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 Infrastructure

3. Datalink Layer

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Future of the Internet

- primarily by optical fiber
  - overwhelmingly high speed (>>1Tbps/core)
- wireless is still necessary
  - wireless backbone (one to many)
    - broadcast internet by satellite
      - killer application should be that of broadcast network
  - wireless access (no wiring necessary)
    - mobile internet
      - killer application should be that of phone network
        - » free conversation!

Datalink Layer

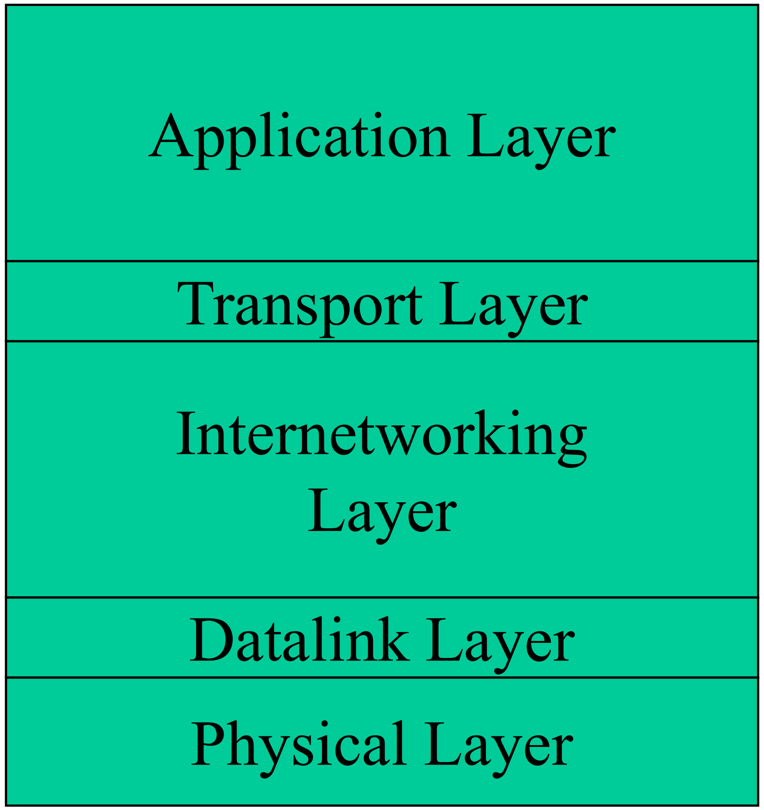
- various datalink layer has been specified for various requirements
  - reliability, guarantee quality of service, etc.
- ethernet is extensively used by the Internet
- phone companies loves ATM
- why ATM disappeared?

Functions of Datalink Layer

- framing
  - byte boundary, packet boundary
- error detection, correction
- identify terminals (MAC address)
- failure detection & avoidance (OAM)
- broadcast/multicast
- QoS guarantee

Layering of the Internet

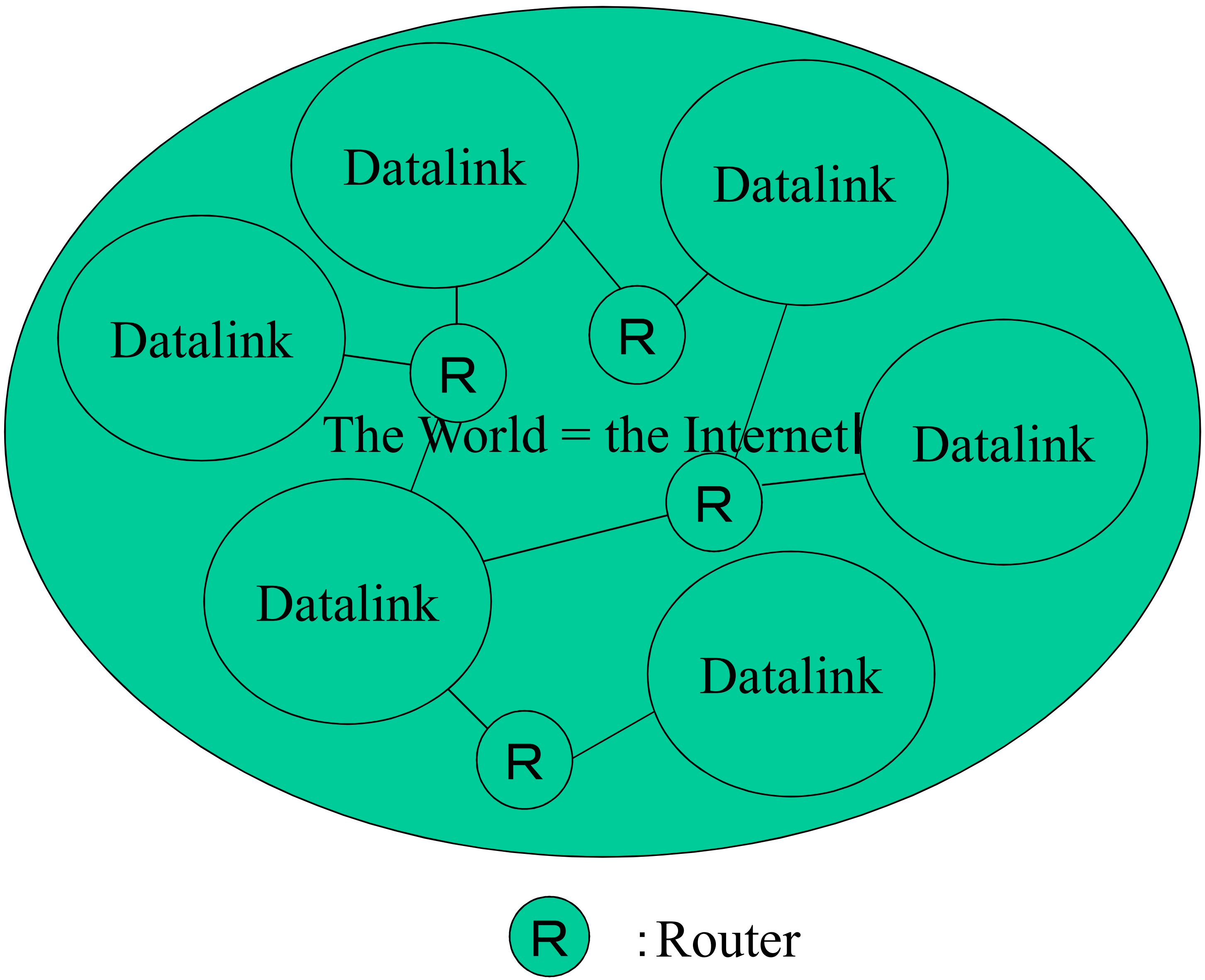
- Physical and Application Layers are Essential
- The Internetworking Layer does as Much Things as Possible
- Datalink and Transport Layers should Avoid to do Thing



Layering Structure of the Internet

CATENET Model

- Connect Small Datalinks by Routers
  - Broadcast is meaningful within each datalink
    - Can communicate without various configuration
  - What is small is # of devices
    - may be large geographically



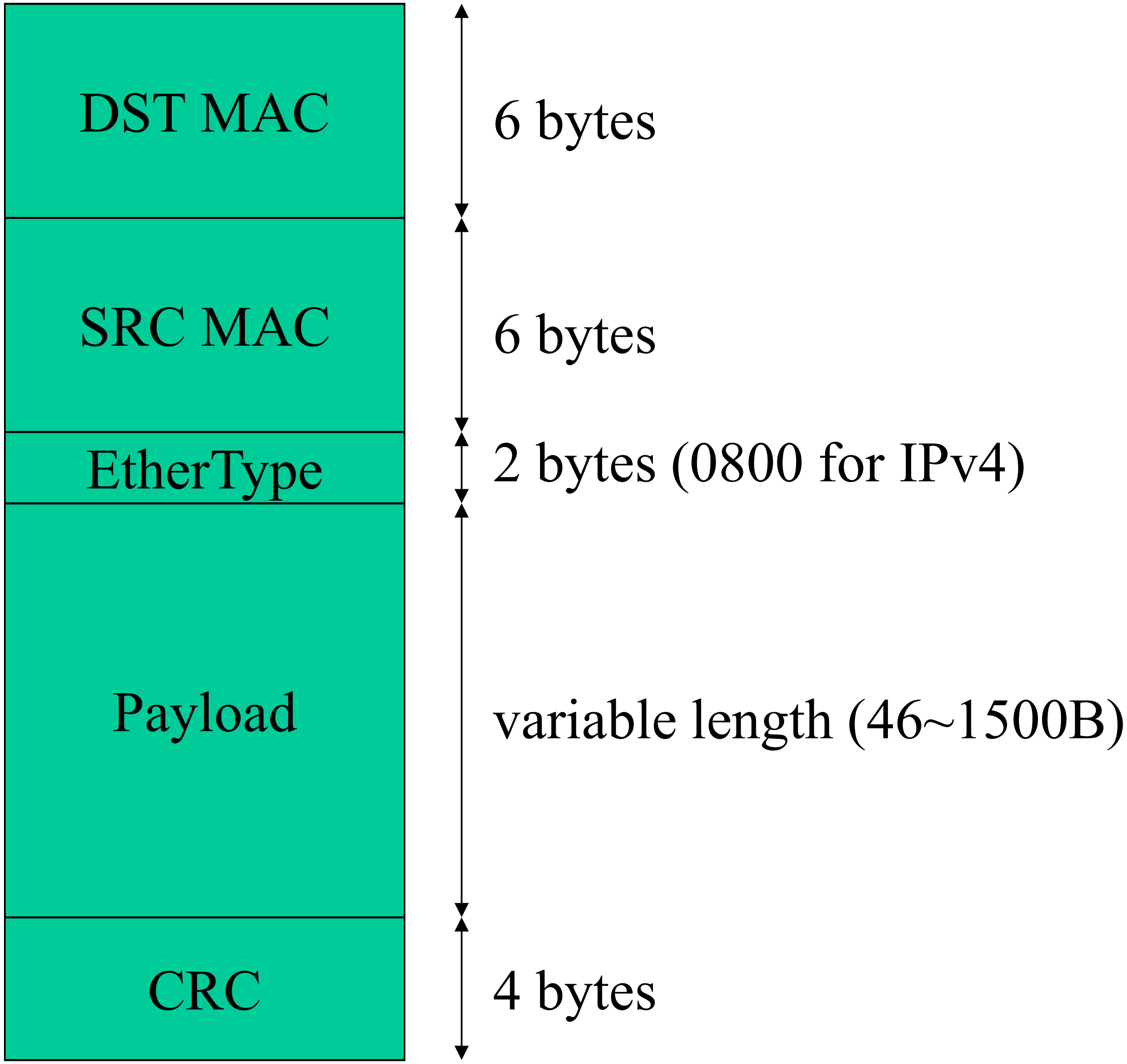
CATENET Model

Examples of Datalink Technologies

- Ethernet (IEEE802.3)
- PPP (Point to Point Protocol)
  - for point to point byte stream (dial-up)
- Wifi (IEEE802.11)
- SONET/SDH
  - time division multiplexing
- ATM/X.25 (ISDN)

Ethernet

- common in the Internet
- devices are overwhelmingly inexpensive
- standardized 10M~100Gbps
  - 400Gbps will be available (upper limit?)
- initially, physical layer is shared
  - collision by simultaneous transmission detected and resend (CSMA/CD)
- recently, physical layer is FD point to point
  - no CSMA/CD, QoS guarantee is easy



basic frame structure of Ethernet

MAC Address

- identify multiple terminals in a datalink
- 48bits for Ethernet
- must be unique within single datalink
  - actually, globally unique
- some MAC addresses are for broadcast/multicast

Ethernet and CSMA/CD

(Carrier Sense Multiple Accesss/Collision Detect)

- original Ethernet
  - multiple senders without prior coordination
    - though, wait if someone else is sending (CS)
  - collision by simultaneous sending detectable
  - resend if collision is detected
    - after waiting random period to avoid repeated collision
    - on multiple collisions, make waiting period longer to reduce sending rate
      - bandwidth depends on congestion and not guaranteed

Recent Ethernet and QoS Guarantee

- some packets are output with priority
- fully duplexed point to point link has only one sender
  - CDMA/CD is unnecessary
  - QoS control is internal queue control
- other cases
  - coordination between multiple sender necessary
  - can be very complex

Problems of Old Ethernet

- wasted bandwidth by 8B/10B encoding (25%)
- 18B header/trailer for each packet
- complex CRC
- delay by collision and resending
- not a problem for optical access network

SONET/SDH

- time division multiplexing used by telephone companies
- basically 156Mbps (52Mbps*3 for SONET, OC-3) byte stream
  - next layer is 4 times faster
  - 16 OC-3 TDMed to form 2.4Gbps OC-48
- used by the Internet combined with ATM or PPP
- can switch to backup link within 0.5s or so

Problems with SONET/SDH

- equipments are expensive
- packet division multiplexing is enough
- header overhead of about 3%
- scrambler period is short (127)
- bandwidth of backup link is wasted
- though phone companies invested on it
  - don’t have to insist on using them, as equipments will soon be obsoleted (2 years?)

