

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

Evaluation with Zoom (draft)

- questions/comments should be asked/made by verbal interruption (or, by **public** chat)
 - raising hand by zoom is hard to be noticed unless dedicated chair is assigned
 - don't hesitate to interrupt my talk
- name/ID and points are declared and given through chat
 - use **private chat**, if you don't want your ID publicly viewed

Advanced Lecture on Internet Infrastructure

3. Datalink Layer

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Future of the Internet

- primarily by optical fiber
 - overwhelmingly high speed ($\gg 1$ Tbps/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

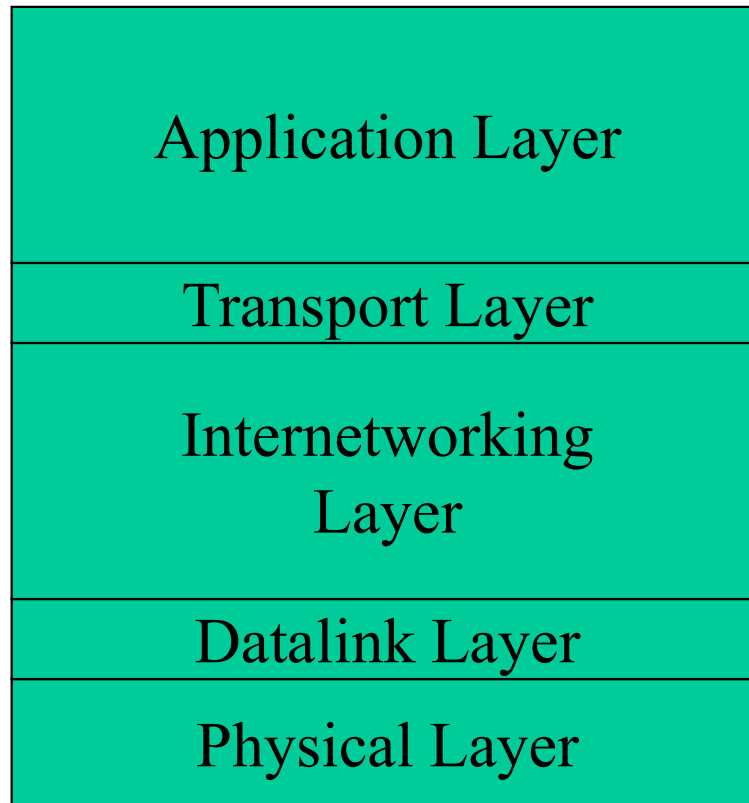
- various datalink layer has been specified for various requirements
 - reliability, guarantee quality of service, etc.
- ethernet is extensively used by the Internet
- phone companies loves ATM
- why ATM disappeared?

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

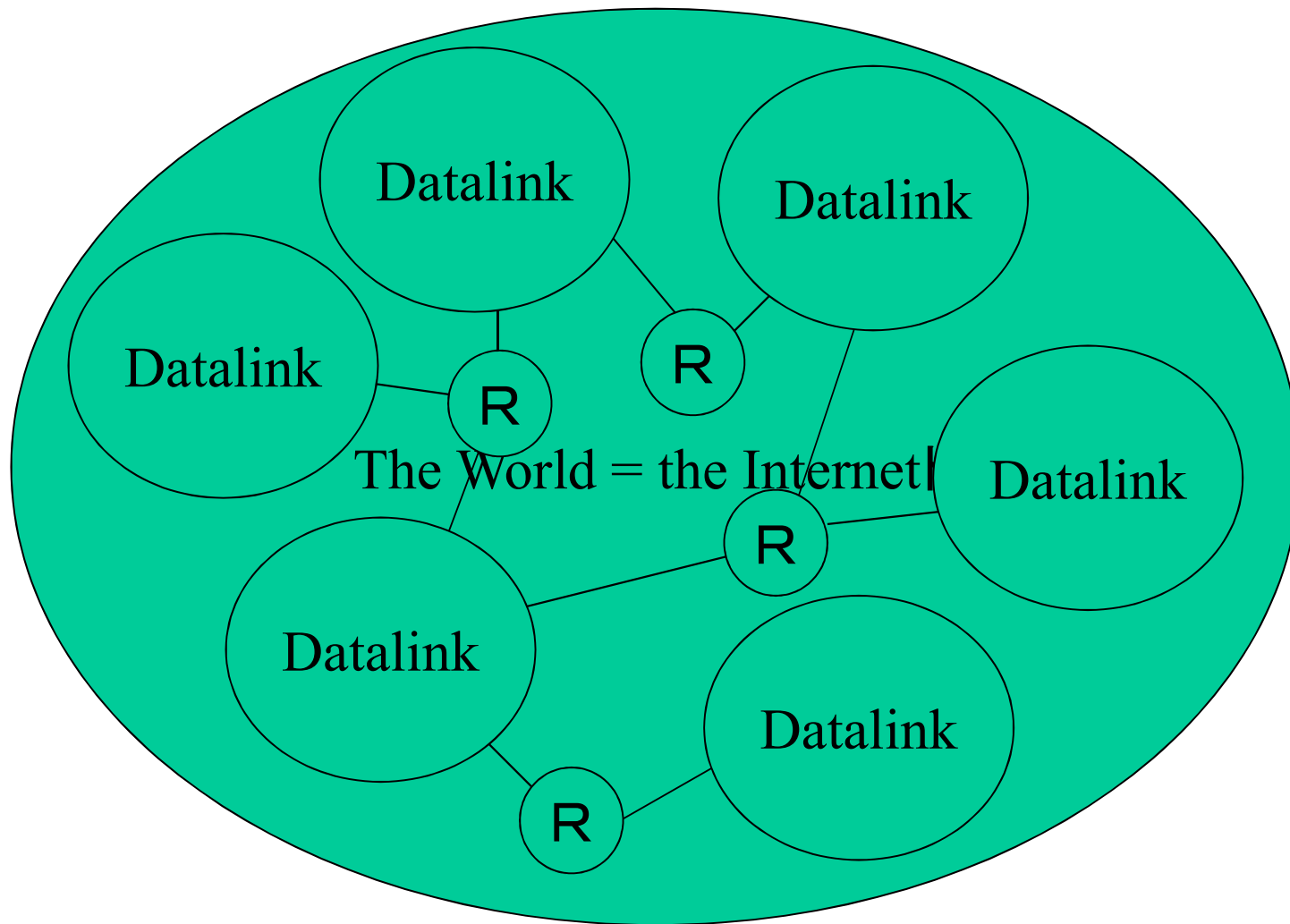
- Physical and Application Layers are Essential
- The Internetworking Layer does as Much Things as Possible
- Datalink and Transport Layers should Avoid to do Thing



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



R : Router

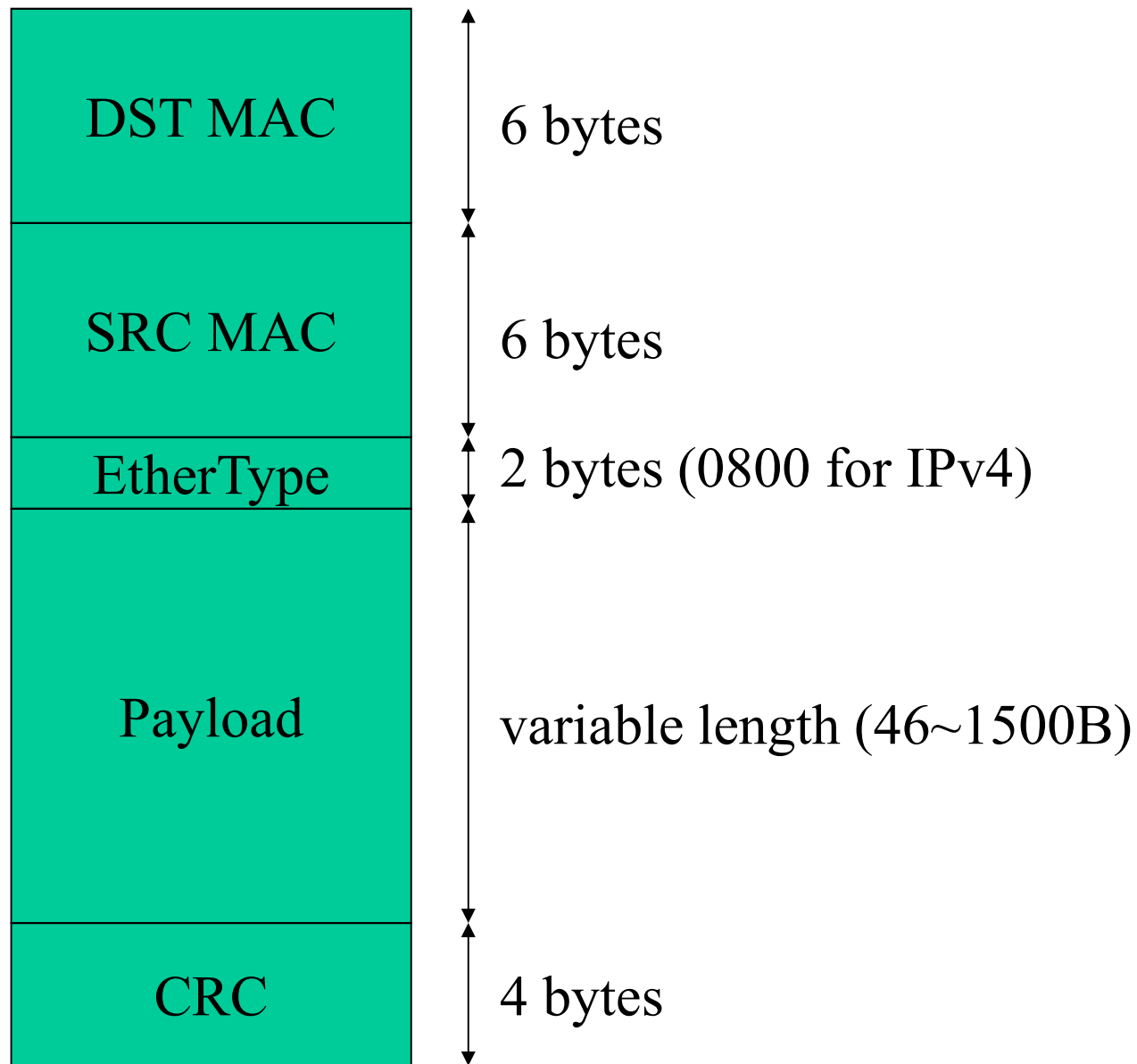
CATENET Model

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 Access/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 ($52\text{Mbps} \times 3$ 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 so¹⁸

