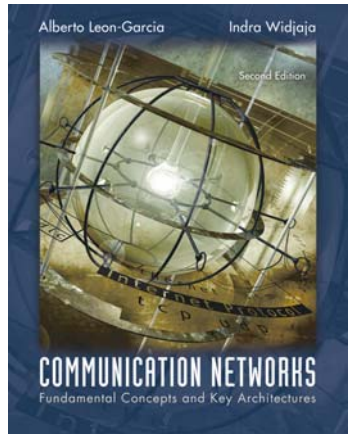
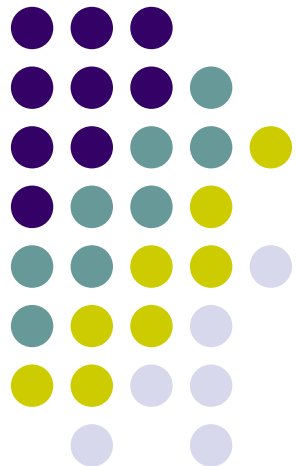
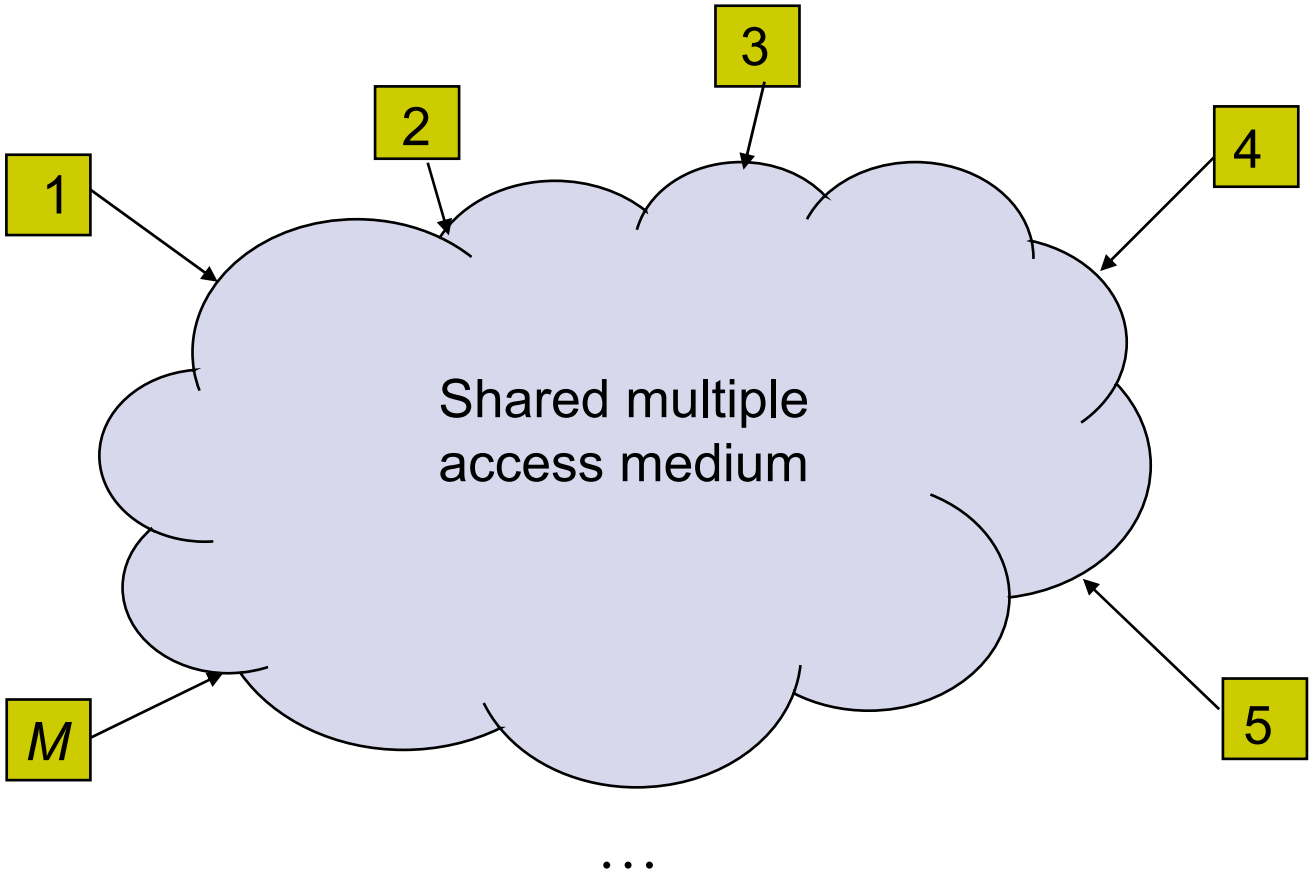
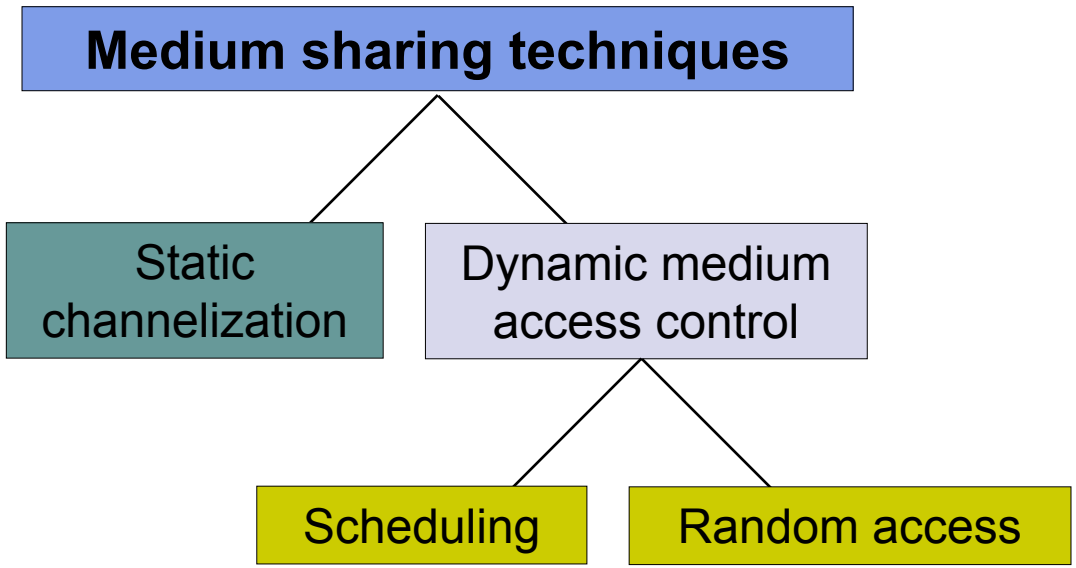
# Chapter 6
# Medium Access Control Protocols and Local Area Networks