PPP (rfc1548)

- Point to Point Protocol
- protocol to send IP packets over byte stream (including SONET/SDH)
  - initially developed for dial-up
    - user authentication function available
- 0x7E is the packet boundary (HDLC based)
  - some byte values (incl. 0x7D and 0x7E) have 2 byte escape representation starting with 0x7D

Problems of PPP

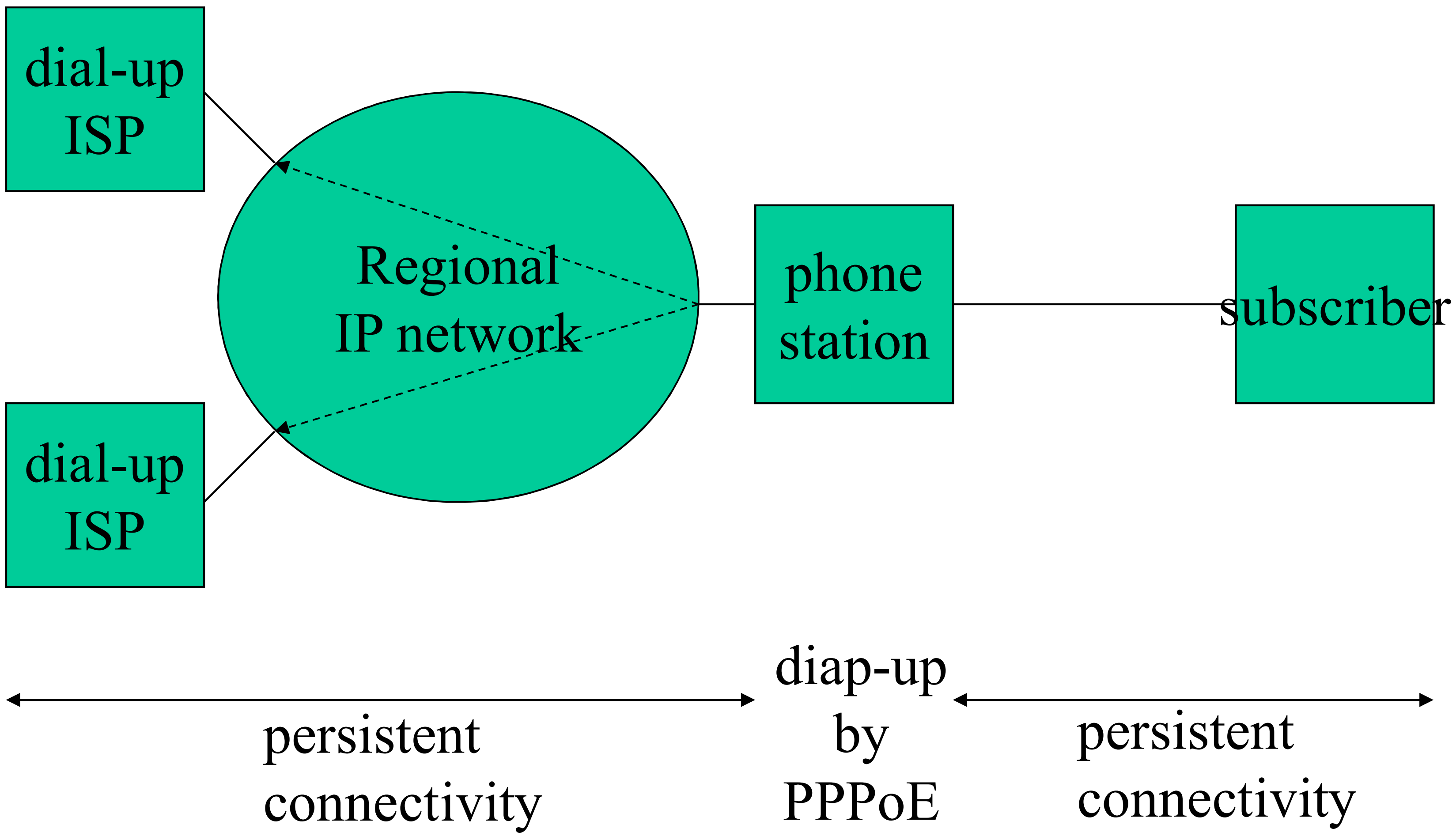
- escape representation to make 1 byte 2 byte is waste of bandwidth of, in average, 1%, in the worst case 100%
  - QoS guarantee is practically impossible
- if used with SONET/SDH, some packets results in consequetive 0s with probability of 1/127
  - detected as link failure

PPP over Ethernet

- PPP frames imposed in Ethernet
- physical layer of ADSL is always connected
  - can’t change connection call by call (whatever call means)
  - dial-up is implemented at datalink layer
  - security by PPP (by username and password)?
    - physical layer has sufficient security

Change Connection Call by Call?

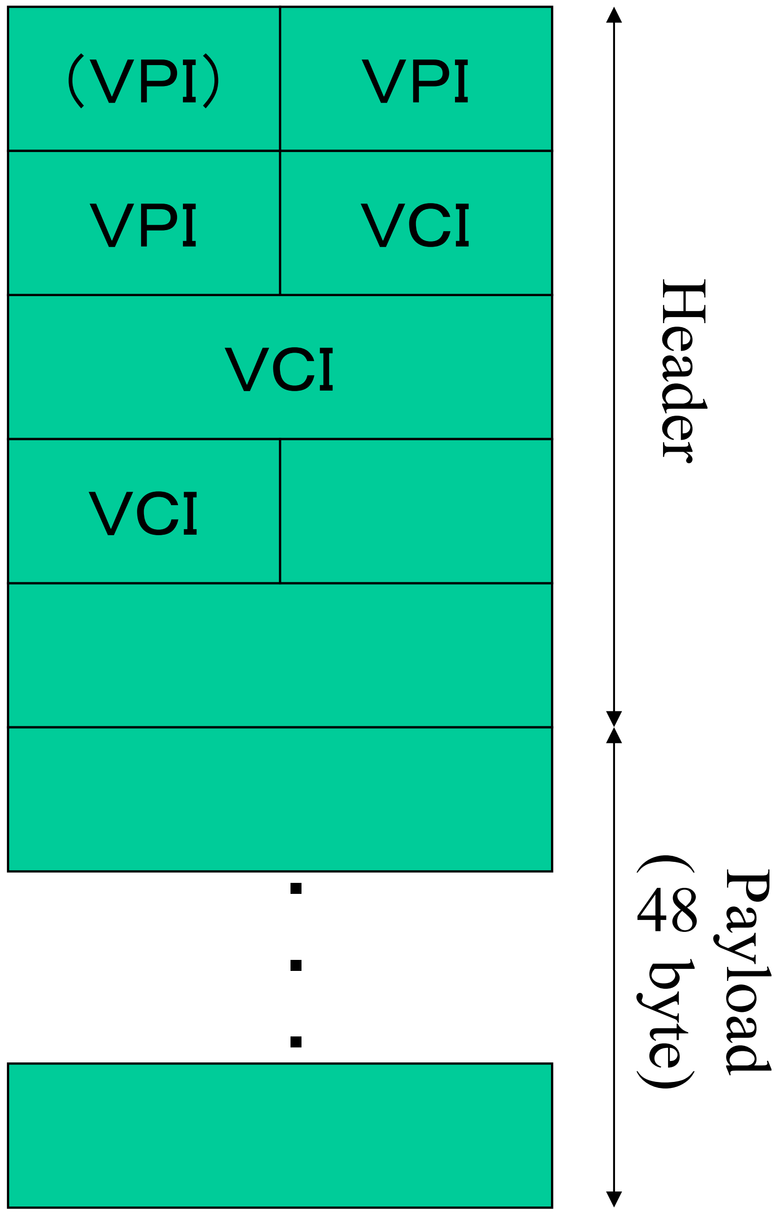
- Any ISP is almost equally OK, as long as connected to the Internet
- have multiple internet connections?
  – if flat rate, waste of money
- may want to connect to private IP network?
  – VPN (IP over IP) is enough
- having "call" denies persistent connection
  – dial-up, though over not phone but Ethernet



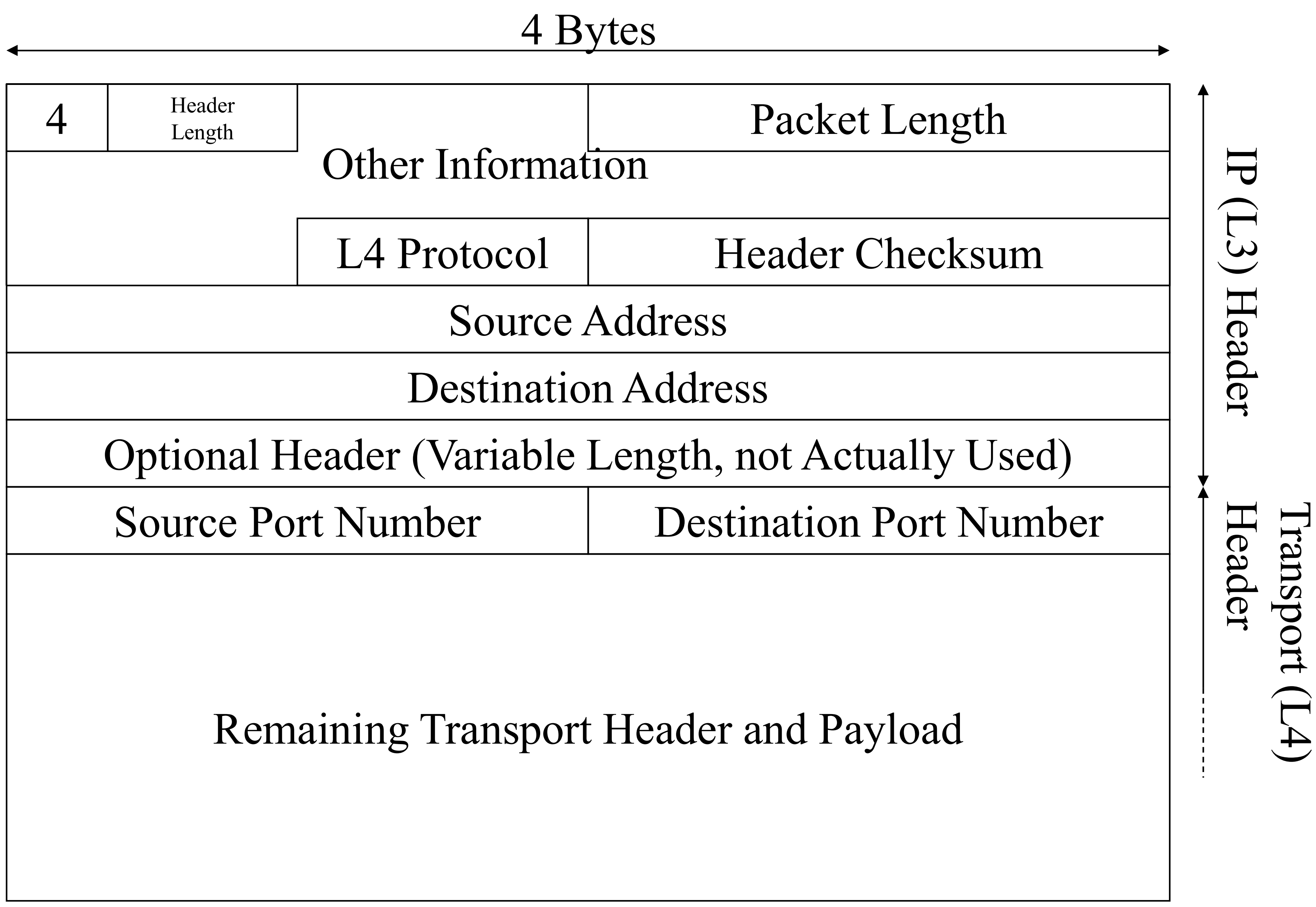
loss of persistent connectivity with FLETS ADSL

ATM (Asynchronous Transfer Mode)

- mechanism for finer grain multiplexing over SONET/SDH (156Mbps is too fast)
- data is divided into fixed length 48B cells and 5B simple header is attached
  - faster than processing complex header?
- cell header identifies individual communication to guarantee required QoS, if everything goes well