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

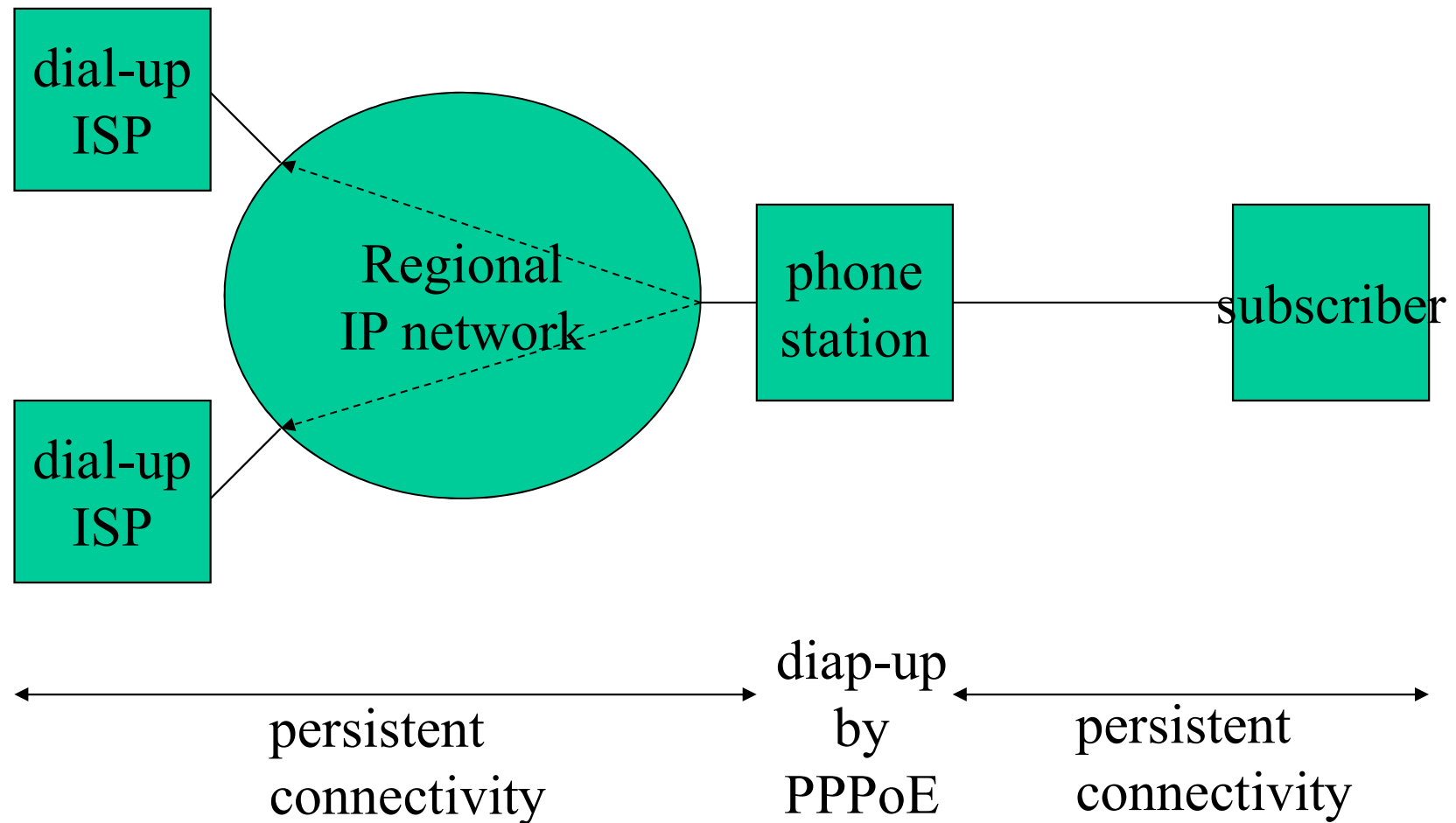
- escape representation to make 1 byte 2 byte is waste of bandwidth of, in average, 1%, in the worst case 100%
 - QoS guarantee is practically impossible
- if used with SONET/SDH, some packets results in consecutive 0s with probability of 1/127
 - detected as link failure

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?

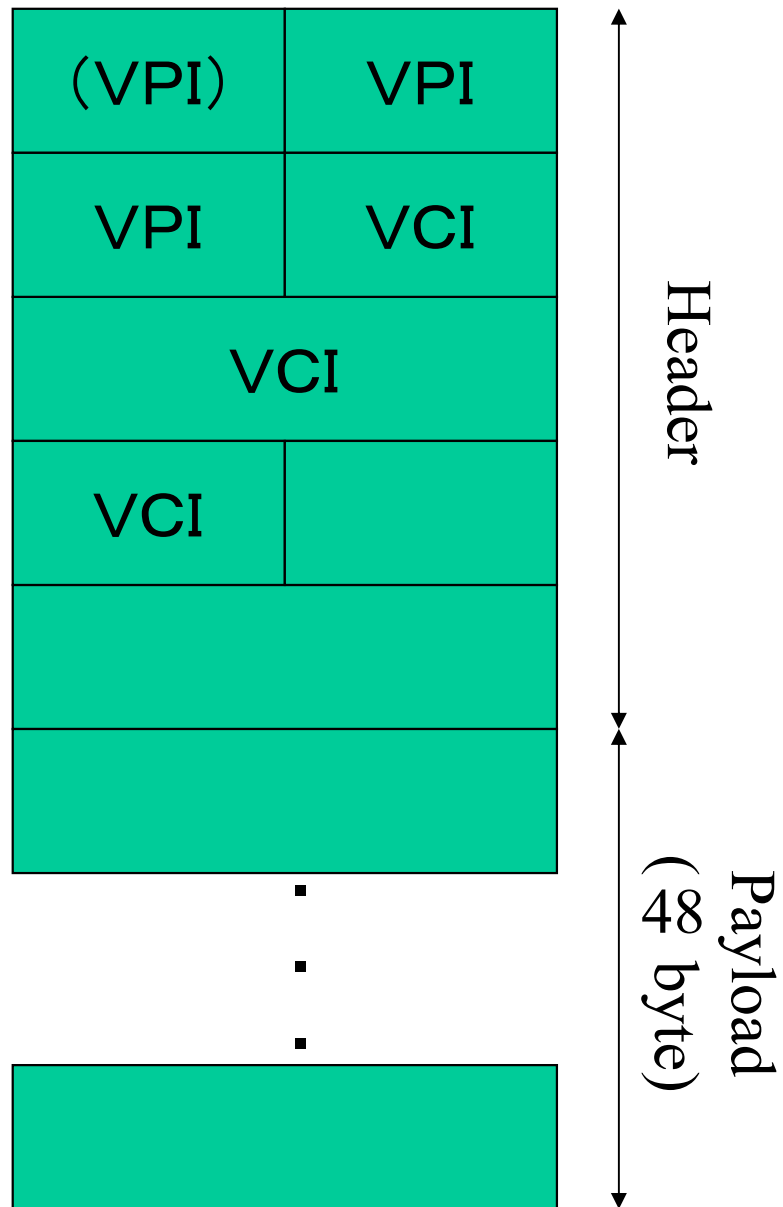
- Any ISP is almost equally OK, as long as connected to the Internet
- have multiple internet connections?
 - if flat rate, waste of money
- may want to connect to private IP network?
 - VPN (IP over IP) is enough
- having “call” denies persistent connection
 - dial-up, though over not phone but Ethernet



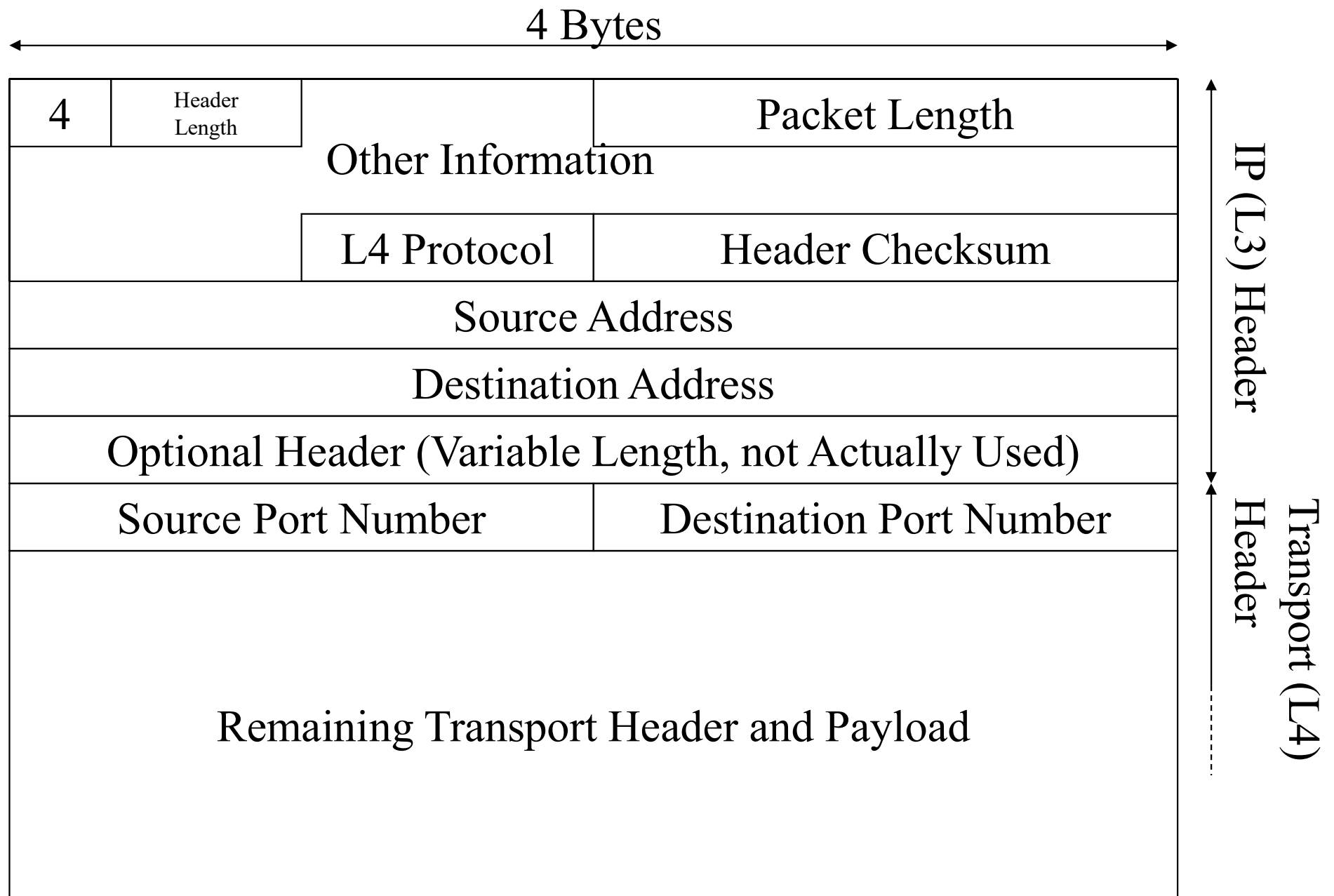
loss of persistent connectivity with FLETS ADSL²⁴