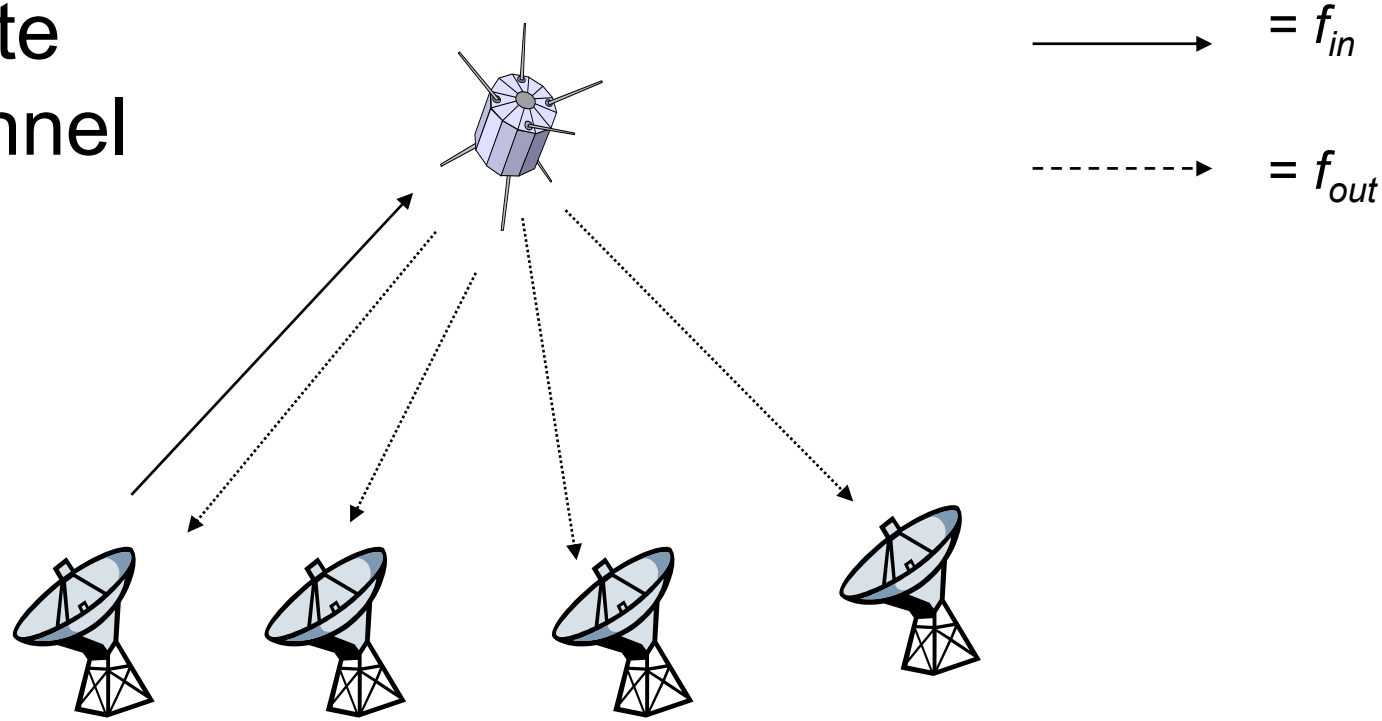

Chapter Figures

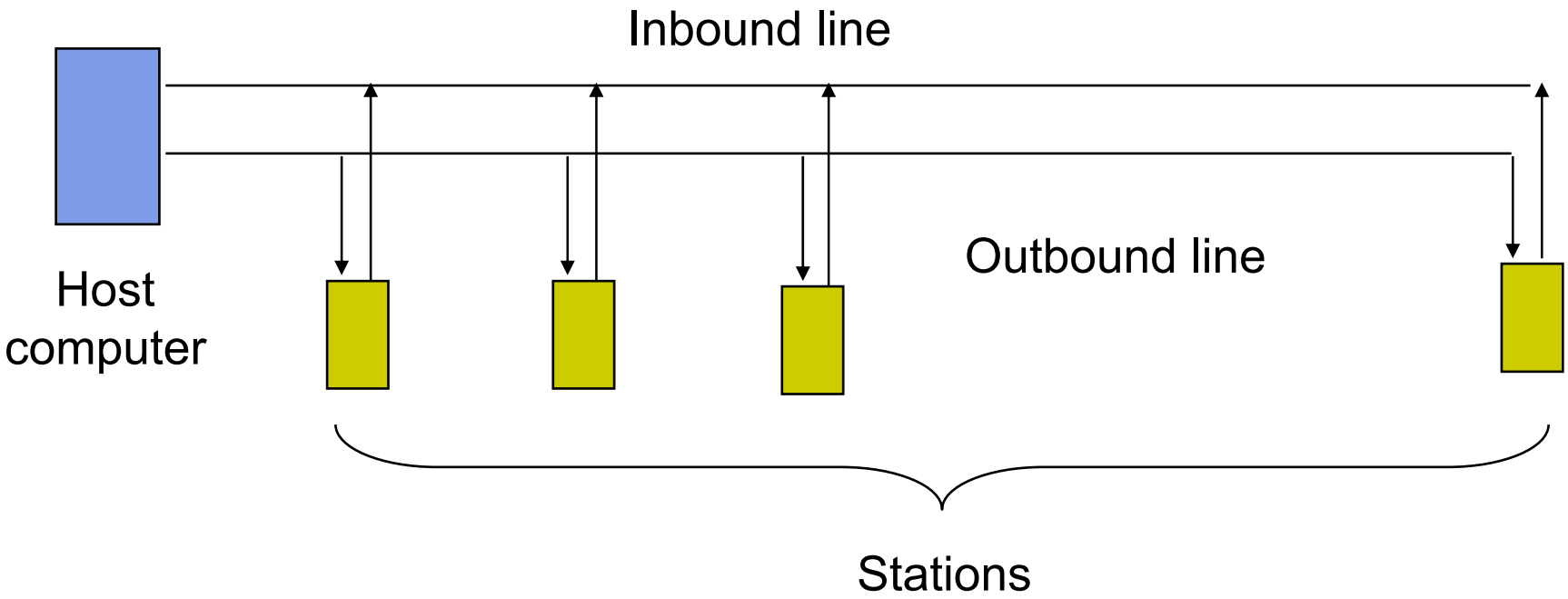


