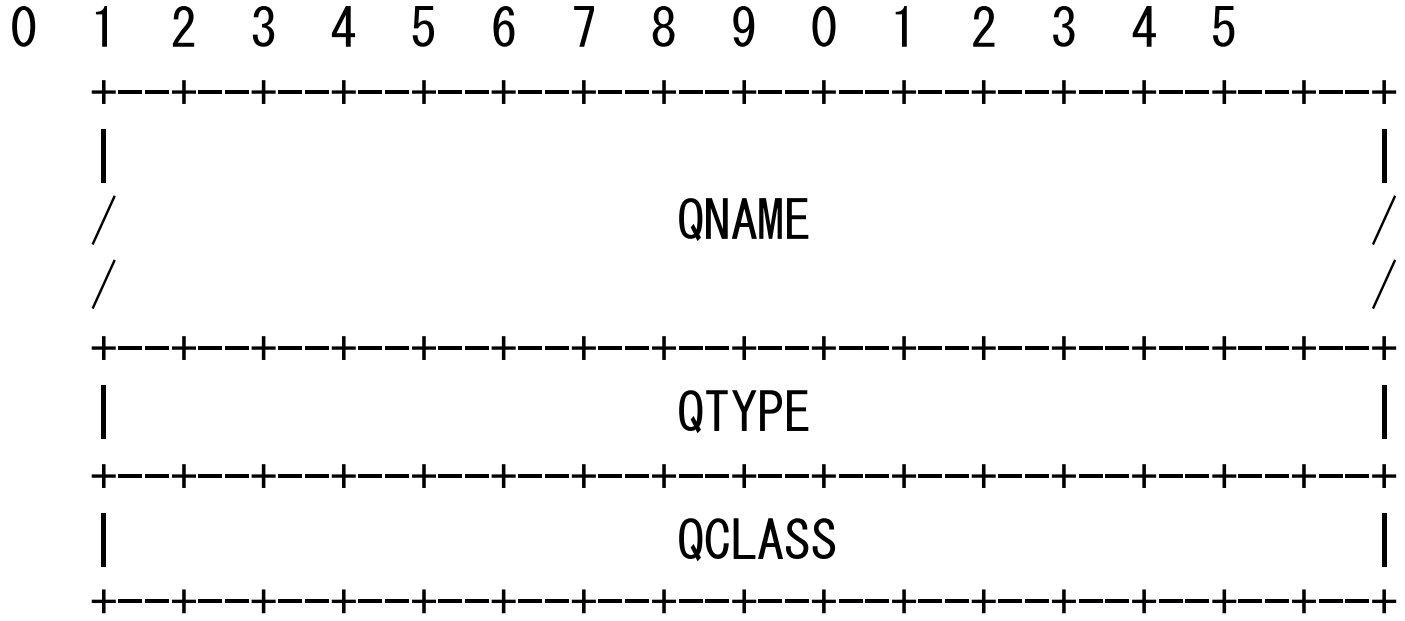
Message Format (over UDP)