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



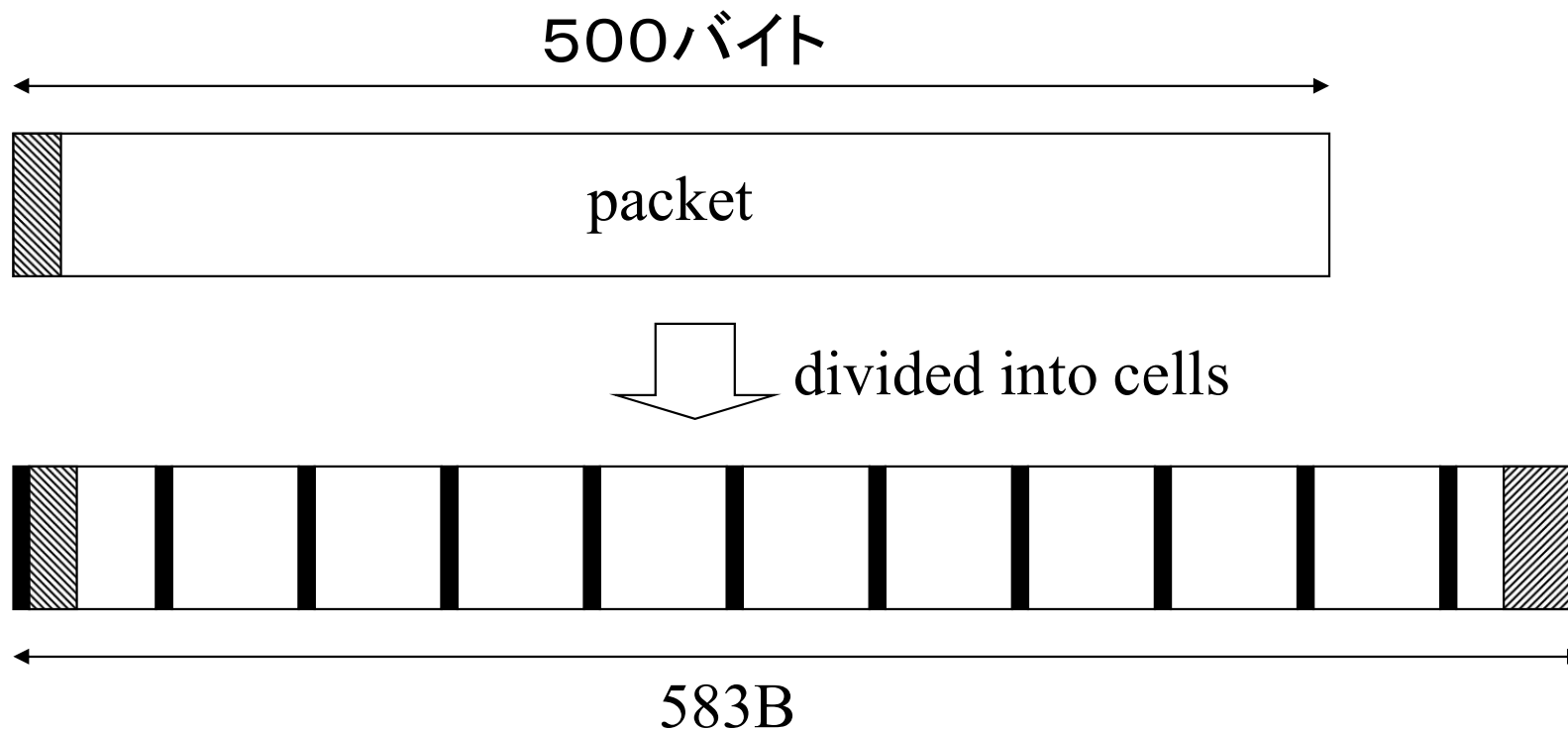
Format of IPv4 Packets

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 $\sim 15\%$
- cell based routing is about 10 times more slower than packet based routing
 - as average packet length is $\sim 500\text{B}$
- no properly working equipments
 - and is expensive
- QoS guarantee, if any, is not meaningful

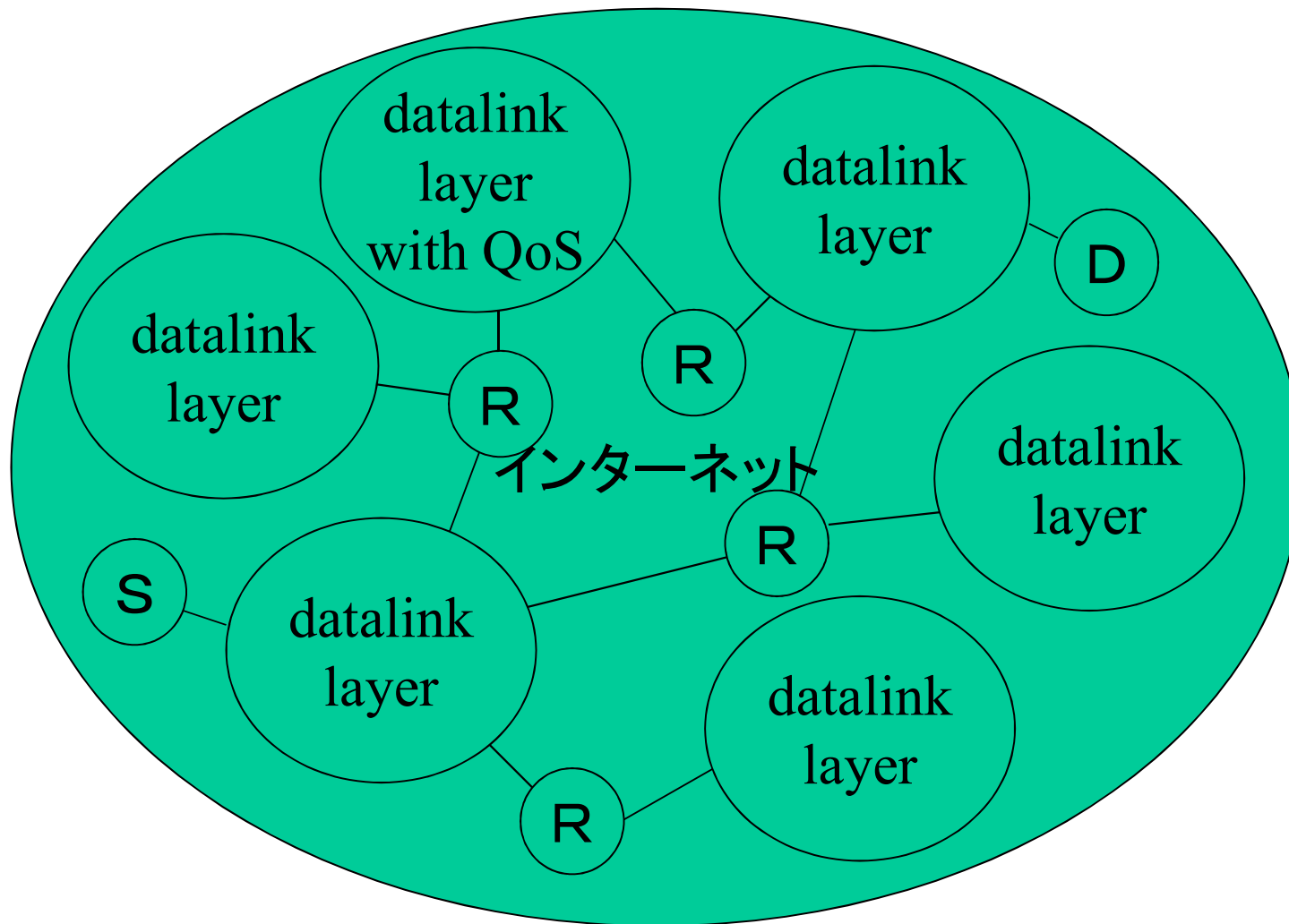


 : packet header (20B)

 : cell header (5B*11)

 : padding (28B)

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



R : Router **S** : Sender **R** : Receiver

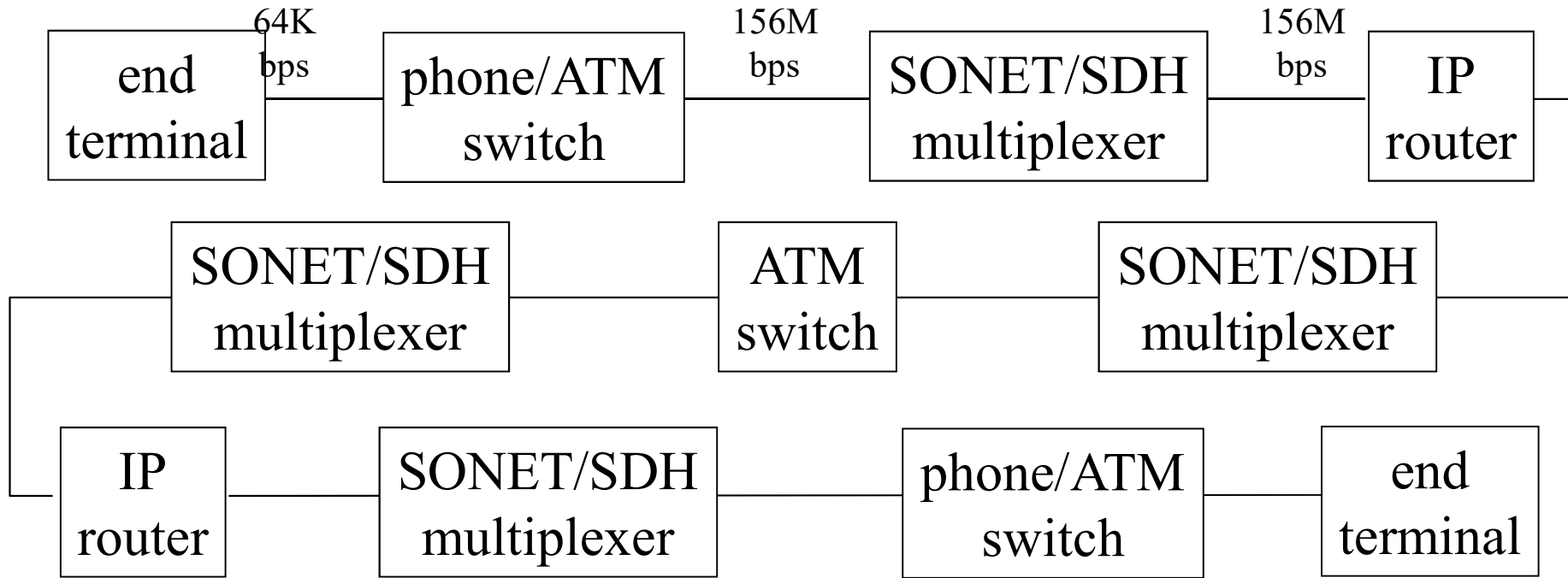
QoS Guarantee and the Internet

Problems of X.25/ATM

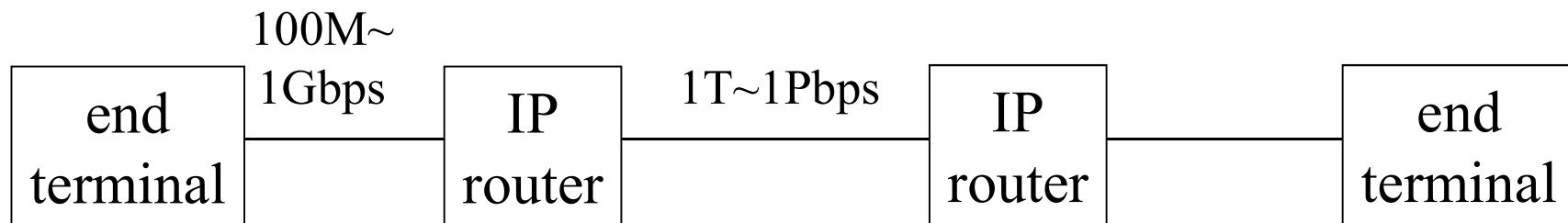
- X.25/ATM maintains each communication
 - cell/packet header identify communication
 - router/switch maintain each communication
 - connection oriented
- IP do not maintain each communication
 - IP header identify destinations
 - router/switch maintain how to reach destinations
 - processing of each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