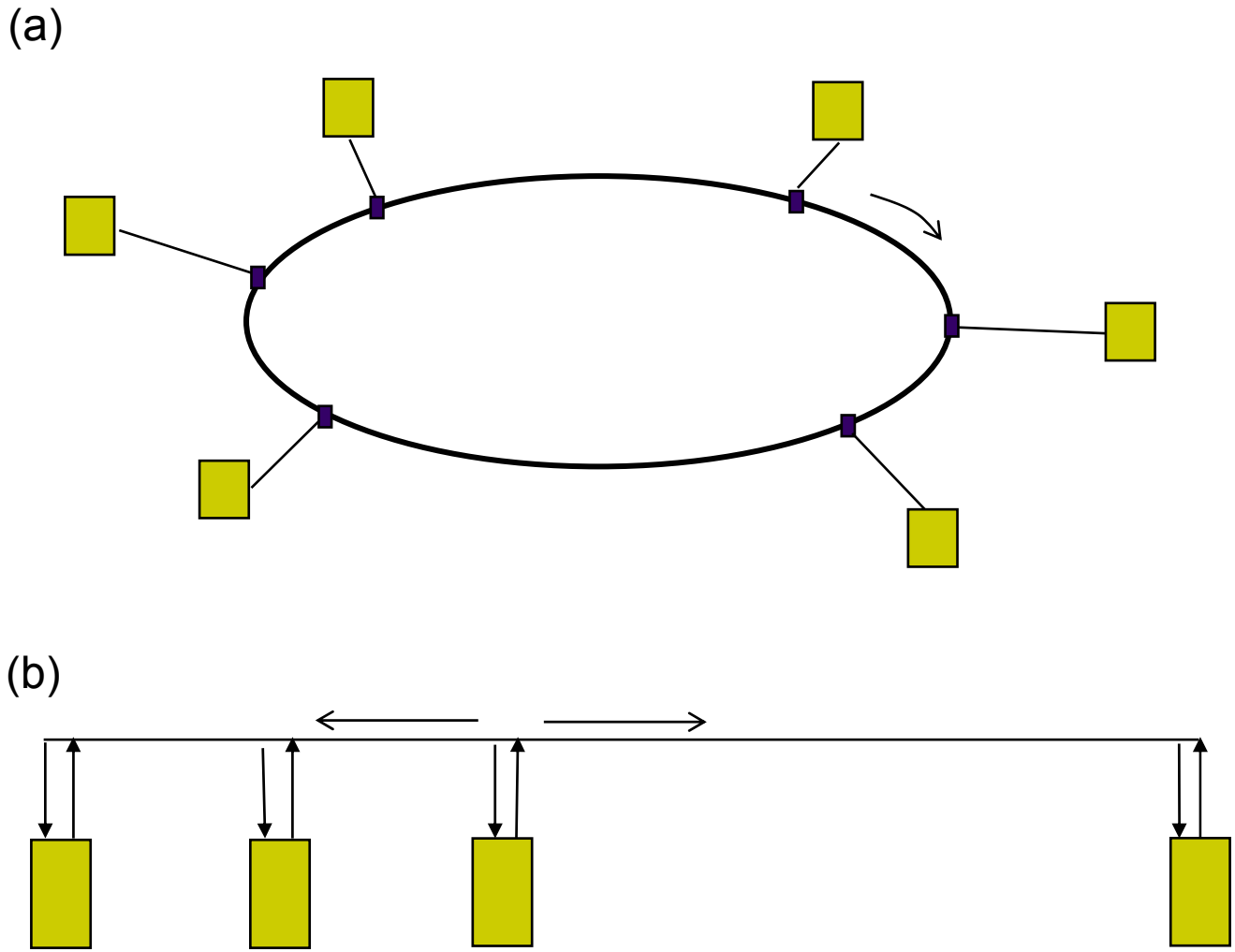

1
2
3
4
5
M
Shared multiple
access medium
. . .

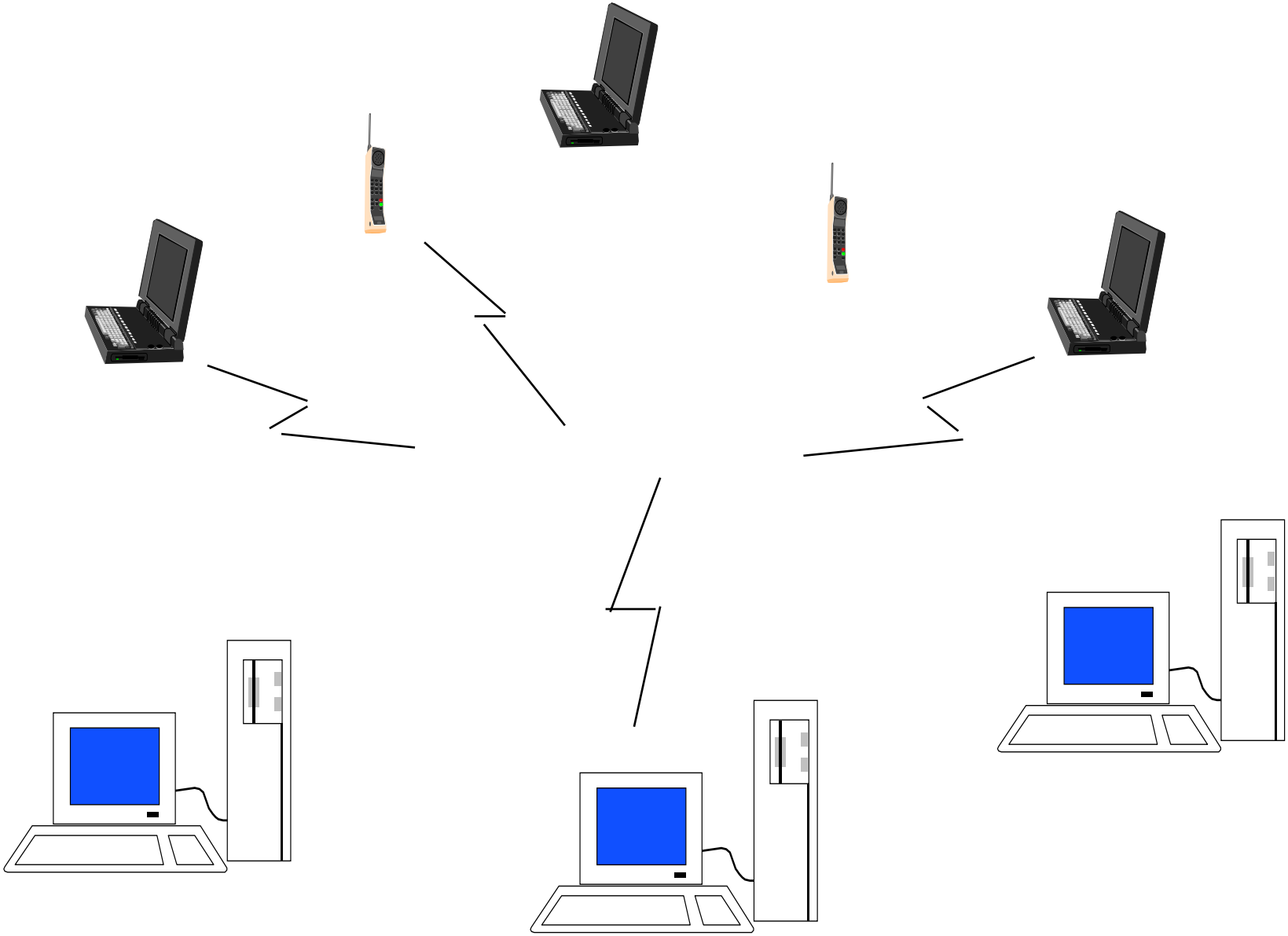

Medium sharing techniques
Static channelization
Dynamic medium access control
Scheduling
Random access