A cell of ATM



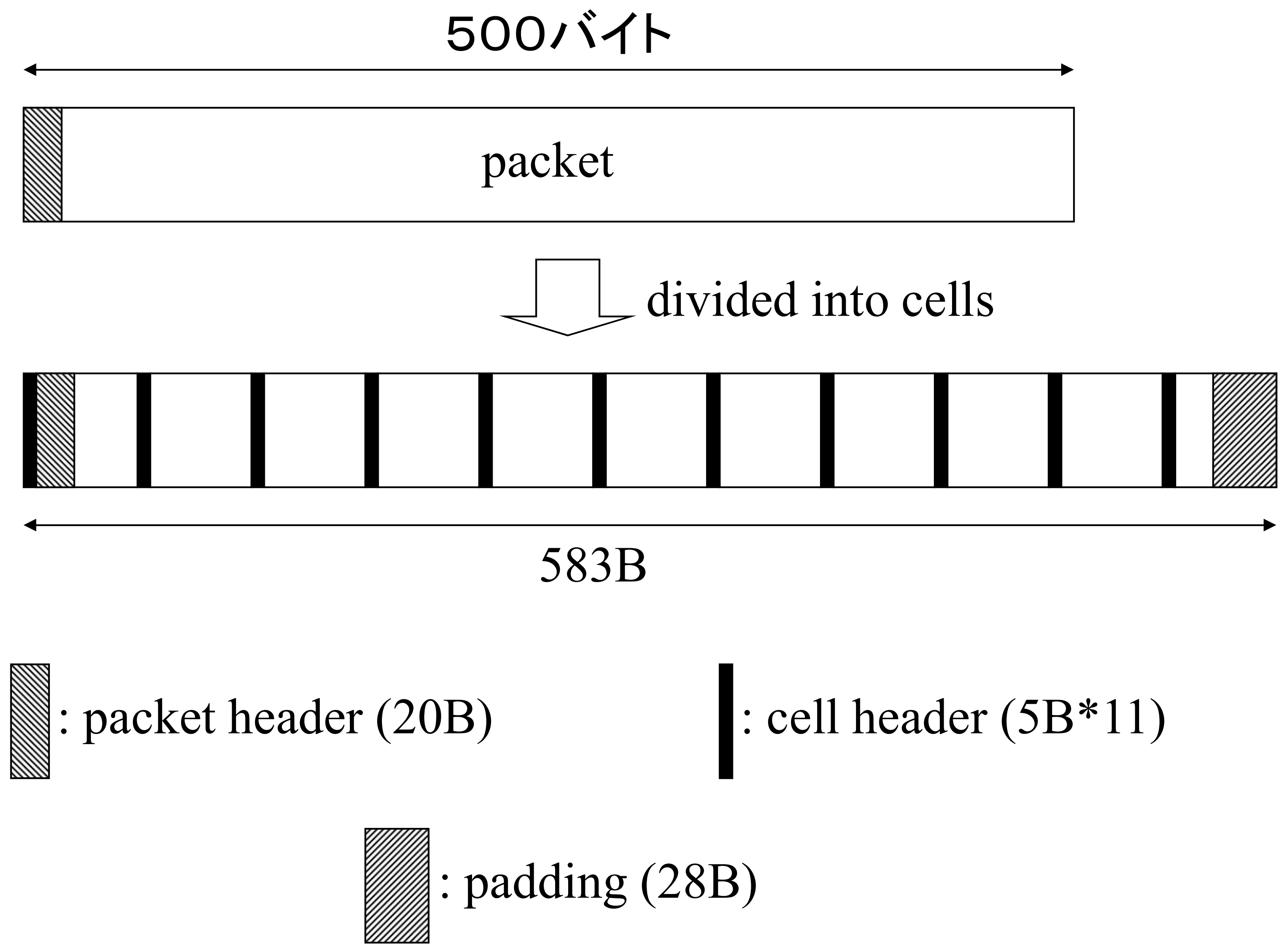
Format of IPv4 Packets

Is ATM fast (faster than IP)?

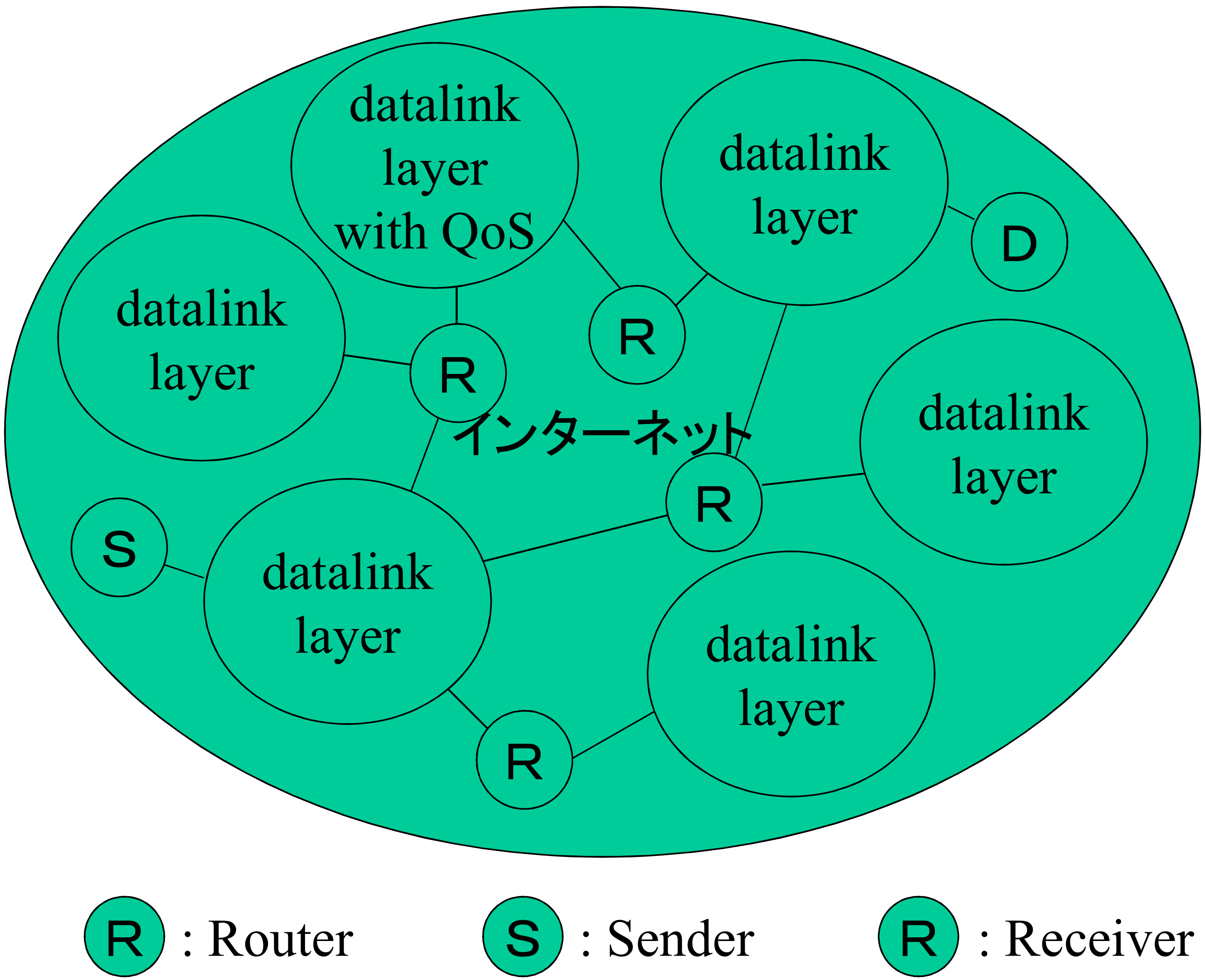
- Processing by IP router/ATM switch
  - input IP packets or ATM cells
  - extract destination information from header
    - simpler with ATM?
  - look-up routing table
    - with ATM, simple RAM lookup is enough
    - IP needs layered, thus, multiple, look up?
  - packets/cells are transferred to output port
  - output

Problems of ATM (1)

- cell multiplexing is unnecessary
  - packet multiplexing by the Internet is enough
- cell means waste of bandwidth of ~15%
- cell based routing is about 10 times more slower than packet based routing
  - as average packet length is ~500B
- no properly working equipments
  - and is expensive
- QoS guarantee, if any, is not meaningful



waste of bandwidth by cells (in case of 500B IPv4 packet)



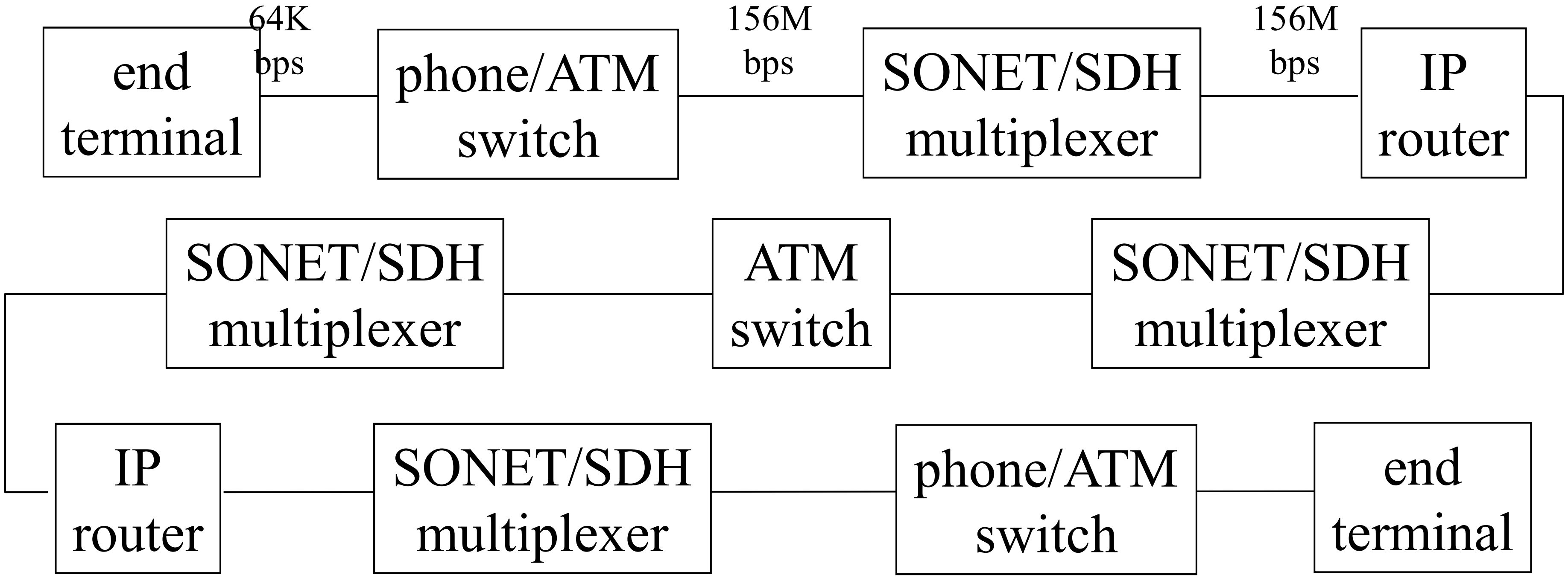
QoS Guarantee and the Internet

Problems of X.25/ATM

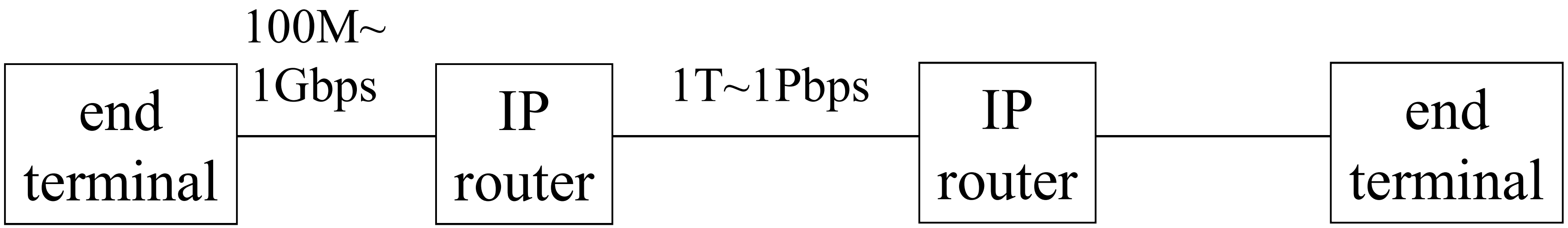
- X.25/ATM maintains each communication
  - cell/packet header identify communication
  - router/switch maintain each communication
    - connection oriented
- IP do not maintain each communication
  - IP header identify destinations
    - router/switch maintain how to reach destinations
    - processing of each packet is independent (connectionless)