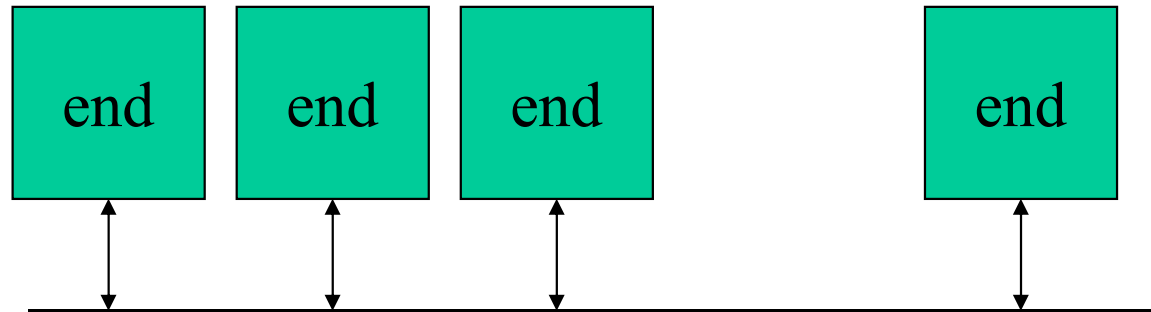
b) the Internet as the infrastructure

Backbone Datalink Layer in the Internet Era (1)

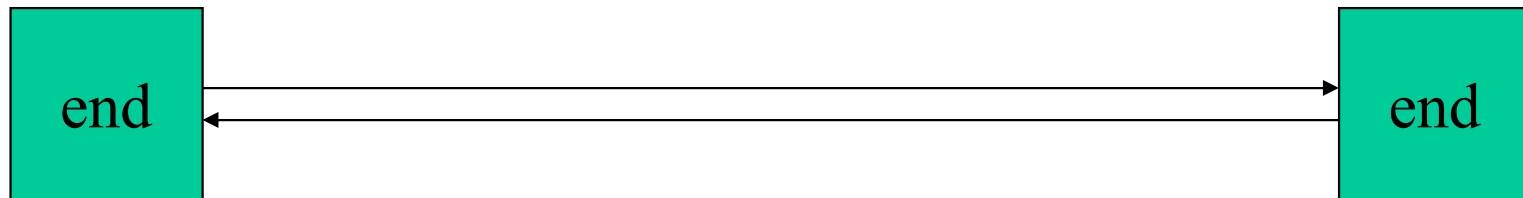
- QoS guarantee by IP layer
 - no QoS guarantee by datalink layer necessary
- Multicast by IP layer
 - no multicast by datalink layer necessary
- tera-bit transmission by WDM or massive parallelism
 - 10~40Gbps without parallelism is fine
- OAM (operation & management) by IP layer
 - no OAM by datalink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

Backbone Datalink Layer in the Internet Era (1)

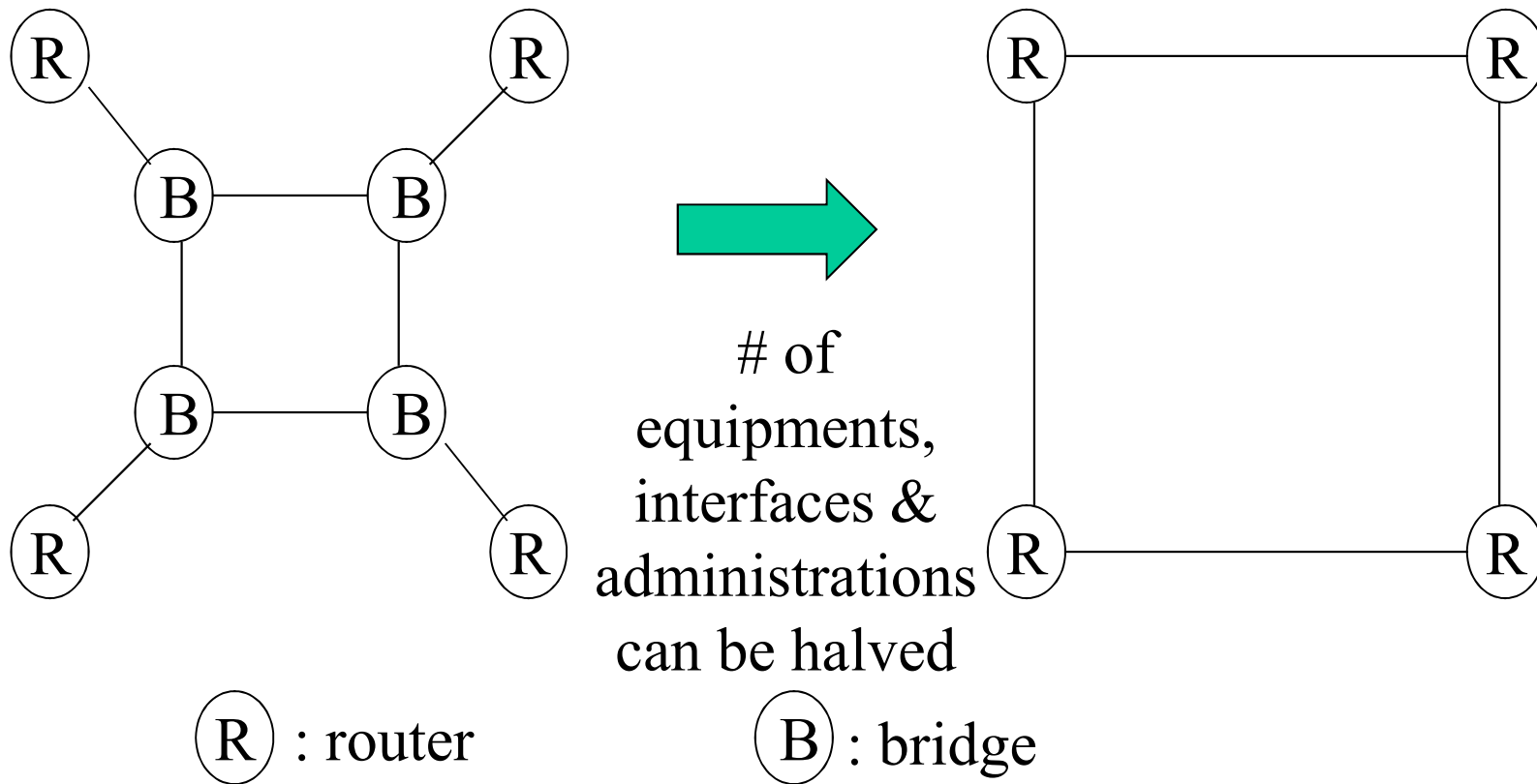
- as L2 switches are as expensive as L3 routers
 - point to point protocols is enough
 - datalink layer with more terminals needs extra complex function for QoS guarantee and multicast
 - QoS guarantee and multicast can be taken care of by IP layer if datalink layer is point to point