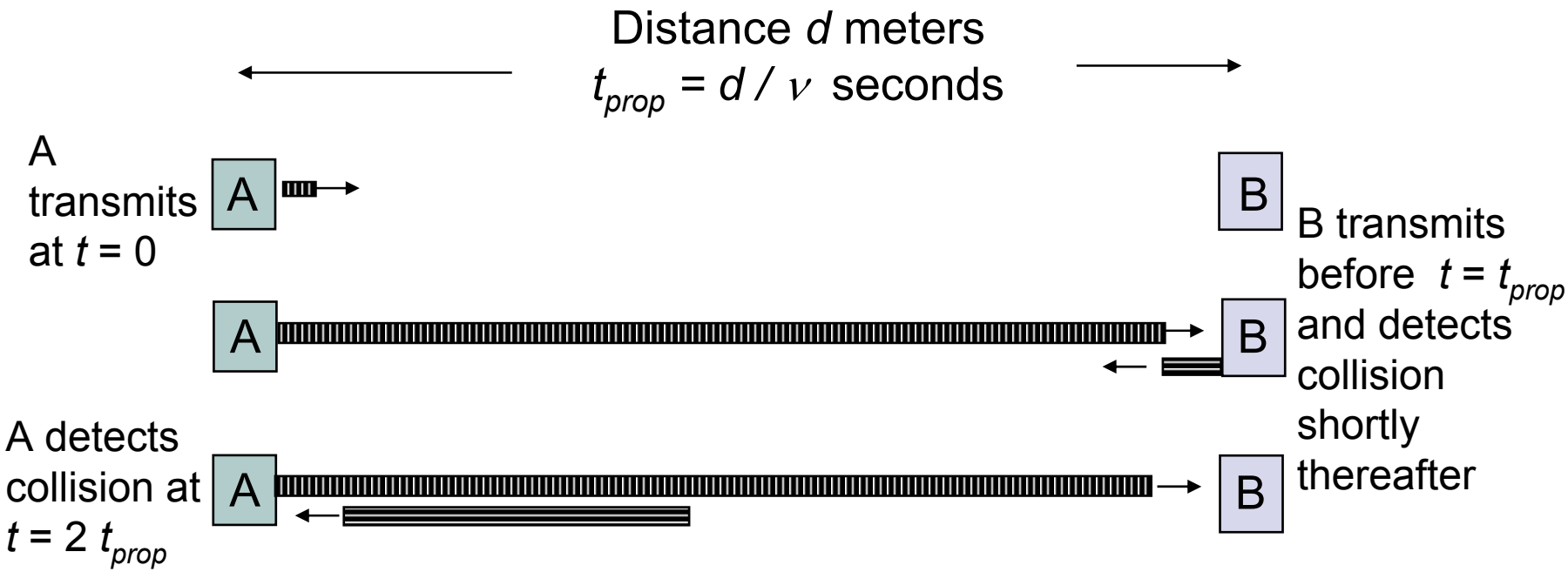
# Satellite channel

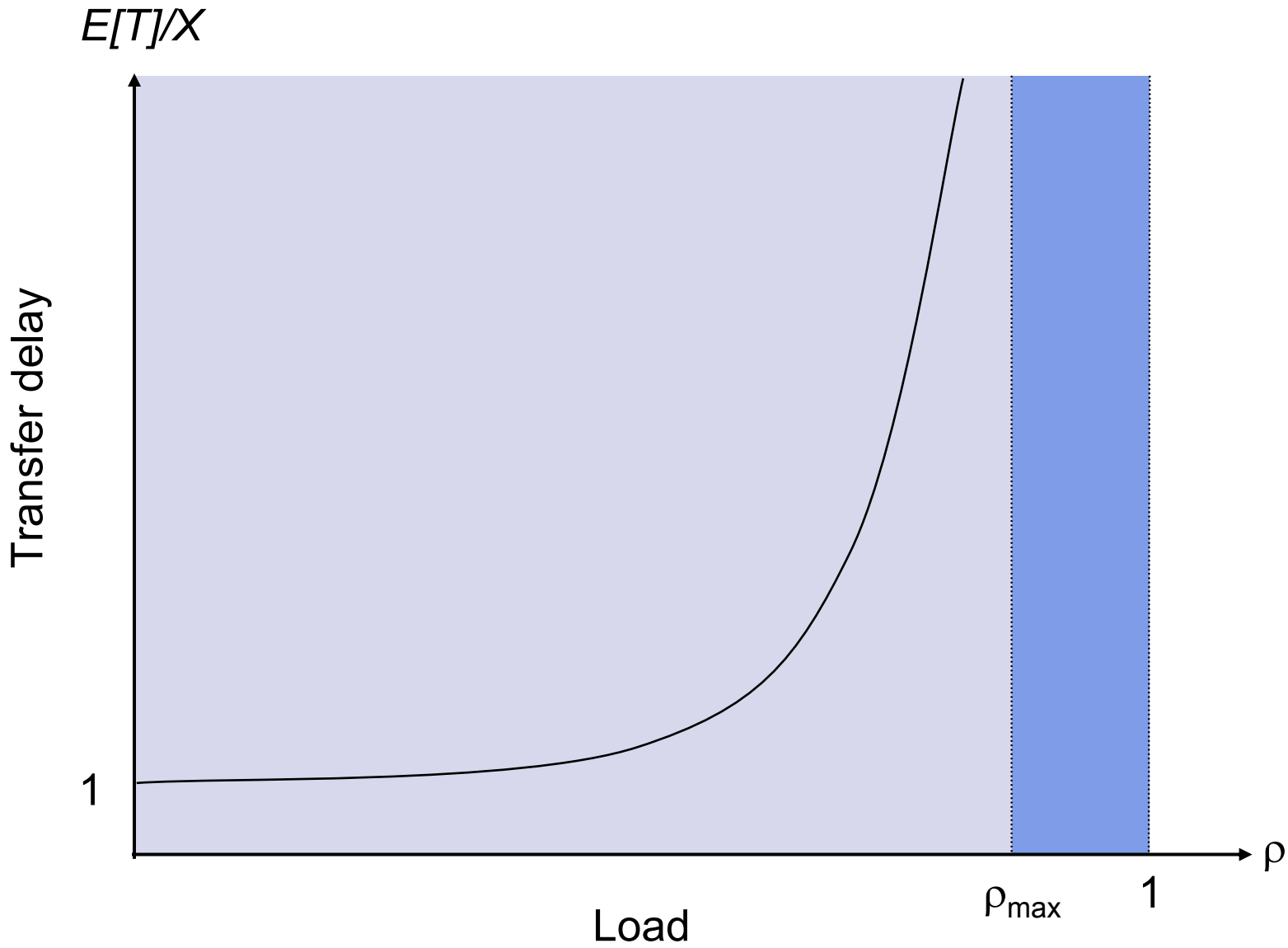