Between IP and Optical Transport

- IP over optical (all optical internet)
- IP-WDM-optical (internet today)
- IP-PPP-HDLC-SONET/SDH-WDM-optical (was popular with phone companies)
- IP-MAC-8B/10B-,,, (Gbit Ethernet)
- IP-LLC/SNAP-AAL5-Cell Multiplexing-SONET/SDH-WDN-optical (dreamed by phone companies with ATM)



a) the Internet over phone network infrastructure



b) the Internet as the infrastructure

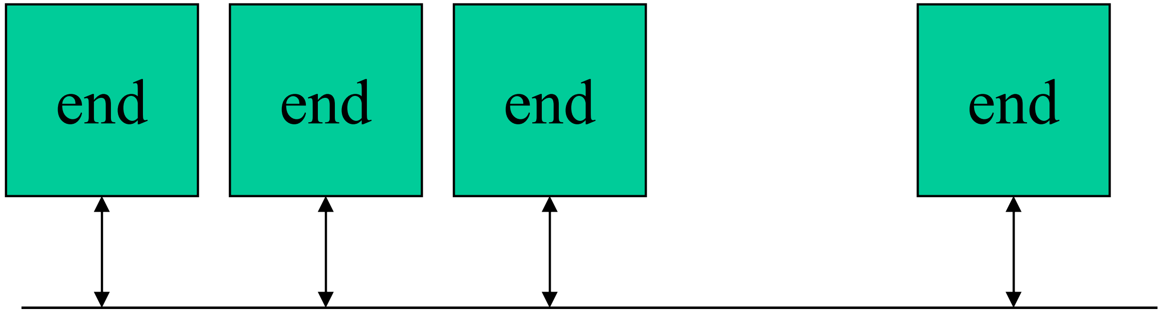
Internet Evolution & Simplification

Backbone Datalink Layer in the Internet Era (1)

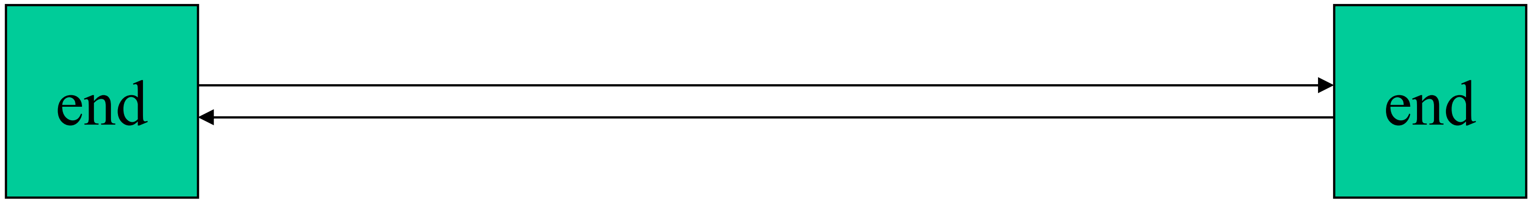
- QoS guarantee by IP layer
  - no QoS guarantee by datalink layer necessary
- Multicast by IP layer
  - no multicast by datalink layer necessary
- tera-bit transmission by WDM or massive parallelism
  - 10~40Gbps without parallelism is fine
- OAM (operation & management) by IP layer
  - no OAM by datalink layer necessary

Backbone Datalink Layer in the Internet Era (1)

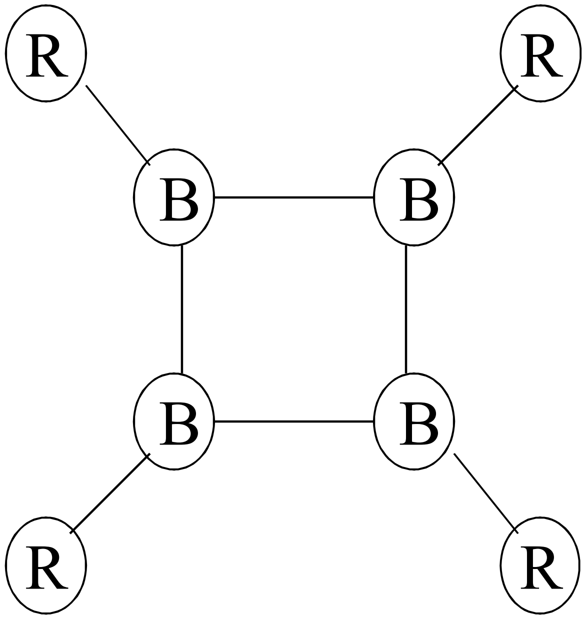
- as L2 switches are as expensive as L3 routers
  - point to point protocols is enough
    - datalink layer with more terminals needs extra complex function for QoS guarantee and multicast
    - QoS guarantee and multicast can be taken care of by IP layer if datalink layer is point to point



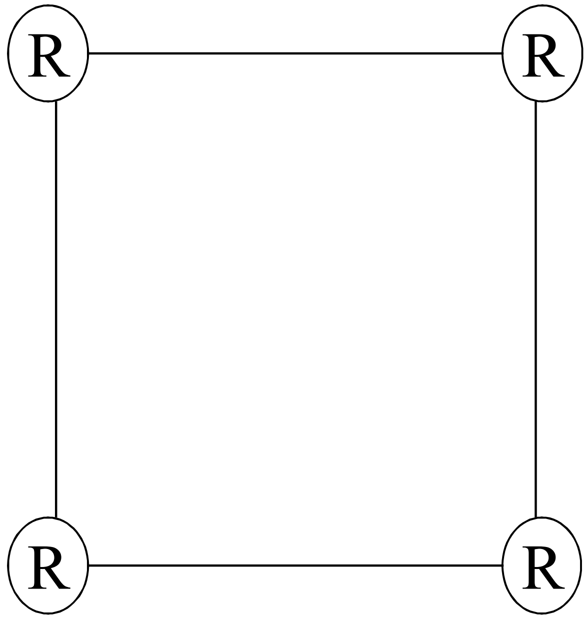
multi access connection



point to point connection



of
equipments,
interfaces &
administrations
can be halved



R : router

B : bridge

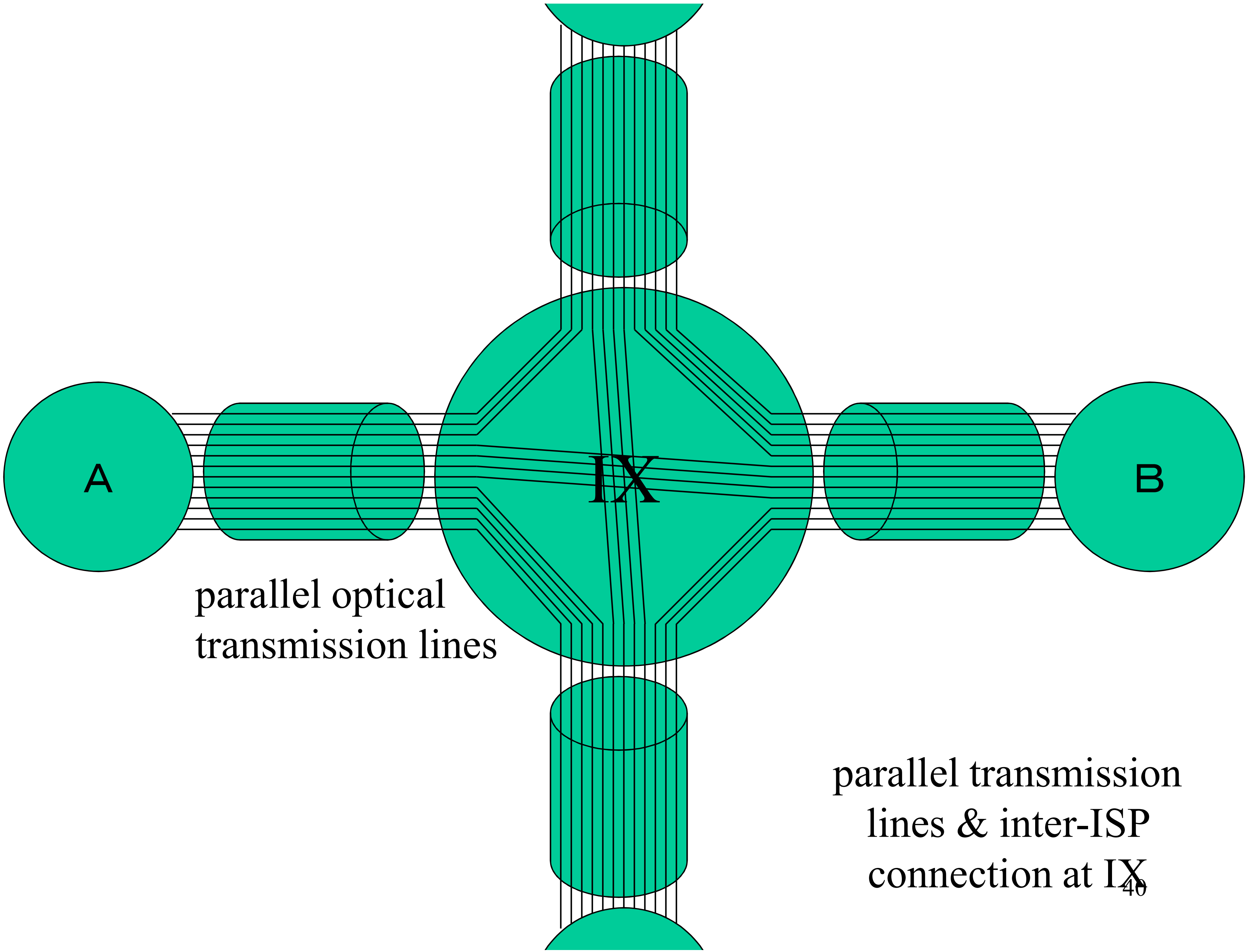
removing bridges

IX needs Multiaccess Datalink?

- at IX (internet exchange), routers of many ISPs are mutually connected
  - # of interfaces prop. to # of ISPs are necessary?
  - if routers are connected through multi-access datalink, only 1 interface is necessary
    - MAPOS (rfc2171) to construct multi-access datalink from SONET/SDH
    - if not so much speed is necessary, fine

IX and Datalink in Ultra High Speed Era

- at IX (internet exchange), routers of many ISPs are mutually connected
  – single interface (10Gbps or so) may be too slow as connection between another ISP
  – routers need at least as many interfaces as # of other ISPs, or even several times more
  – no need for multi access datalink



parallel transmission
lines & inter-ISP
connection at IX

Functions of Datalink Layer

- framing
  - byte boundary, packet boundary
- error detection, correction
- identify terminals (MAC address)
- failure detection & avoidance (OAM)
- broadcast/multicast
- QoS guarantee
- failure recovery

Functions of Datalink Layer Necessary for the Internet

- framing
  - byte boundary not necessary, packet boundary
- error detection, correction
- not necessary for P2P physical layer
  - identify terminals (MAC address)
  - failure detection & avoidance (OAM)
  - broadcast/multicast
  - QoS guarantee
  - failure recovery by L3 routing

IOG (IP over Glass)

- simple and fast (10~40Gbps) protocol specifically designed for IP over light
- point to point
- fixed 2kB frame and variable length packet up to 1535B
- frame wise synchronization, scrambling & CRC
- 4B packet headeer