multi access connection



point to point connection



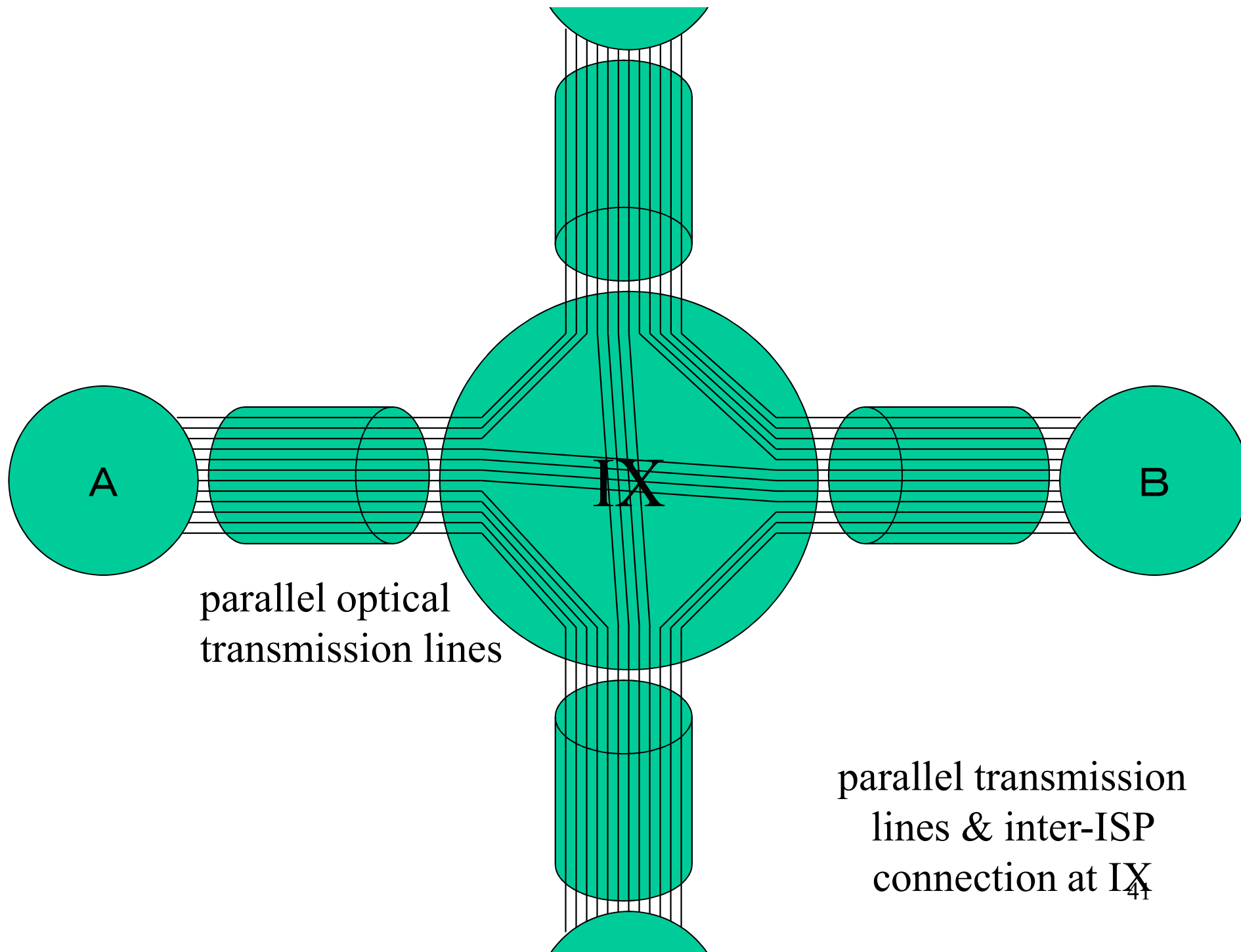
removing bridges

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



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 header

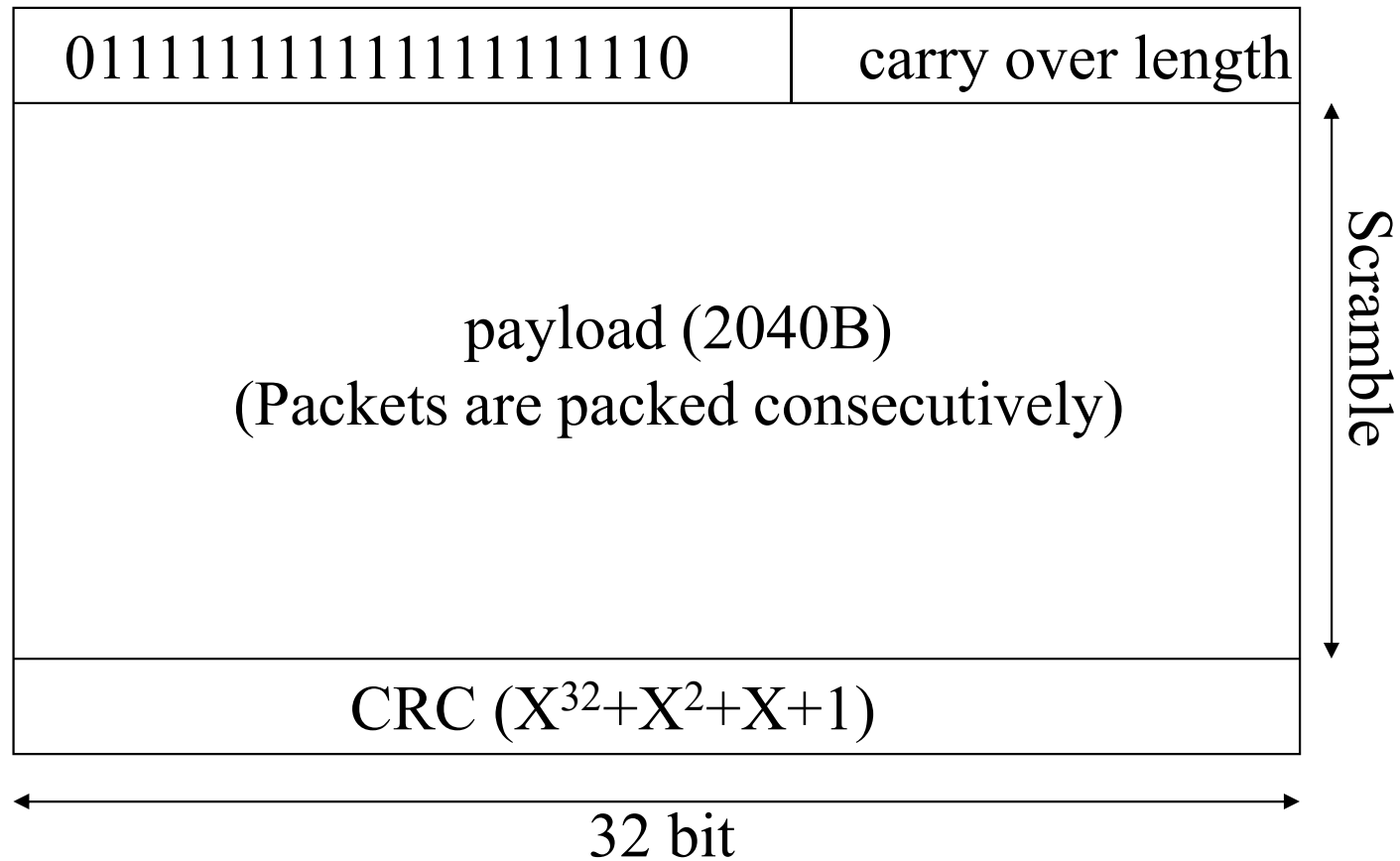
Features of IOG

- 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

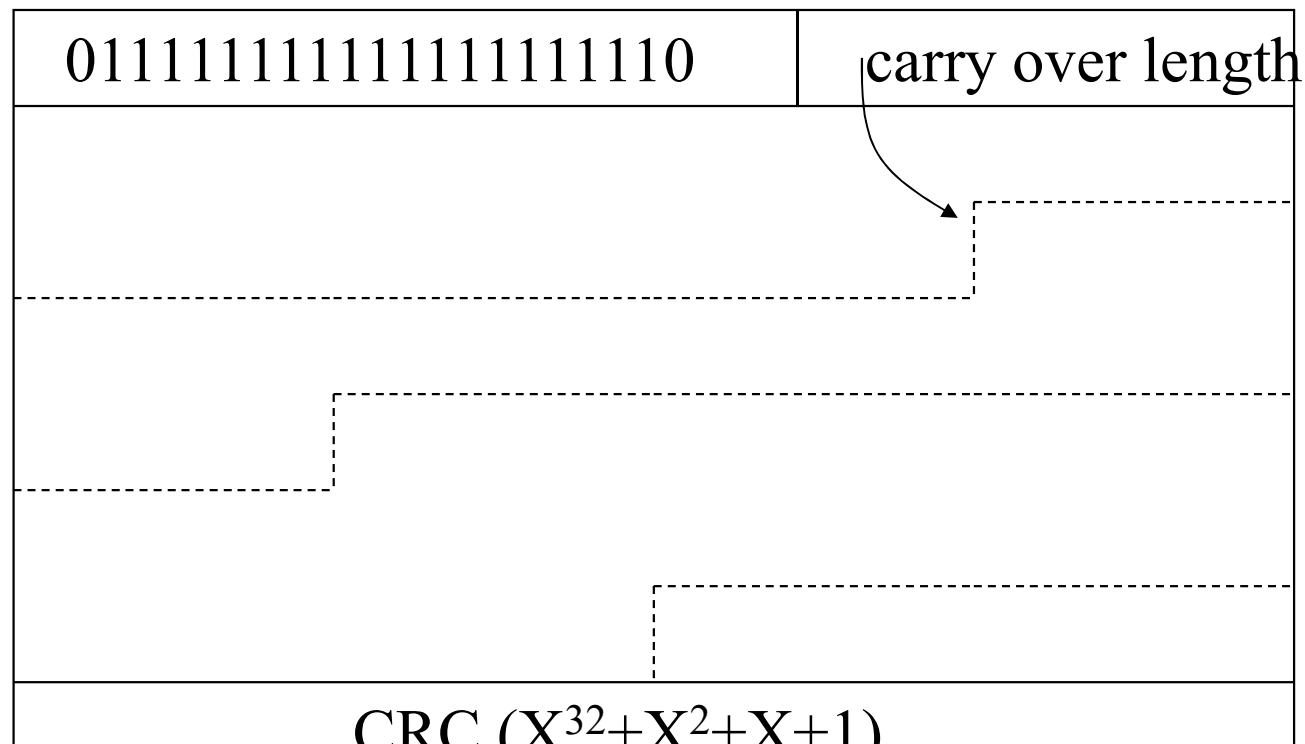
- $X^{32}+X^2+X+1$ is chosen have factor of 21st degree primitive polynomial
 - hamming distance of 3 < 2Mbit data
 - another factor of $X+1$
 - hamming distance is 4 (SEC, DED)
- 32 or 64 parallel computation is simple
 - # of fan in of XOR gates is small
 - fan in of 5 for 32 parallel (18 for 64 parallel)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

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

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

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
- maximum 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 necessary for wireless LAN

Ethernet and CSMA/CD

(Carrier Sense Multiple Access/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 unreliable₅
 - important difference to Ethernet

Immediate access when medium is free $\geq$ DIFS

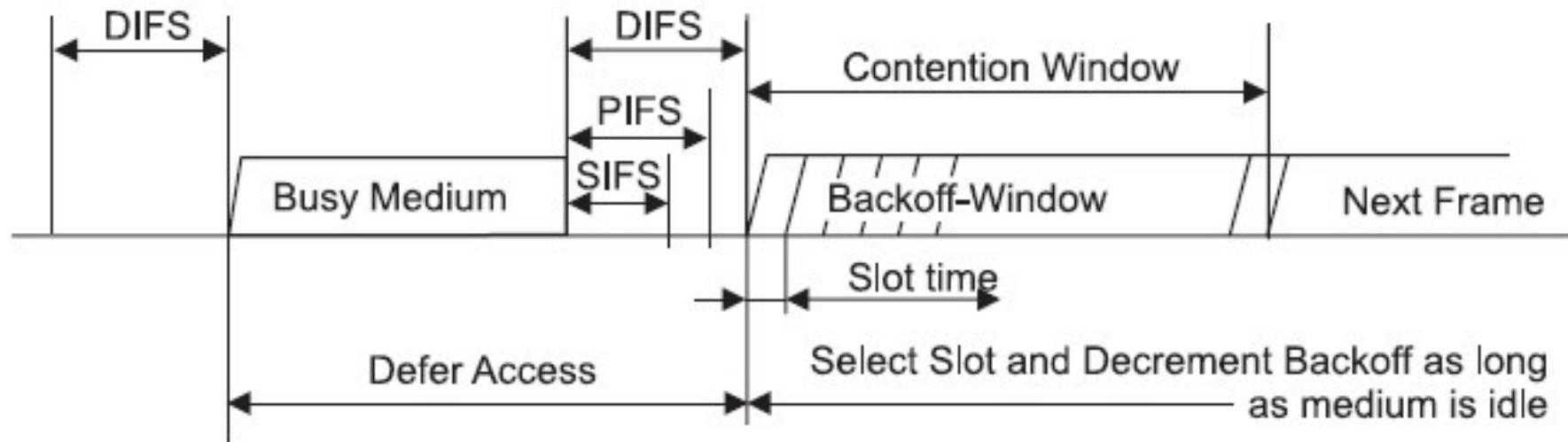


Figure 49—Some IFS relationships

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
 - ?