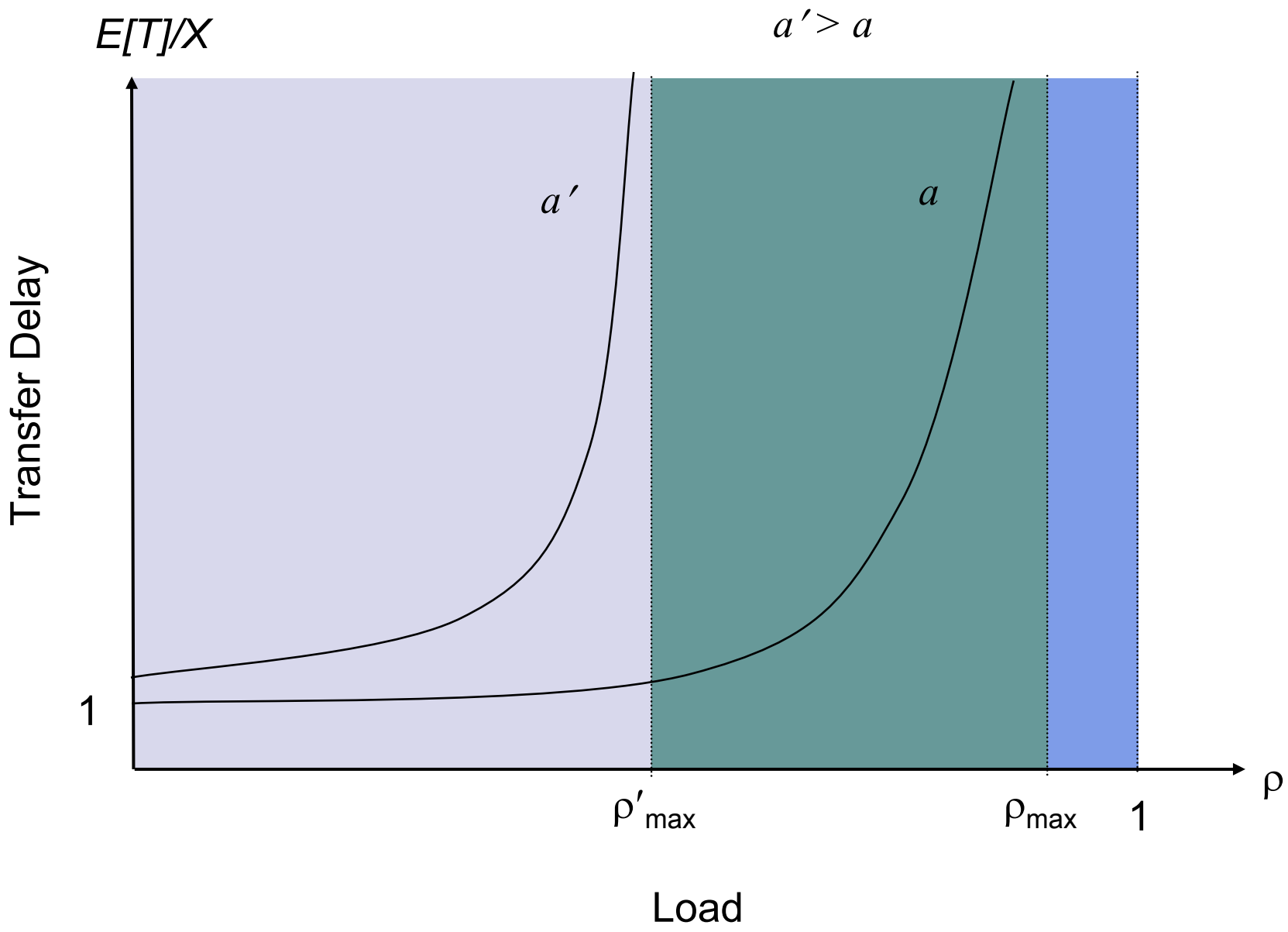

Inbound line
Host