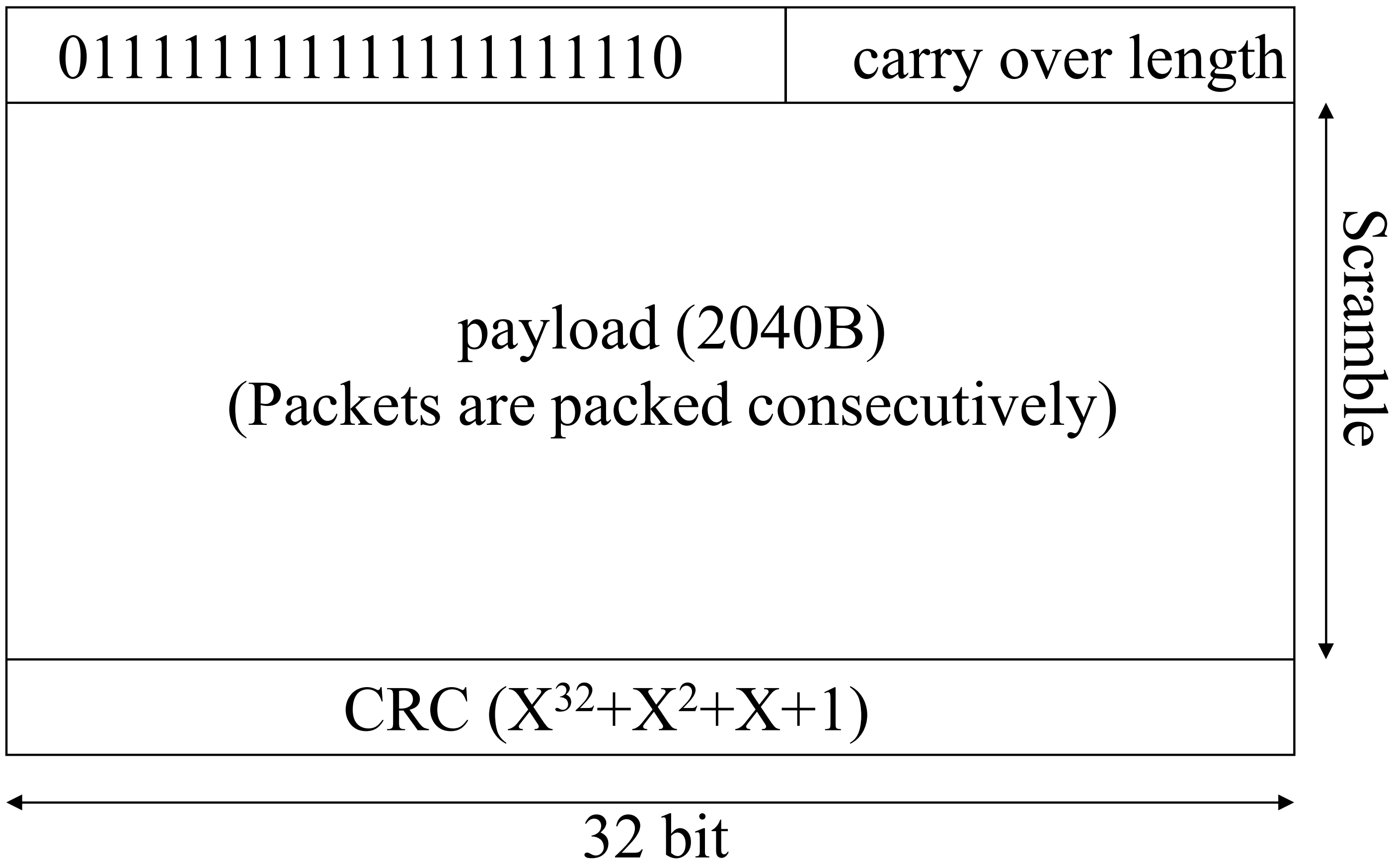
Features of IOG

- long scrambler period (2^43)
- minimum overhead
  - 8B/frame (synchronization flag+CRC)
  - 4B/packet (length+type(label))
- CRC polynomial for fast computation
  - $X^{15}+X+1$ (scrambler)
  - $X^{32}+X^{2}+X+1$ (CRC)
- packet length 20B~1535B

CRC of IOG

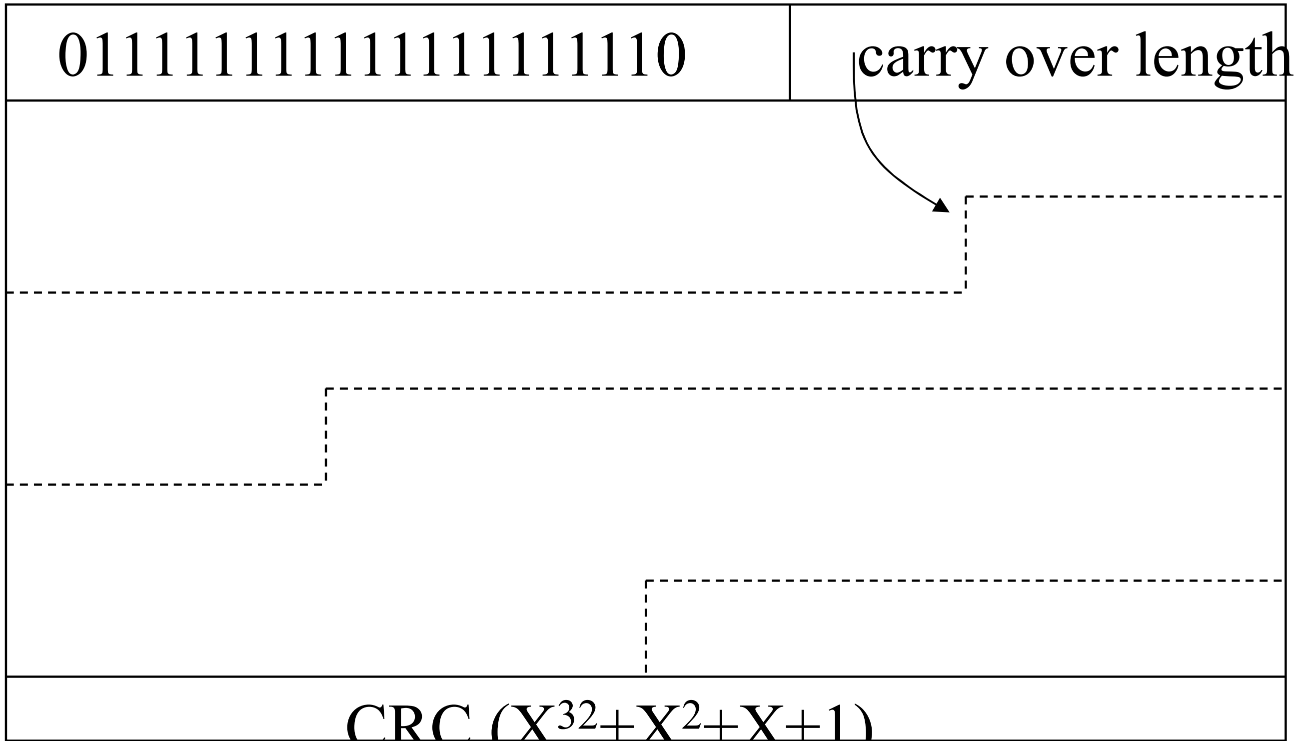
- $X^{32}+X^{2}+X+1$ is chosenhave factor of 21st degree primitive polynomial
    - hamming distance of 3 < 2Mbit data
    - another factor of X+1
        - – hamming distance is 4 (SEC, DED)
- – 32 or 64 parallel computation is simple
    - # of fan in of XOR gates is small
        - – fan in of 5 for 32 parallel (18 for 64 parallel)
        - – for faster computing (3 or 5 serial 2 input XOR)

Frame Structure of IOG



IOG Frame and Packet Boundary

- synchronization is by frames
- first packet boundary is marked



Packets of IOG

length (11 bits)	0 (5 bits)	EtherType (16 bits)	packet contents

length (11 bits)	label (21 bits)	packet contents

Maximum Packet Length

- longer, less header overhead
- longer, harder to stuff data (esp. real time)
- 1500B for Ethernet (9kB in practice)
- minimum of 68B required by IPv4
  - longer packets can be fragmented
- minimum of 1280B required by IPv6
- maximu packet length is automatically detected by IPv6 (though often impossible)

- a little more than 1500B is enough?

Radio Waves and the Internet

- short distance (low power)
  - install many stations (not phone network of 5G)
  - mobile internet service can be realized by IP mobility
- long distance (high power)
  - radio waves are good for one to many
  - is satellite internet fast?
    - fast only for one to many

Datalink Layer for Wireless Access

- as physical layer is multi access
  - identification of terminals by MAC necessary
- may assume central stations
  - acting as center of coordination
    - equal relationship between terminals not necessary
- QoS guarantee needs complicated control
  - though relieved by central stations
- should be inexpensive (IEEE802.11, Wifi)

Wireless Access Network & Security

- with dial-up way of thinking
  - PPP authentication upon connection open
    - secure for phone network or PPPoE
      - connection with same peer is maintained
    - not enough for wireless LAN
      - can always communicate with multiple peers
      - authentication necessary to confirm identity of peers
        - » MAC address is not reliable, DoS of jamming easy
- packet-wise authentication is nececcary for wireless LAN

Ethernet and CSMA/CD

(Carrier Sense Multiple Accesss/Collision Detect)

- original Ethernet
  - multiple senders without prior coordination
    - though, wait if someone else is sending (CS)
  - collision by simultaneous sending detectable
  - resend if collision is detected
    - after waiting random period to avoid repeated collision
    - on multiple collisions, make waiting period longer to reduce sending rate
      - bandwidth depends on congestion and not guaranteed

Wireless LAN and CSMA/CA

(Carrier Sense Multiple Access/Collision Avoidance)

- collision detection is impossible for wireless
  - too much power difference between transmitted and received signal
    - if one is transmitting, can't detect someone else transmitting
  - can't detect transmission near receiver far from transmitter (hidden terminals)
  - collisions detected by lack of ACK
    - other behavior is mostly same as CSMA/CD
    - broadcast/multicast can't use ACK and is unreliable
      - important difference to Ethernet

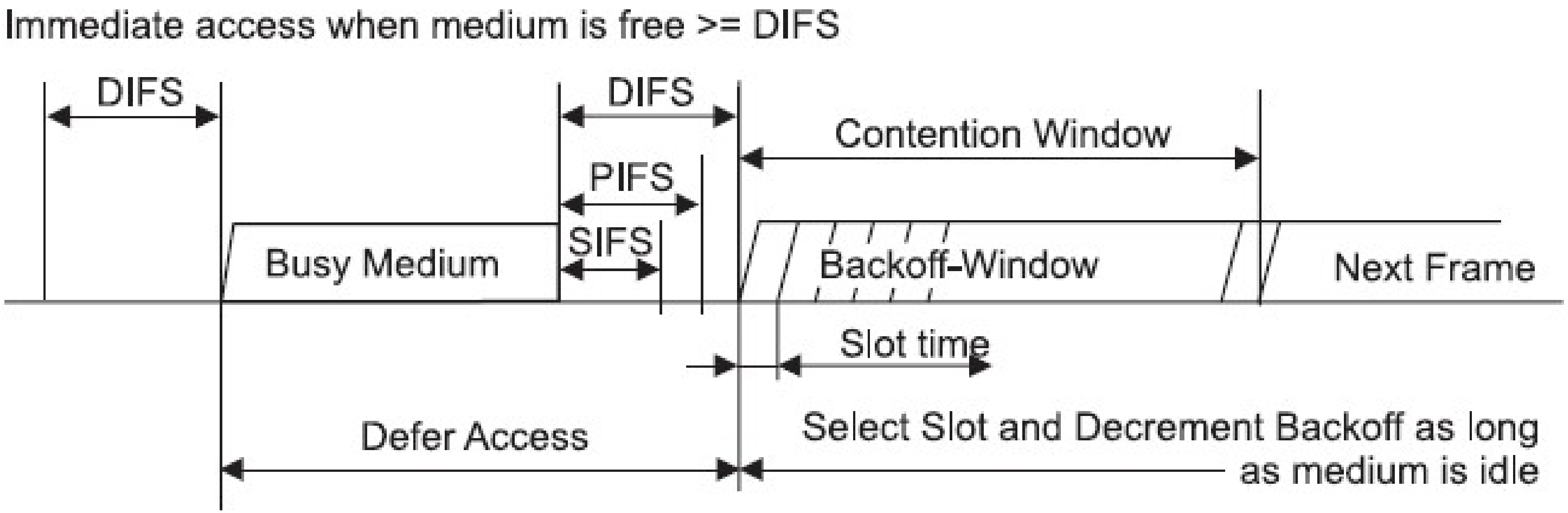


Figure 49—Some IFS relationships

from specification of IEEE 802.11

Datalink Layer for One to Many Communication with Radio Waves

- MPEG2-TS?
  - deployed by digital broadcasting (DVB etc.)
  - designed for MPEG images
  - possible to carry IP as MPEG payload
    - what if everything is over IP?
    - MPEG over IP over MPEG2-TS?
- native IP datalink should be better

Physical Layer in the Future

- fixed backbone and fixed access
  - optical fiber (point to point
- mobile access
  - radio waves (one to many)
- one to extremely many backbone and access
  - radio wave broadcast

Datalink Layer in the Future

- fixed backbone
  - Ethernet?, all-optical router?
- fixed access
  - Ethernet
- mobile access
  - IEEE 802.11 (Wifi)
- one to extremely many backbone and access
  - ?