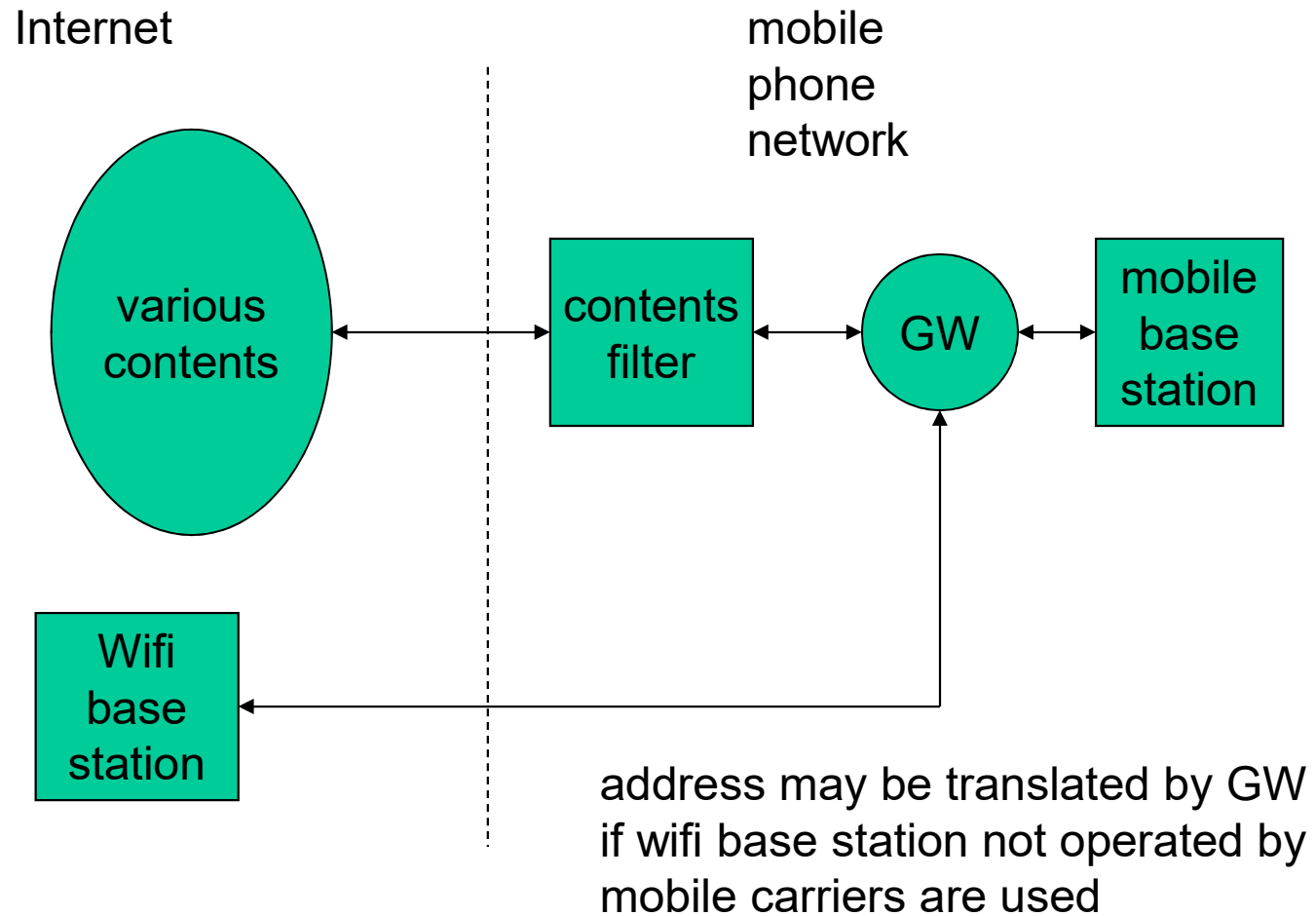
Technologies of WAN and LAN

- 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

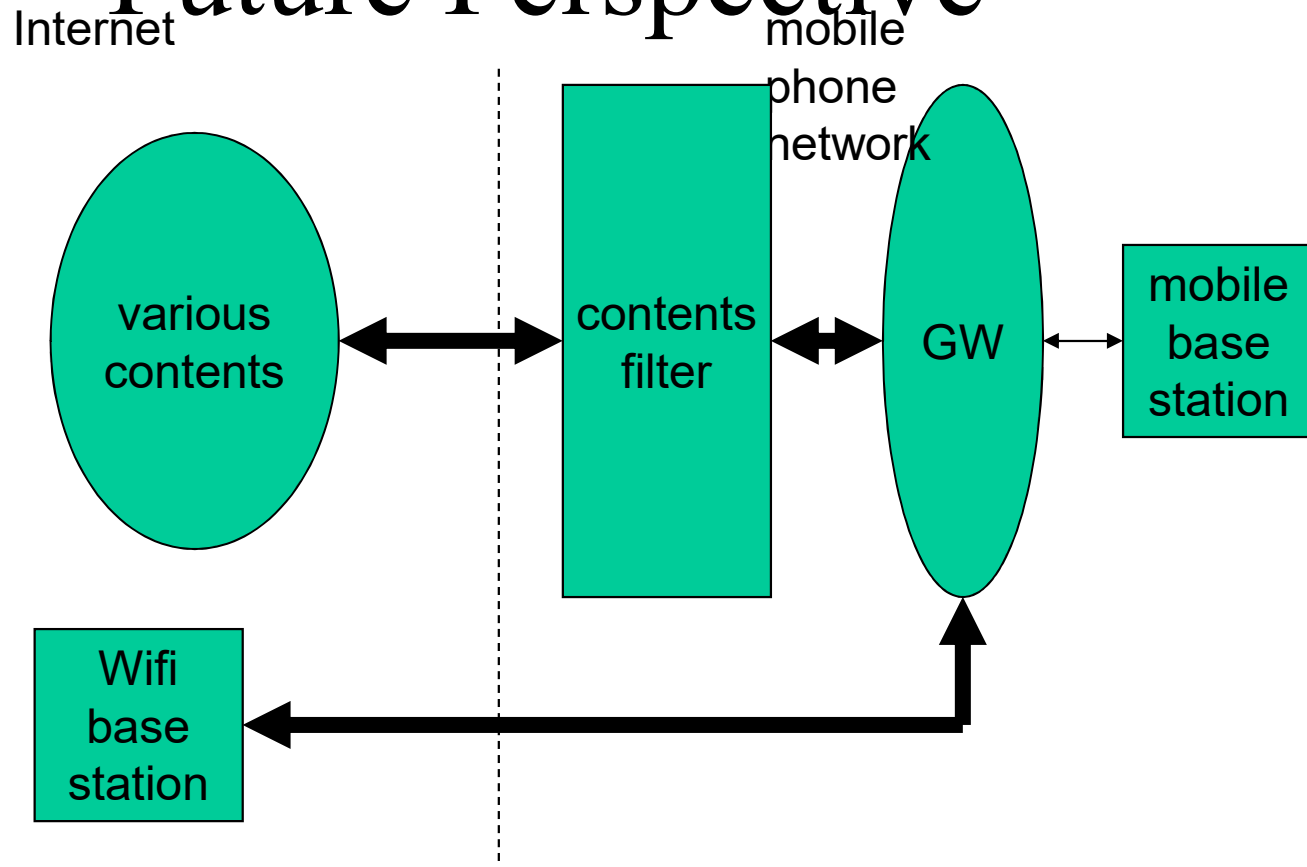
- not enough capacity
- mobile phone network is expensive
 - want to use wifi as bypass
- does wifi complements 3/4/5G?
 - complexity of phone network forever
- does wifi replace 3/4/5G?
 - room for cost reduction, simplification and better efficiency