computer
Outbound line
Stations

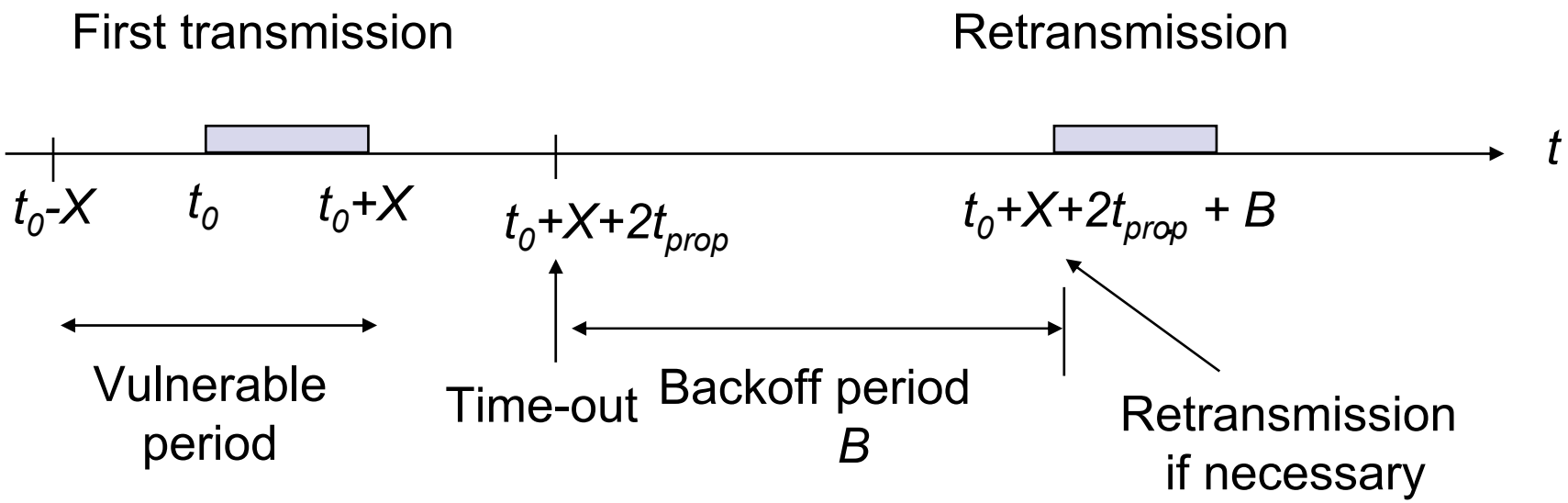

(a)
(b)