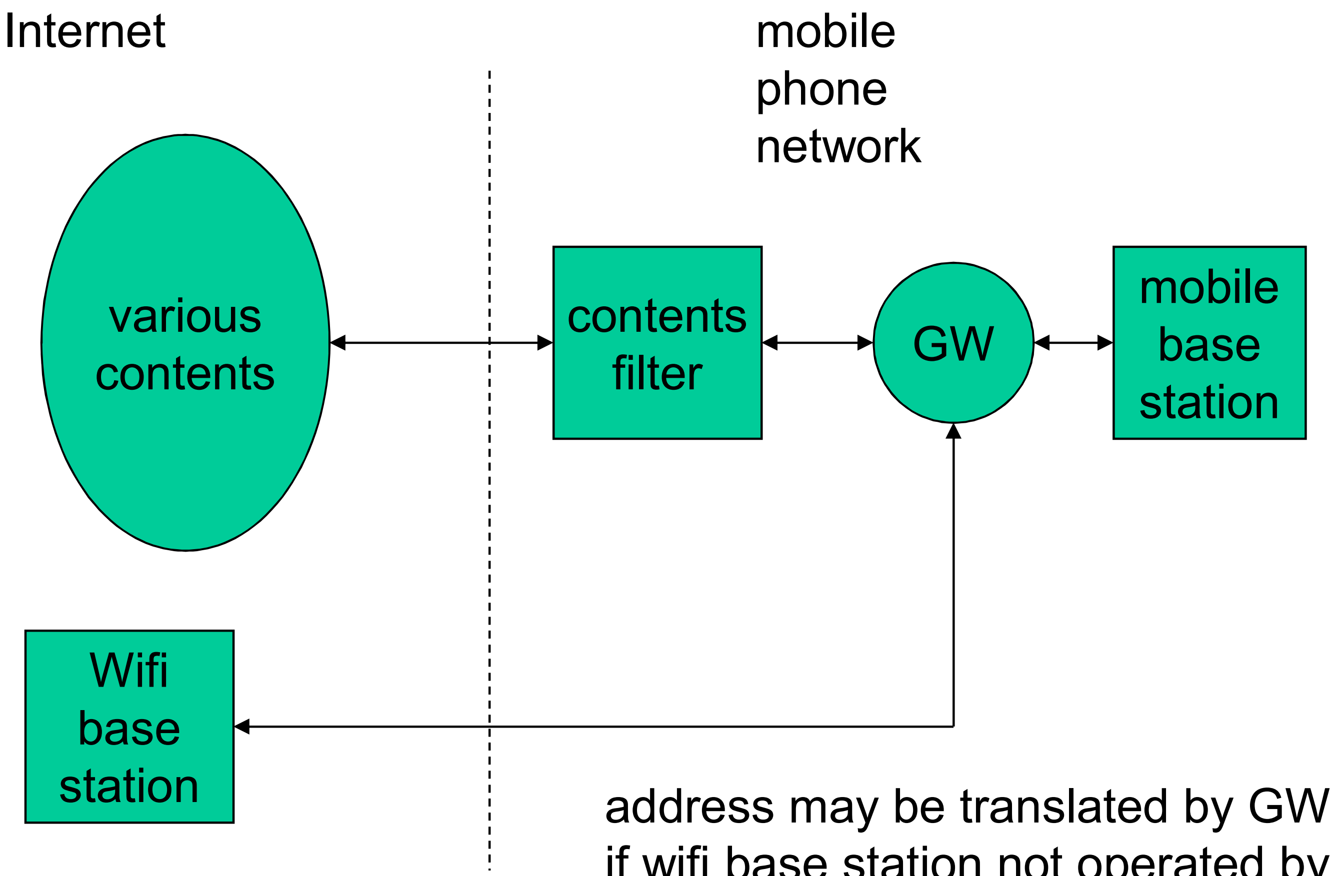
Technologies of WAN and LAN

- WAN
  - (was) strongly regulated
  - formal international standard (by ISO, ITU etc.) was important
    - price and performance is of secondary importance
- LAN
  - world of free competition
  - price and performance are the only concern
    - standardization is not very important
    - most advanced technology is used extensively

Future of Mobile Phone

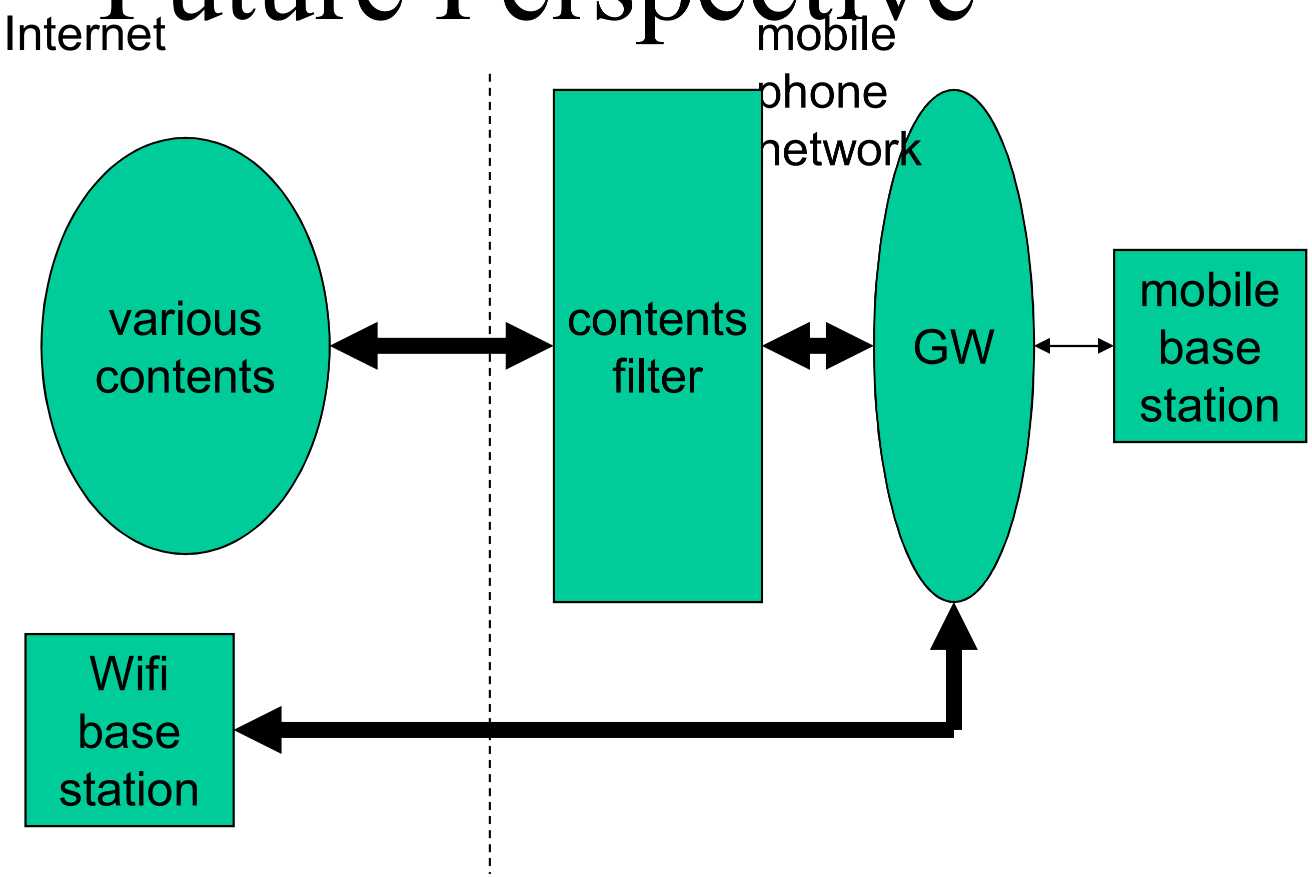
- not enough capacity
- mobile phone network is expensive
  - want to use wifi as bypass
- does wifi complements 3/4/5G?
  - complexity of phone network forever
- does wifi replace 3/4/5G?
  - room for cost reduction, simplification and better efficiency

Wifi as Complement of 3/4/5G

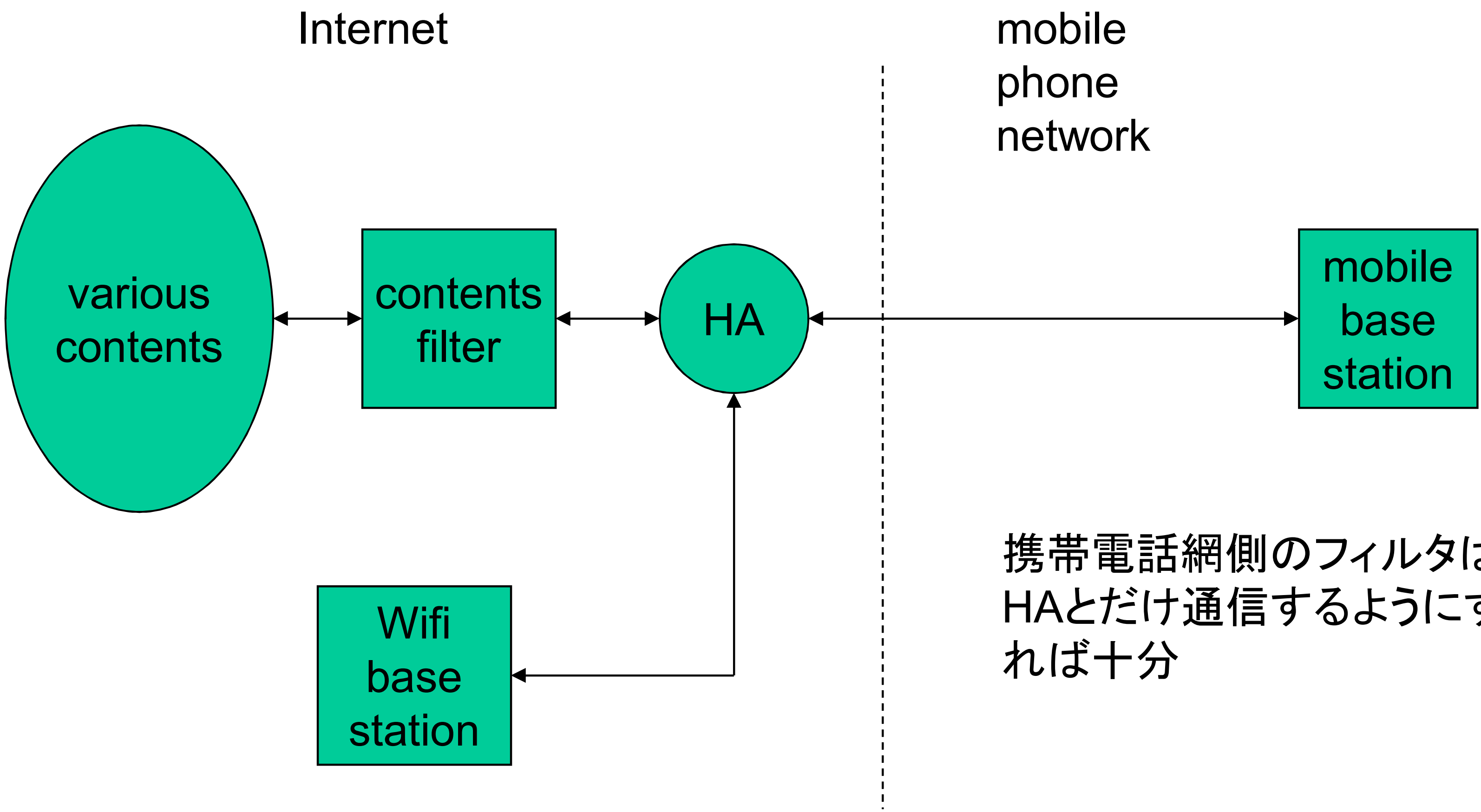


address may be translated by GW
if wifi base station not operated by
mobile carriers are used