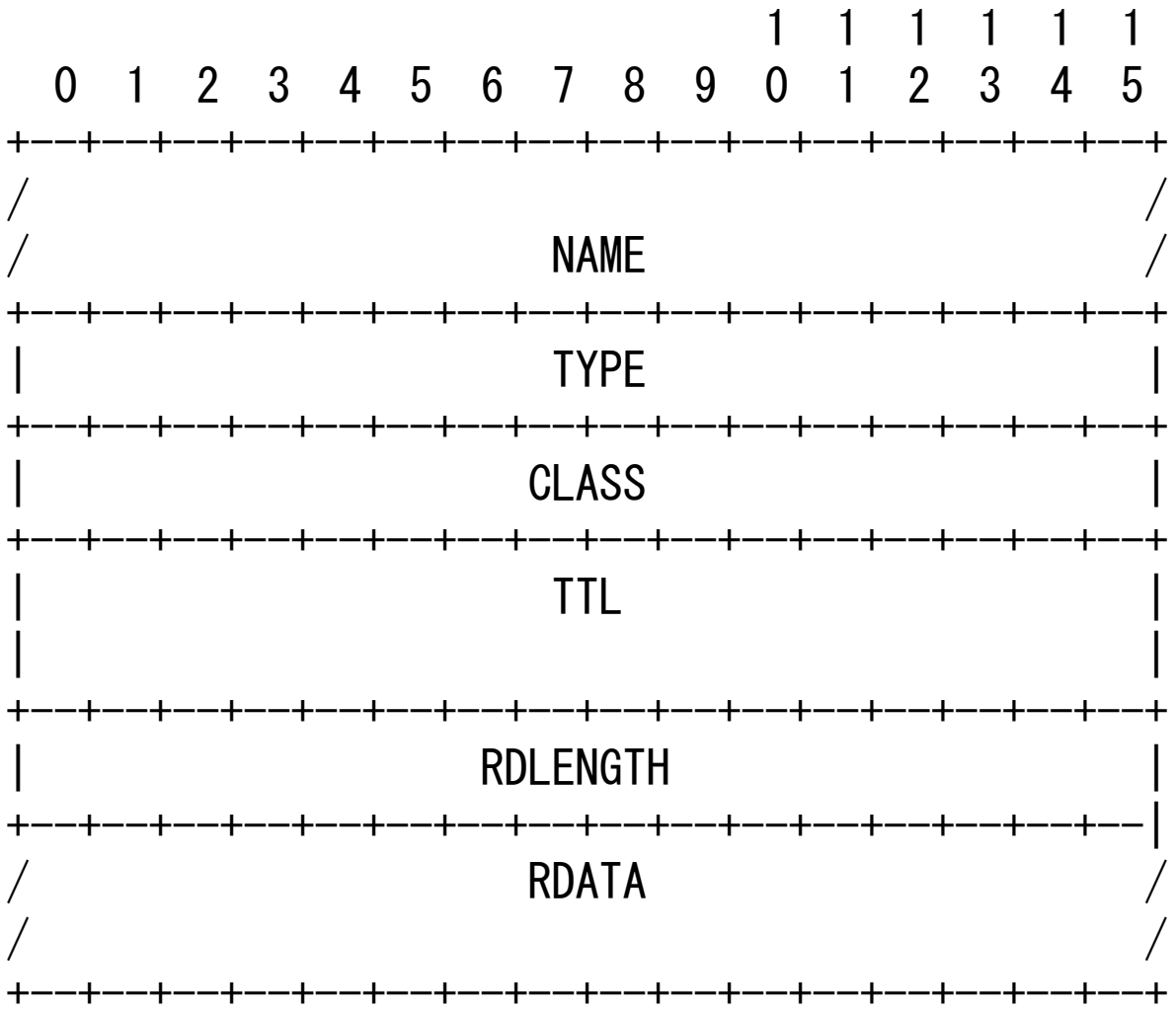
Header Format



Question Section Format



Resource Record Format



How DNS Works

- applications
  - ask resolver perform query
- resolver
  - may maintain cache
  - ask queries to name servers
  - may ask again for reply with intermediate result
    - stub resolvers ask recursive resolver for final result
- name server
  - reply queries using zone information of NS
  - may also have resolver function

DNS and Cache

- resolver may cache old queries
  - reduce load on name servers
- cache interval is specified by TTL of RRs
  - short TTL for frequently updated information
  - long TTL for seldom updated and often queried information
    - especially information on “.”
- additional section may be filled from cache

Resolver Operation

- if answer is in cache
  - reply the answer
- if not
  - ask some name server
- if referred to other name server
  - ask again to the name server
- if answer is CNAME and query type is not CNAME
  - ask again with the canonical name

Name Server Operation

- if queried node is in zones served by the NS (or below them)
  - reply the answer (or referral)
- if answer is in cache
  - reply the answer
- OW,
  - reply referral to name servers of lowest possible (at worst, ".") upper zone

Message Size of DNS

- All IPv4 hosts are required to accept at least 576B packets
  - IPv4 header is at most 60B
- UDP payload can be 508B (not 512B) long
  - though DNS message can be 512B long!
- long DNS data can not be sent over UDP
  - fragmentation with UDP? ordering? retransmisson?
    - instead, just rely on TCP

DNS and E2E Principle

- DNS globally identify (IP addresses) of end systems by ASCII strings
- tree structure of DNS is, in general, unrelated to network topology
  - identification local to end systems is impossible
  - must have some NS in the network
    - location of NS is unrelated to end systems in zones served by the NS
  - is against the E2E principle
    - NS may fail even if end systems are alive

Implication of Violation of E2E Principle by DNS

- violation of E2E principle means
  - vaulnerable to server down
    - DNS specifies zones must have multiple servers
      - end to end multihoming
  - load concentration on name servers
    - especially on root NSes
    - should use light weight protocol of UDP
    - anycast root server?
      - have a lot of root servers sharing same IP address and choose the nearest on by routing system

Wrap Up

- the Internet is information/communication infrastructure
  - not applications (not web or e-mail)
- the E2E principle is basis of the Internet
- IP, the datagram, is the protocol of the Internet
- UDP is light weight
- DNS is basically over LW UDP
  - public key cryptography is not very useful