Wifi as Complement of 3/4/5G

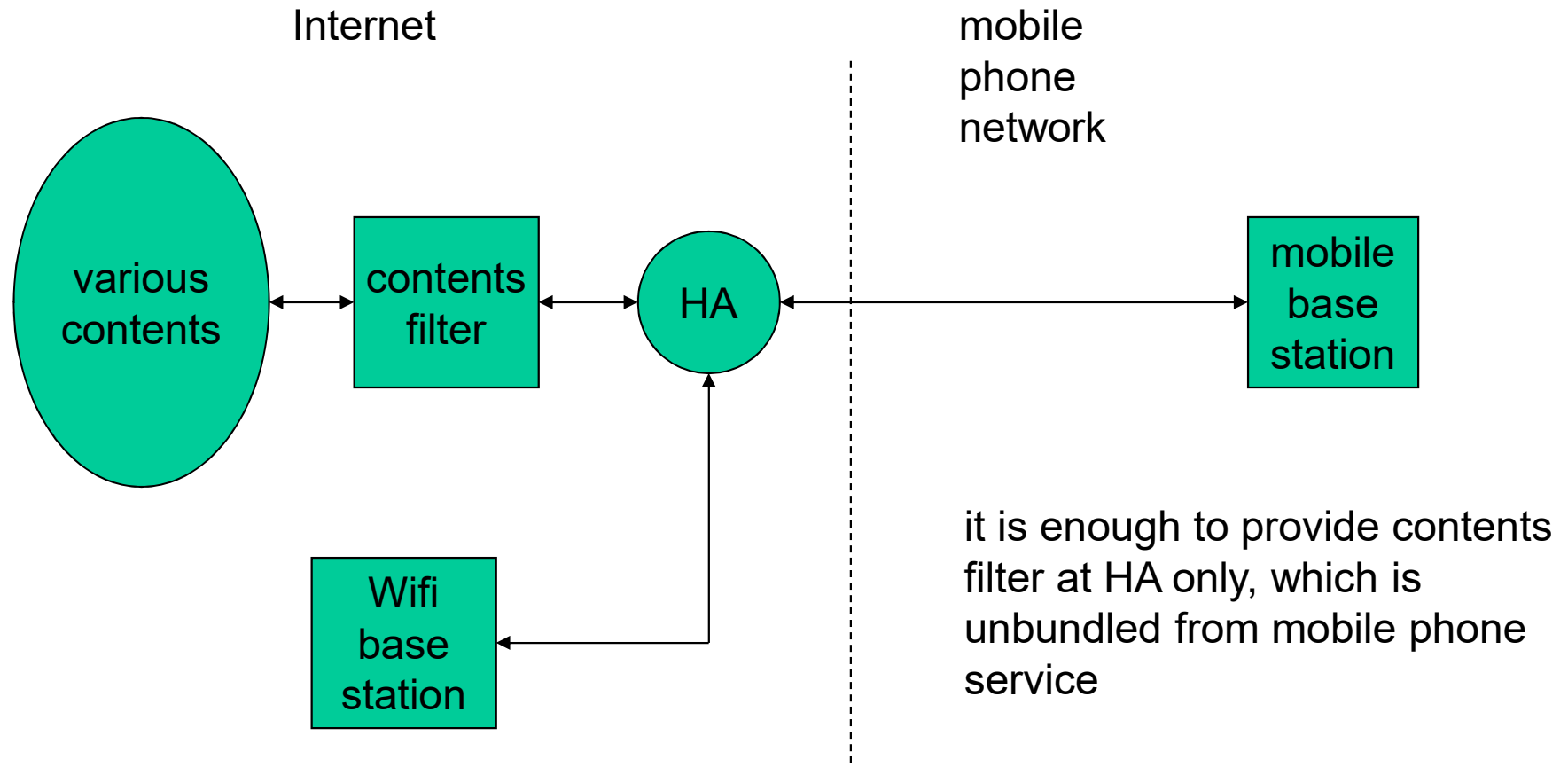


Wifi as Complement of 3/4/5G

Future Perspective

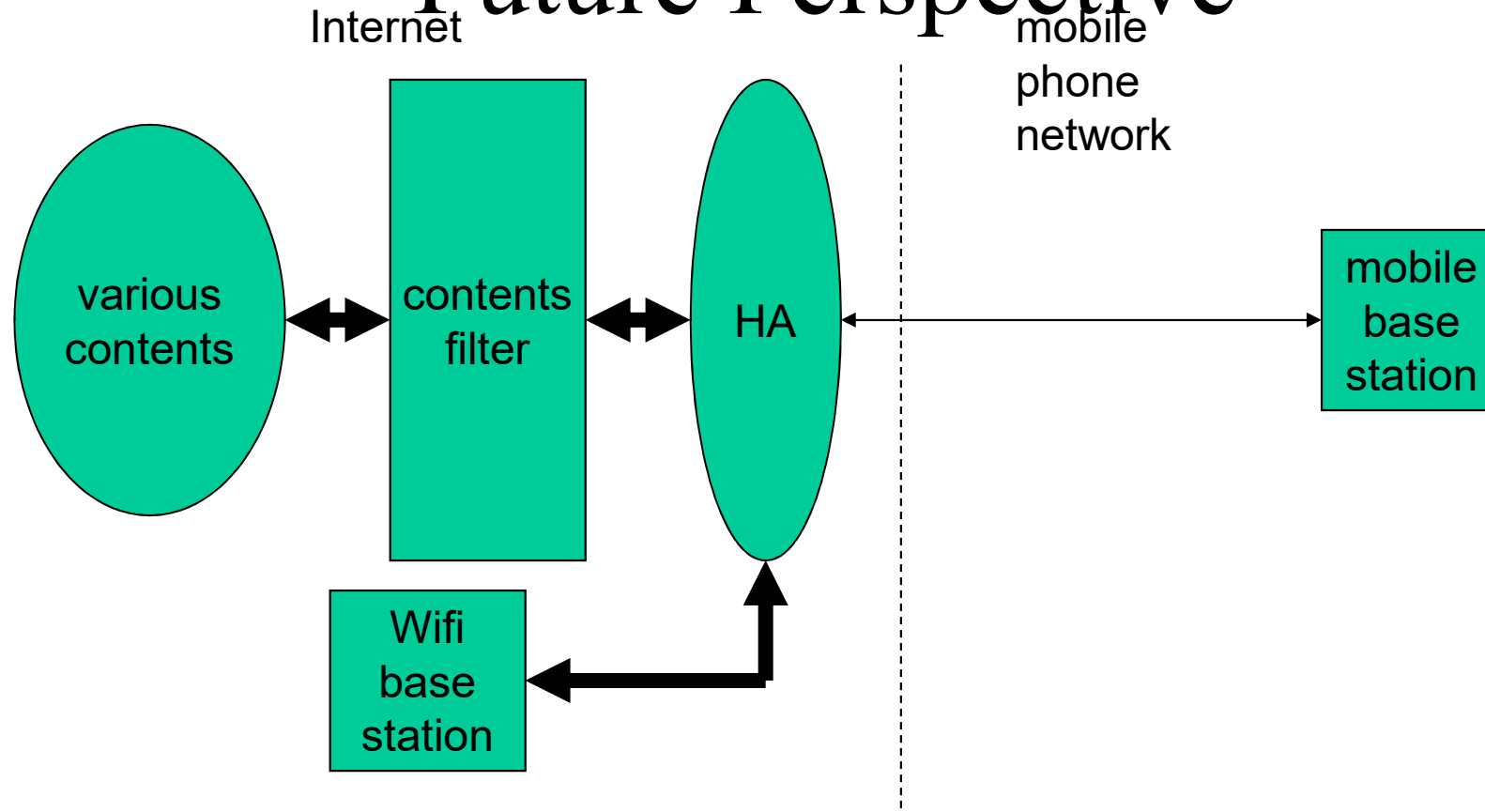


WiFi to Replace 3/4/5G



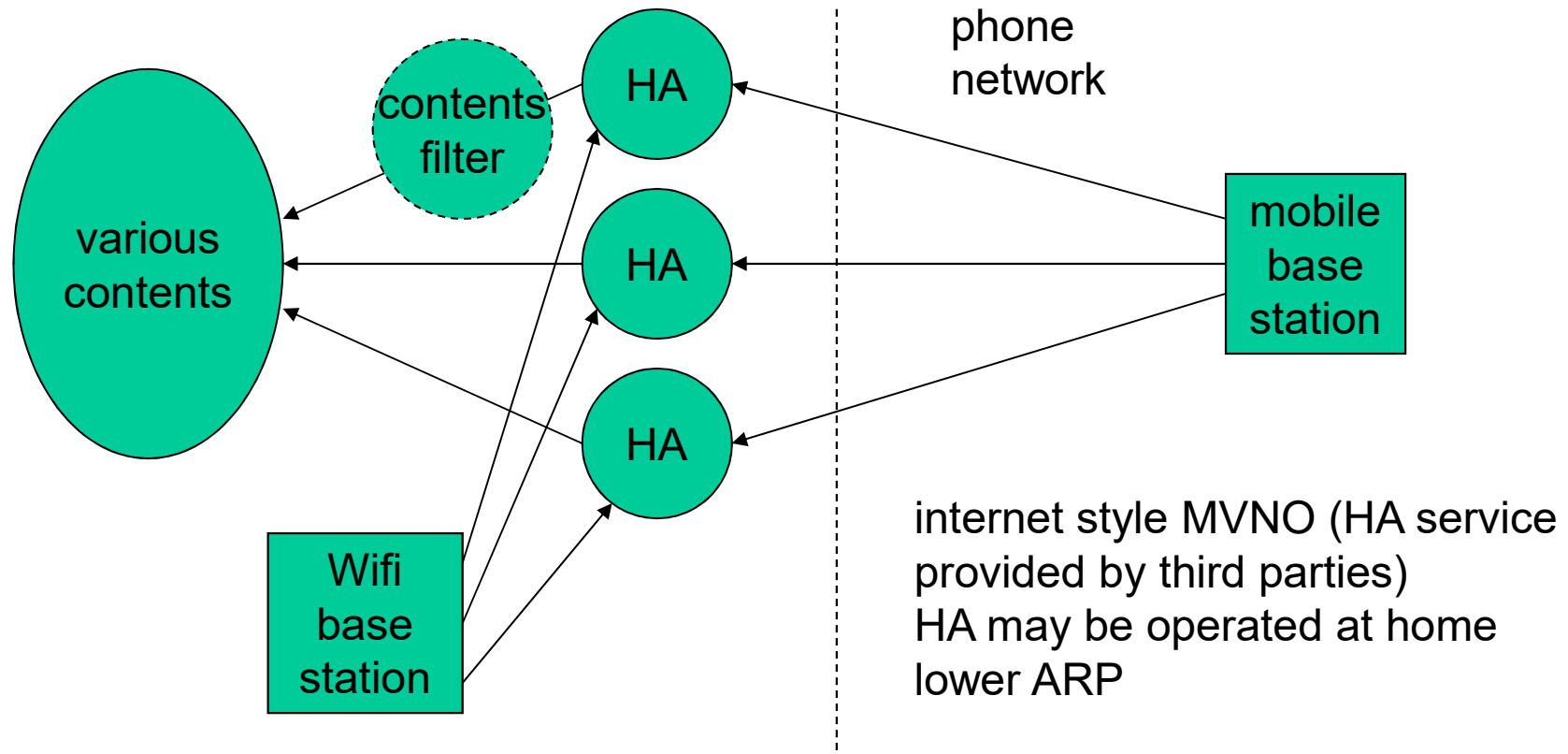
WiFi to Replace 3/4/5G

Future Perspective



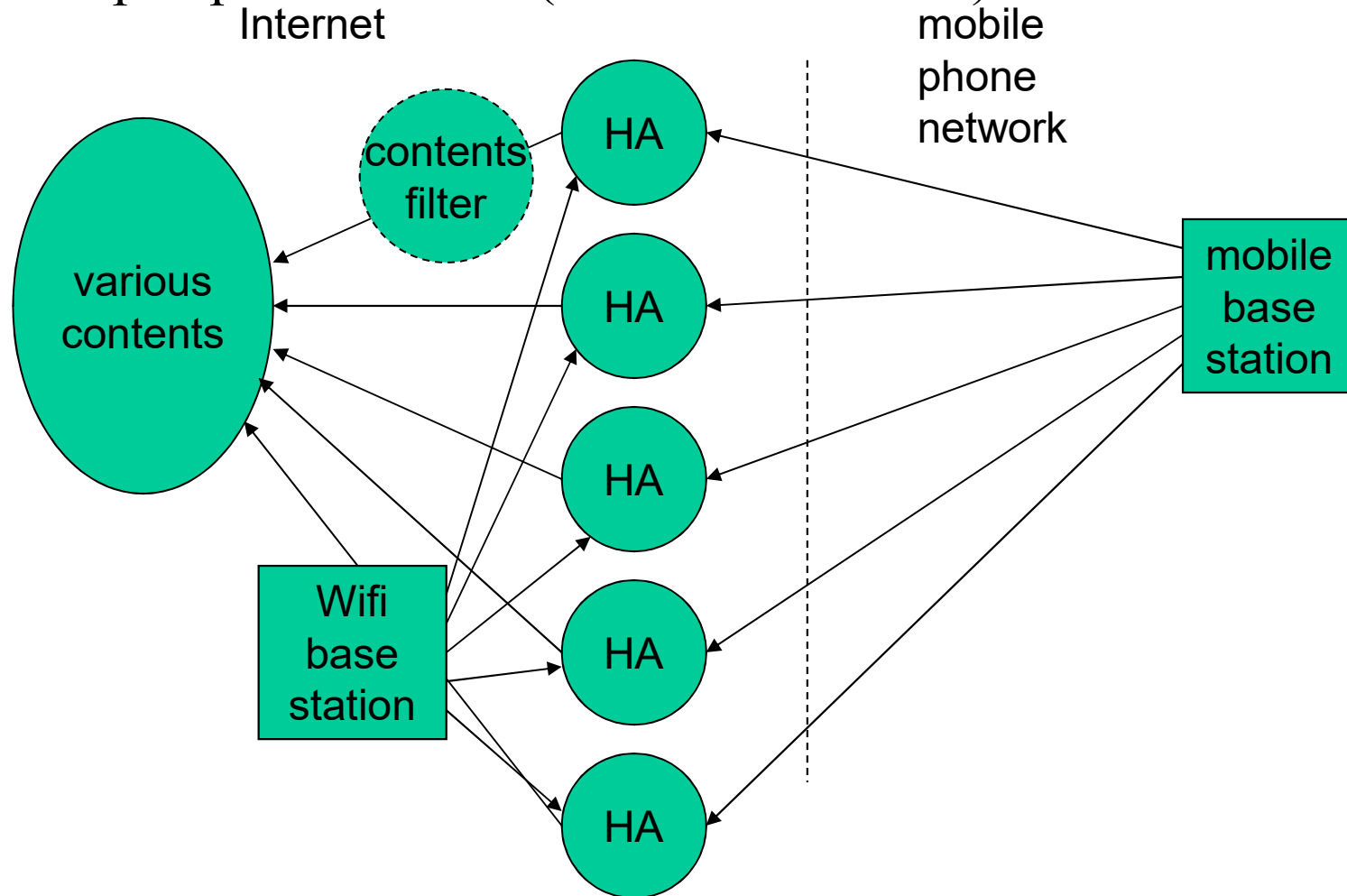
WiFi to Replace 3/4/5G

if HA (and content filter) service is unbundled



WiFi to Replace 3/4/5G

future perspective if HA (and content 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 $(\text{cell size})/(\text{moving speed})$
- mobile stations may not produce packet so often
 - may not enough for base stations locate mobile stations accurately 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