Wifi as Complement of 3/4/5G Future Perspective

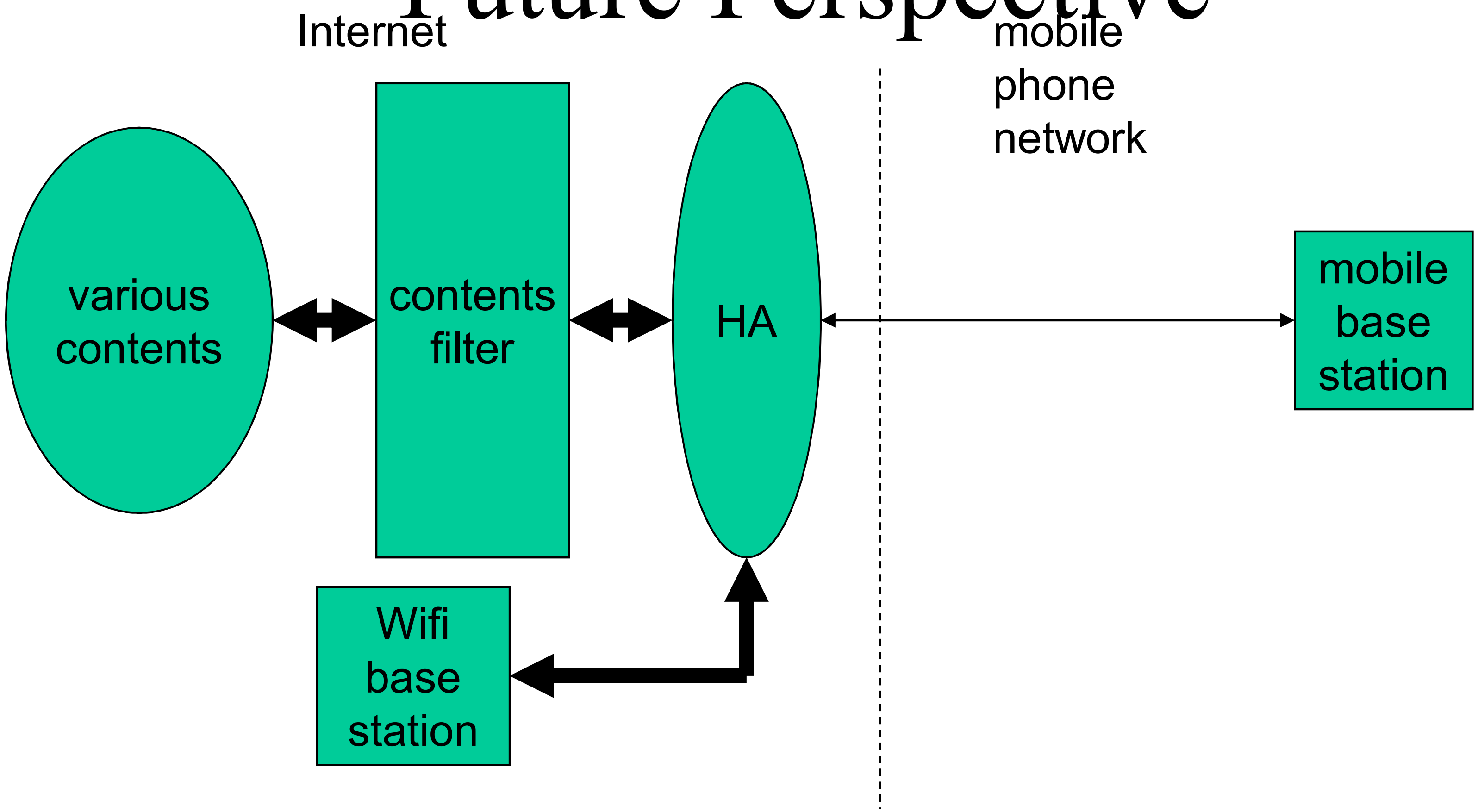


WiFi to Replace 3/4/5G



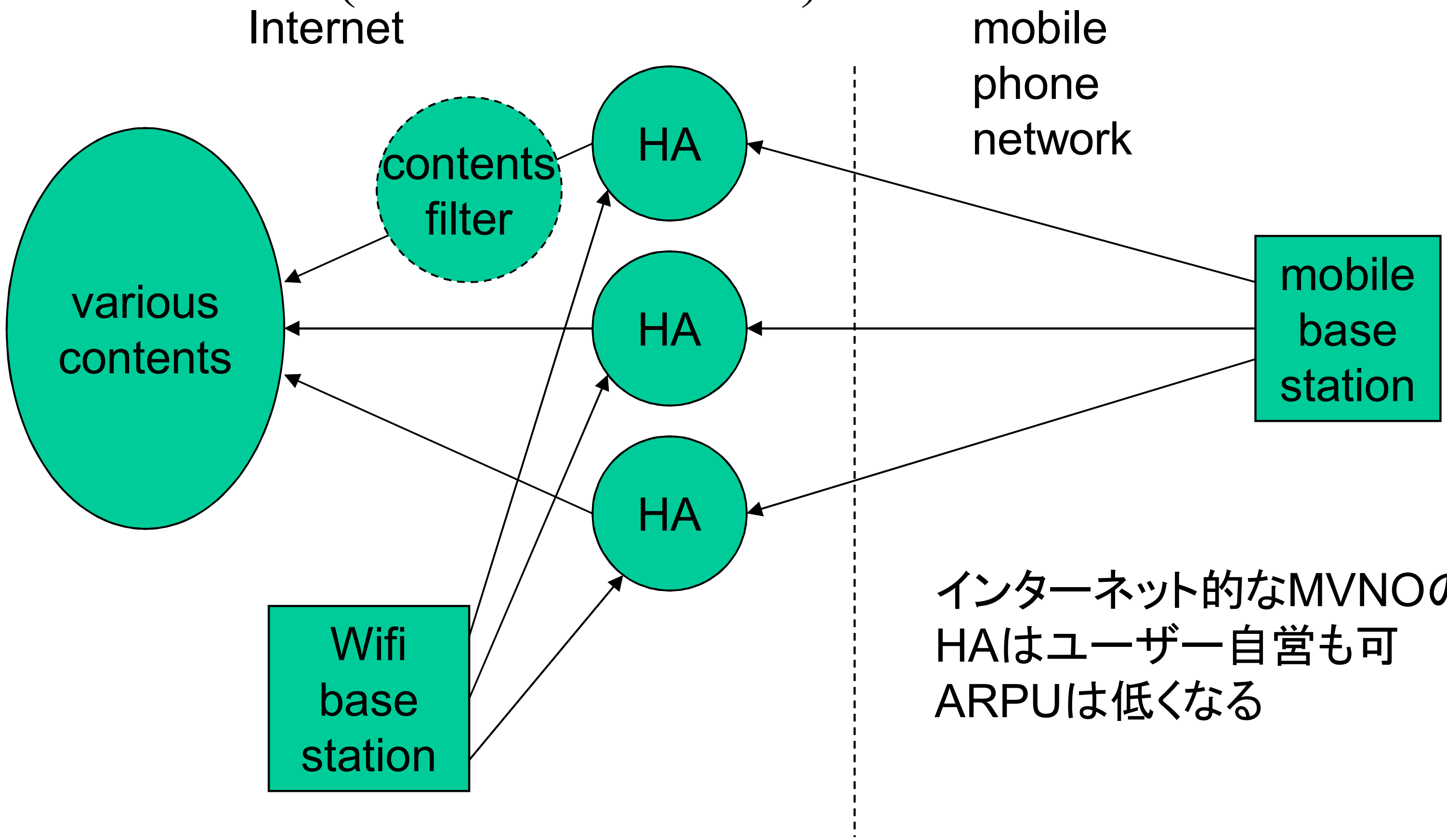
携帯電話網側のフィルタは、
HAとだけ通信するようにす
れば十分

WiFi to Replace 3/4/5G Future Perspective



WiFi to Replace 3/4/5G

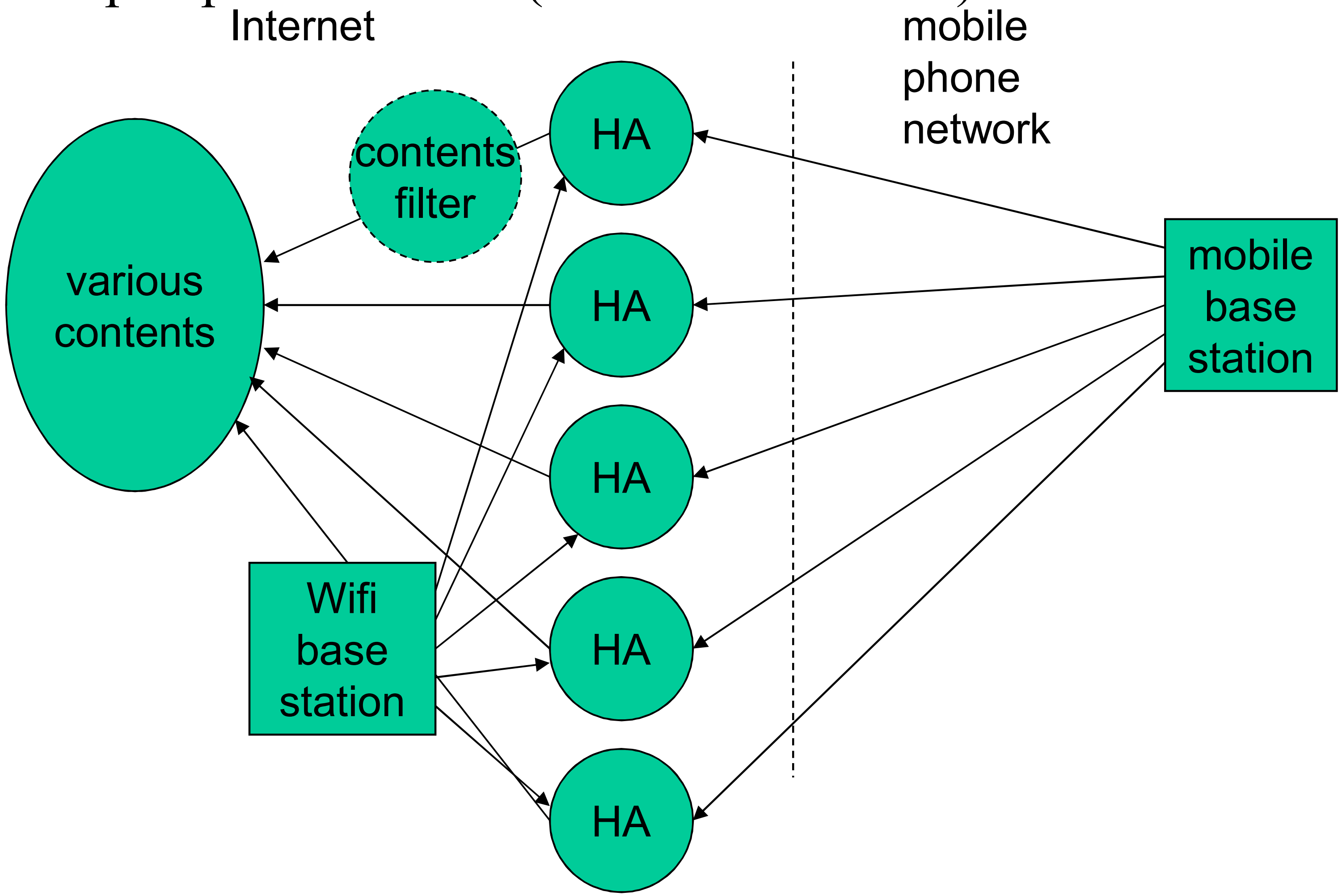
if HA (and contenst filter) service is unbundled



インターネット的なMVNOのあり方
HAはユーザー自営も可
ARPUは低くなる

WiFi to Replace 3/4/5G

future perspective if HA (and contenst filter) service is unbundled



Wrap-up

- datalink layer can be simple
  - if physical layer is point to point, datalink layer can be point to point
    - with persistent connectivity
  - functions offered by IP not necessary
  - function not supported end to end (e.g. QoS guarantee) can't be used and is meaningless
- LAN technologies are faster and less expensive

New Communication Paradigm for Cellular Internetworking：

Packet Division Multiple Access (PDMA)

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What Happened to Wired Communication

- initially, dial-up Internet access
  - slow, expensive, usage based charge, waste of BW
- multiplexing necessary for the Internet
  - packet multiplexing only
- as broadband era evolves
  - LAN (Ethernet) technologies widely deployed by WAN
  - phone style multiplexing (SONET/SDH, ATM) to disappear

Note on Best Effort and Guarantee

- on phone network
  - QoS is guaranteed if connection established
  - connection establishment is best effort
- on the Internet today
  - connection establishment is almost guaranteed
  - QoS of connection is best effort

Existing “Special Purpose” Cellular Network

- cellular network as phone network
- “special” property of phone application
  - continuous communication
    - traffic continues for certain period of time (3 min.?)
  - bi-directional communication
    - with same bandwidth in both directions
  - (mostly) fixed bandwidth
    - fixed bandwidth is allocated to each communication
- as relative amount of phone traffic reducing to be negligible

Cellular Network, in General

- No “special” property of phone assumed
- communication, in general
  - discontinuous communication
    - hard to predict when traffic happens
  - uni-directional communication
    - traffic, in general, flows only uni-directionally
  - BW not fixed
    - amount of desired BW unpredictable

Property of General Packet Cellular Network

- traffic generated packet-wise
- data packet generation is not predictable
- base station generate beacon (packet) relatively frequently (several tens of times in a second ~ once in several seconds?)
- mobile stations exchange registration messages with base stations (once in several tens of seconds?
- no other packets should be necessary

General Packet Cellular Network and Moving Speed

- base stations should generate beacon a lot more frequently than (cell size)/(moving speed)
- mobile stations may not produce packet so often
  - may not enough for base stations locate mobile stations acculately for active beam forming
    - especially with short wavelength of 5G
      - 60km/s means 1.66cm/ms

Property of the Internet and Cellular Network

- Internet is packet (datagram) network
- any traffic characteristic possible
  - packet drop upon congestion
    - against which end systems react to reduce speed
    - though phone traffic over the Internet has same characteristic as that over phone network
      - amount of traffic negligible
- cellular network needs
  - mechanisms to be able to adopt general traffic

CSMA/CA and 802.11 Protocol Suites

- random wait before transmission
  - communication slot is dynamically allocated
    - can adopt to any traffic pattern
      - including that of phone
- if BW is not enough?
  - retransmission after increased random delay
    - drop, if several attempts fail
    - compatible with best effort internet

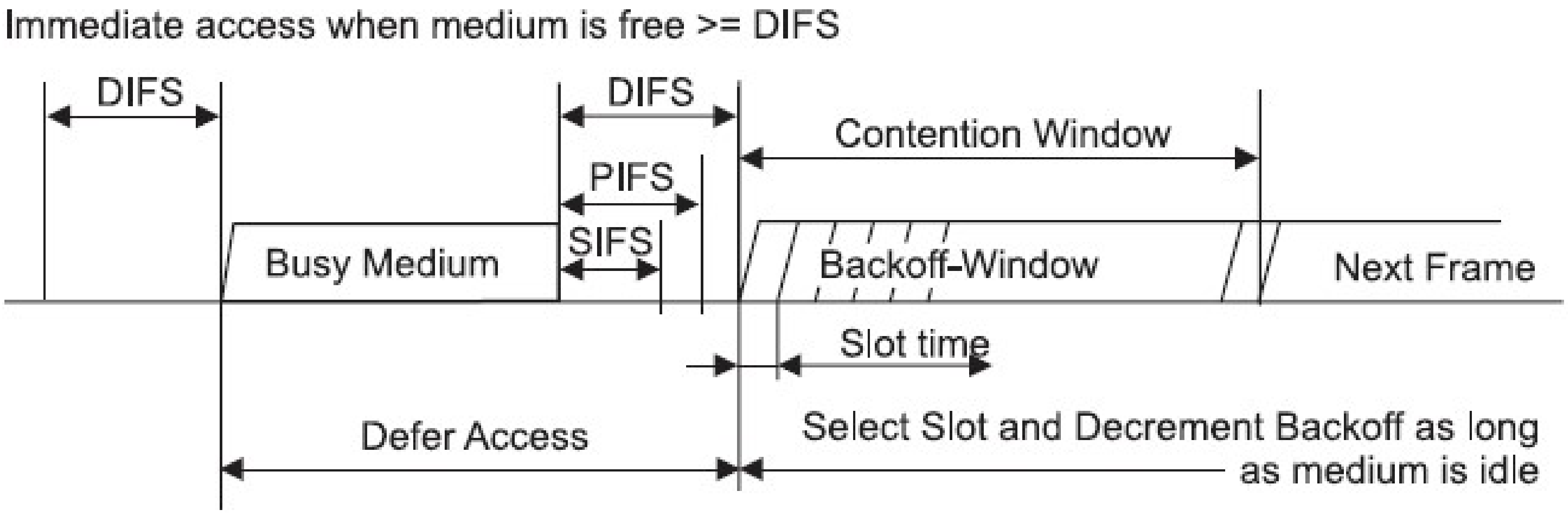
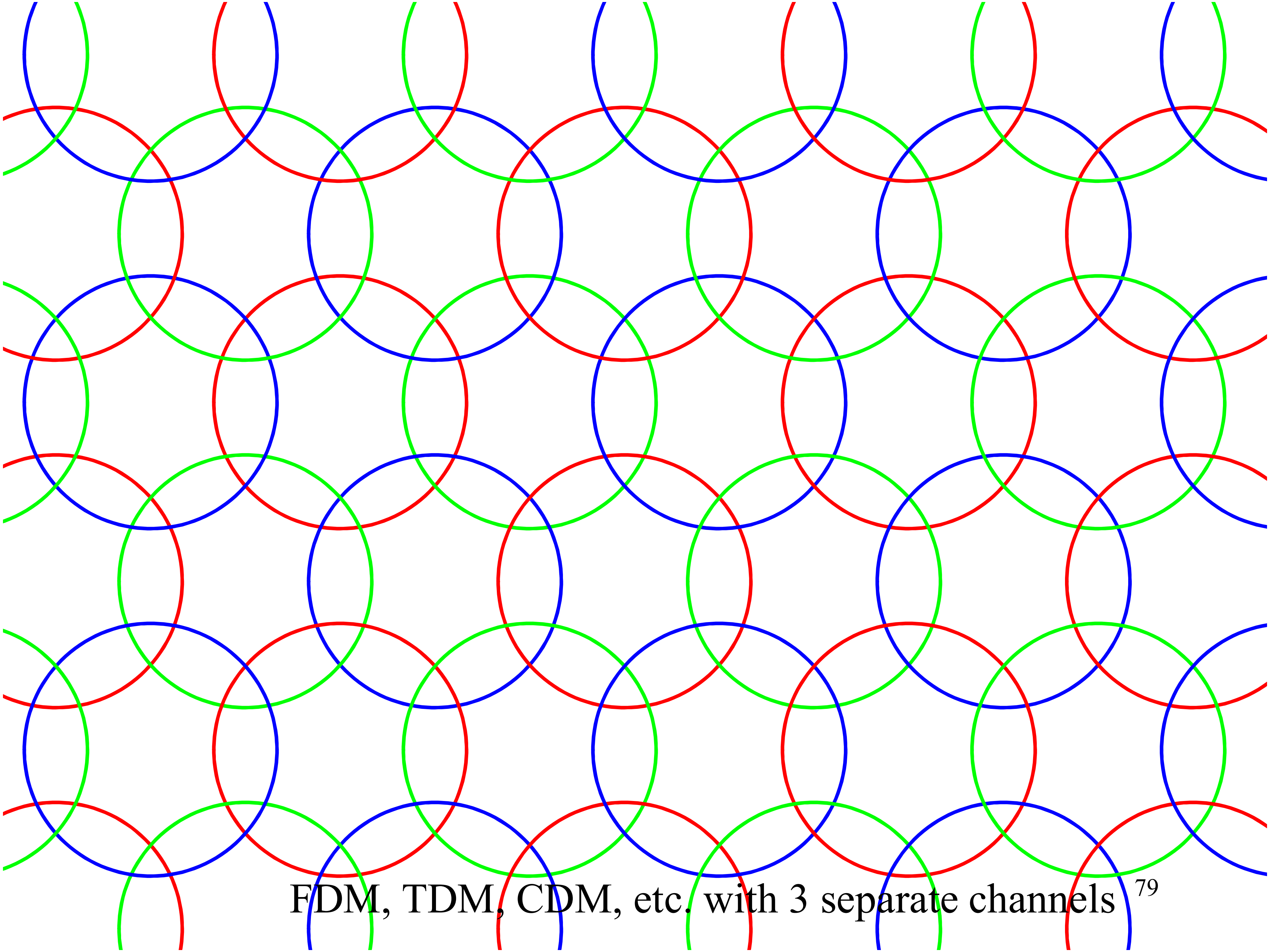


Figure 49—Some IFS relationships

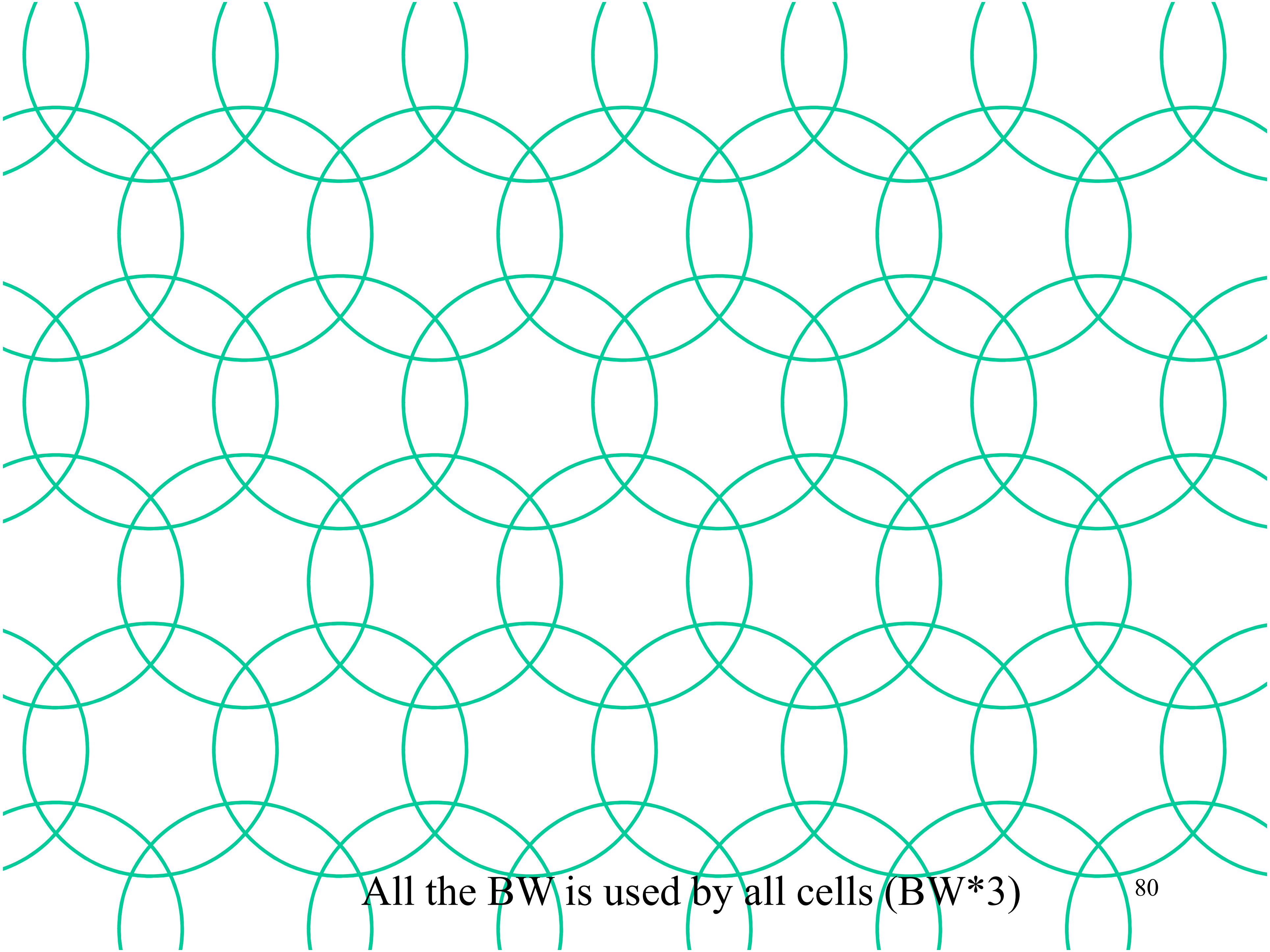
from specification of IEEE 802.11

PDMA (Packet Division Multiple Access)

- paradigm to use packet-wise fully dynamic communication slot allocation mechamism (CSMA/CA) for inter cellular coordination
  - all BW is shared by all cells
    - dynamic BW utilization between cells possible
    - cell design not necessary
- some overhead by CSMA/CA



FDM, TDM, CDM, etc. with 3 separate channels



All the BW is used by all cells (BW*3)

Properties of PDMA

- smooth handover between cells easy
  - make-before-break with same frequency
    - original motivation of study
- coordination by CSMA/CA between cells
  - and between operators, fully automatically
    - all the operators can share all the BW

Efficiency of PDMA (CSMA/CA) within a Cell

- same timing as 802.11a, cell radius 500m, datalink header 34B, packet length 1500B, bitrate 100Mbps
  - packet duration: 122.7μs
  - average gap between packets: 128μs
  - effective spped 47Mbps, about 50% of efficiency

Efficiency of PDMA between Cells

- if amount of traffic is mostly same for all cells
  - not very different from other technologies
- if traffic concentrate in a single cell
  - the cell can automatically enjoy all the available BW

Emergency Communication and QoS Guarantee

- 802.11 protocol suites allow packets with shorter waiting period
  - certain prioritization is possible
  - even with high volume of usual packets
    - certain BW is reserved for prioritized packets
      - may be used for control packets (beacon, registration)
      - may be used for emergency communication
      - may be used for QoS gurarantee

PDMA and Policy on Radio Wave Allocation

- all the available BW can be shared by all operators and end users
  - can maximally utilize limited BW resource
  - no coordination between operators necessary
  - no allocation of BW to each operators necessary
    - no frequency auction necessary
- flat rate for BE communication
  - usage based charge for QoS guaranteed communication

Experiment with PDMA

- jointly with NICT
  - 108Mbps (802.11a, 2ch)
  - mobile IP
  - smooth handover