Immediate access when medium is free $\geq$ DIFS

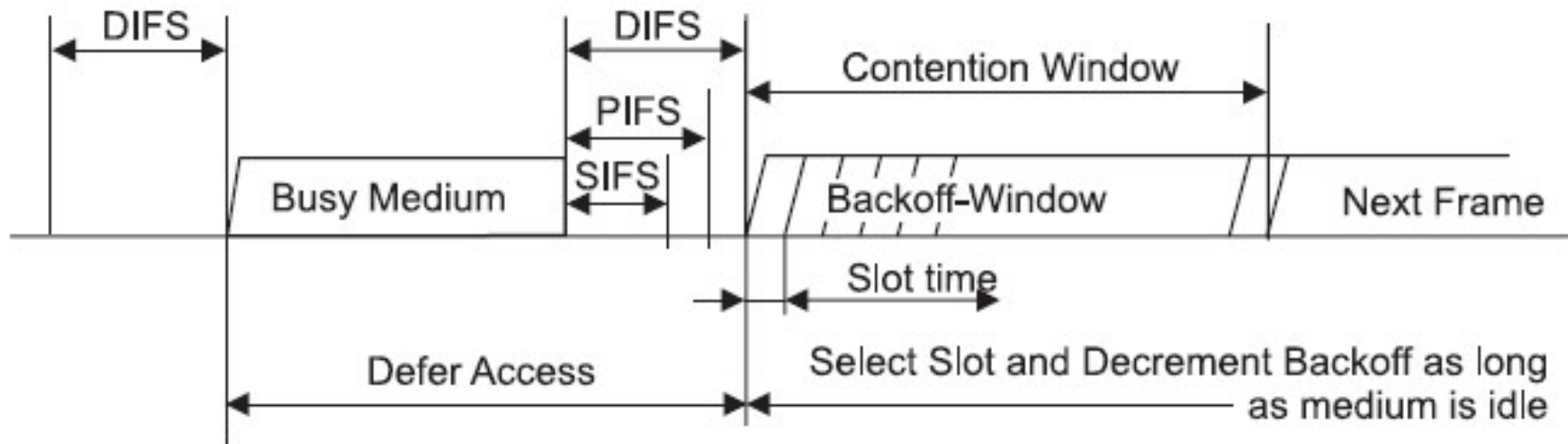
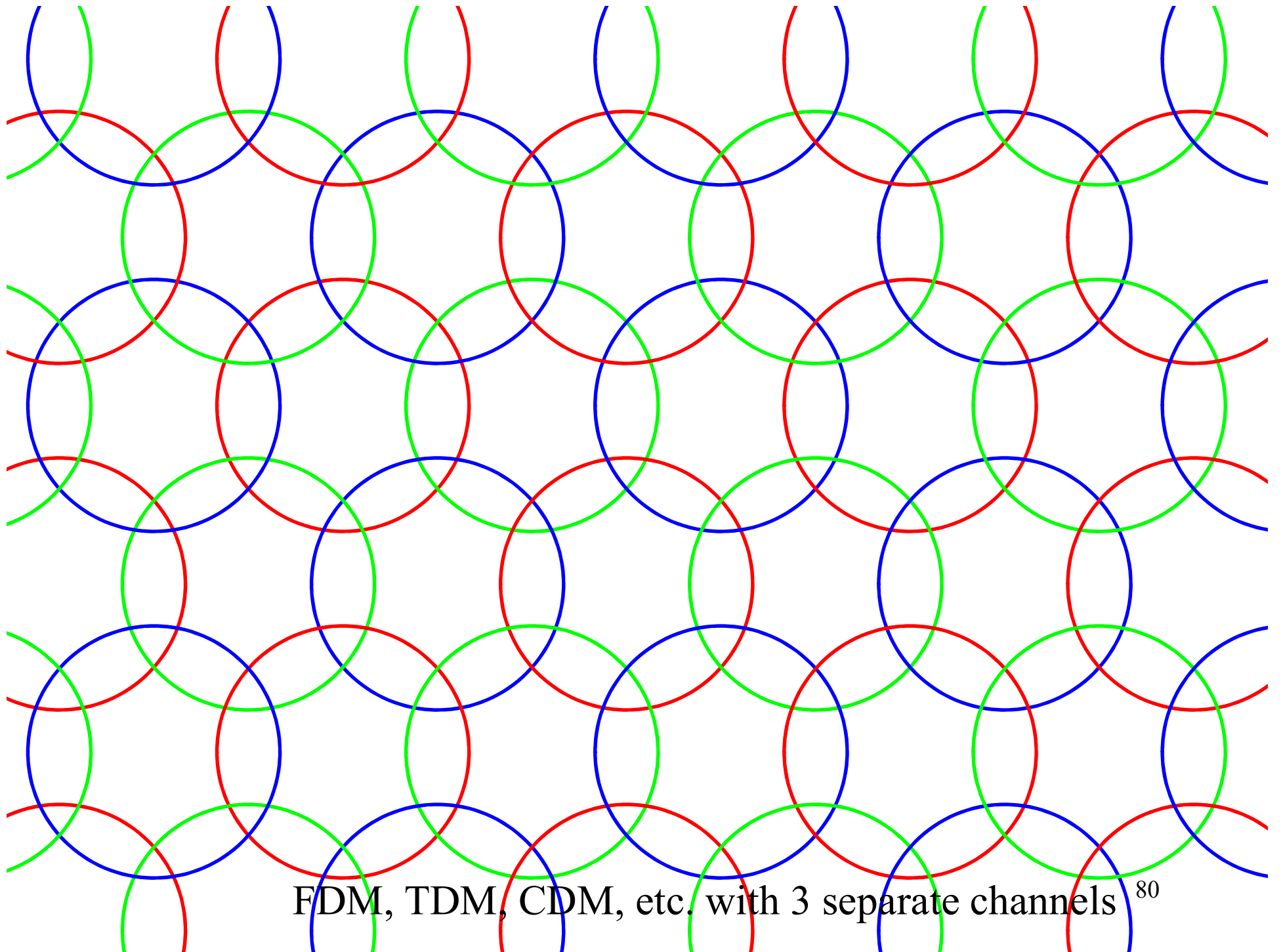


Figure 49—Some IFS relationships

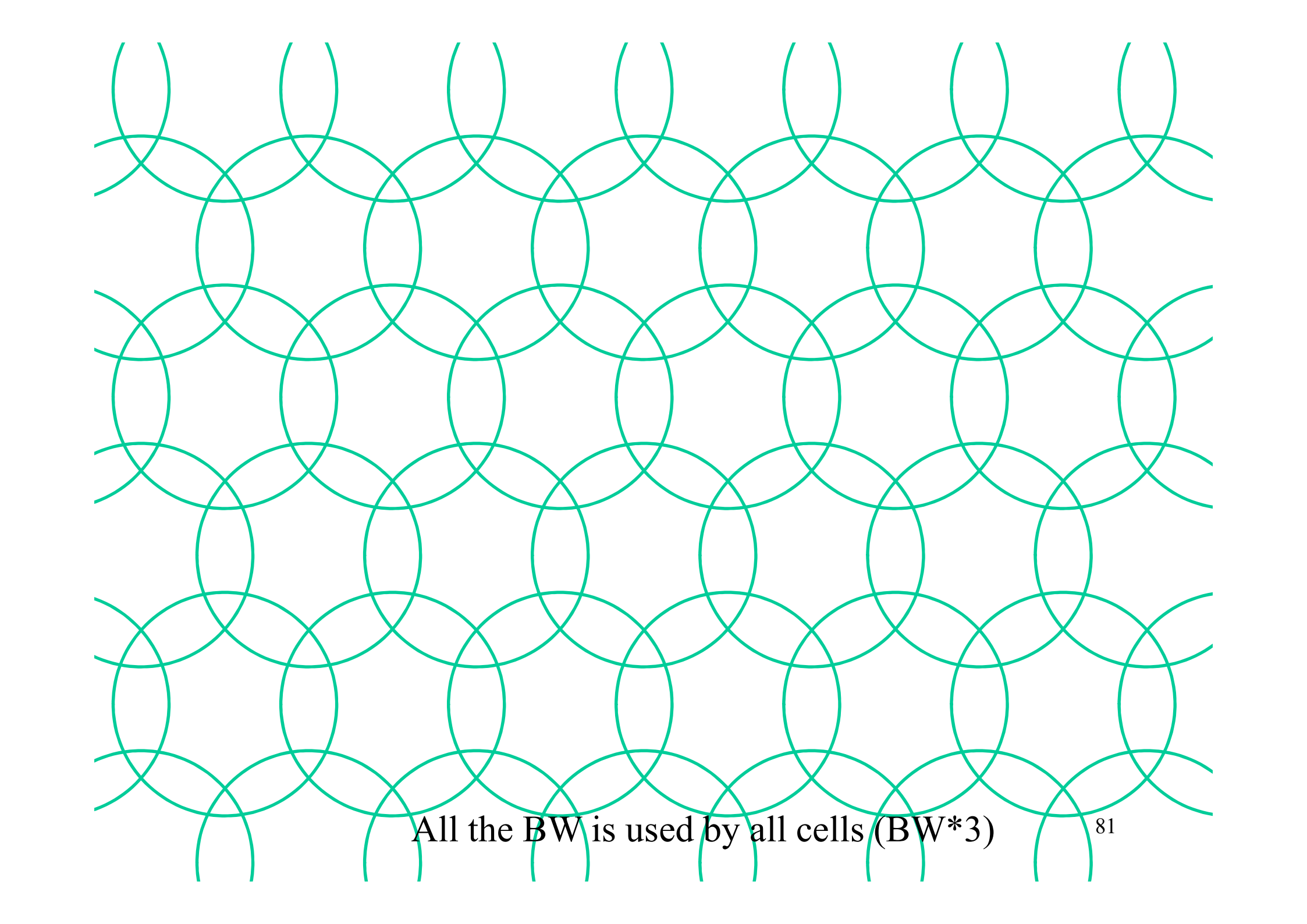
from specification of IEEE 802.11

PDMA (Packet Division Multiple Access)

- paradigm to use packet-wise fully dynamic communication slot allocation mechanism (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 channels⁸⁰



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: $122.7\mu\text{s}$
 - average gap between packets: $128\mu\text{s}$
 - effective speed 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 guarantee

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