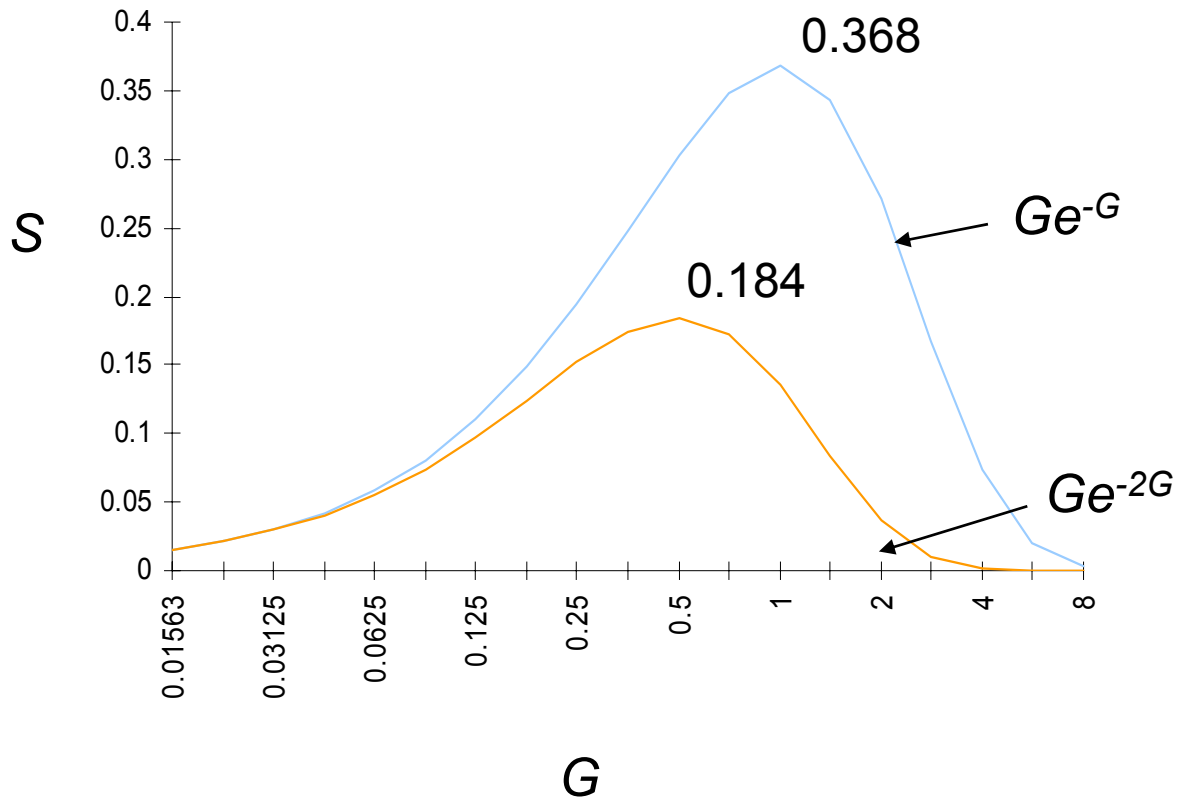


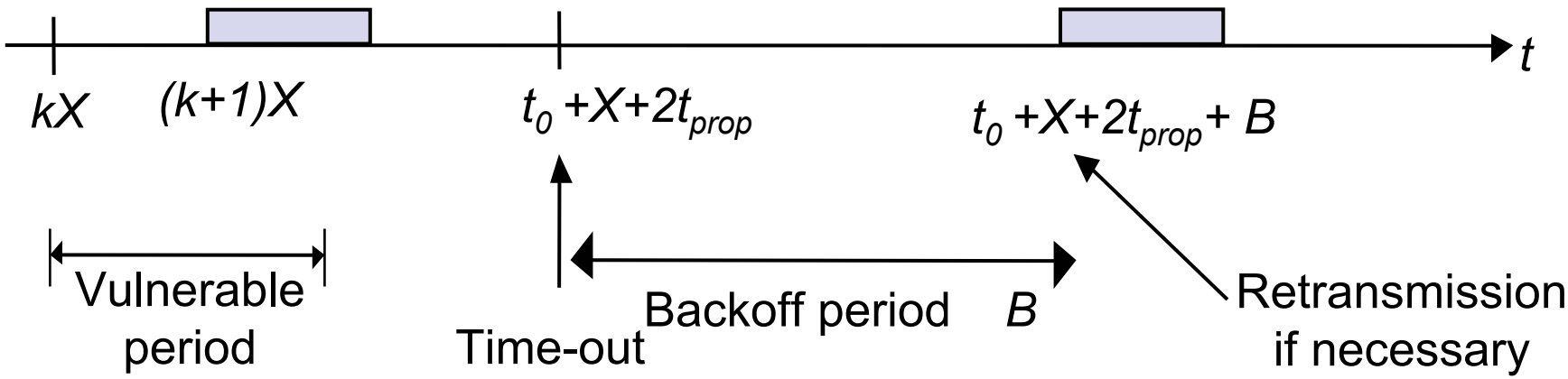

Distance d meters
$t_{prop} = d / \nu$ seconds
A transmits at $t = 0$
A
B
B transmits before $t = t_{prop}$ and detects collision shortly thereafter
A detects collision at $t = 2\ t_{prop}$


E[T]/X
Transfer delay
1
ρ
ρmax
1
Load

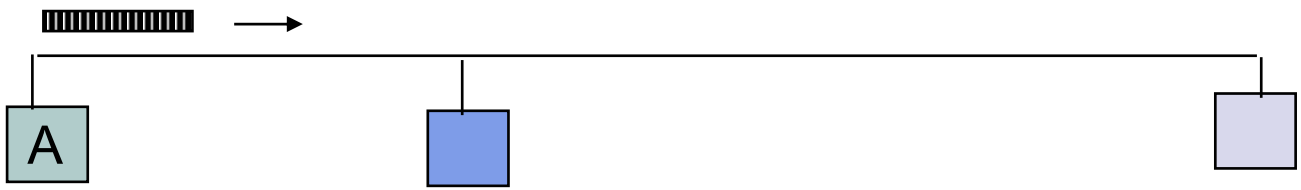

E[T]/X
a′ > a
a′
a
Transfer Delay
1
ρ
ρ′max
ρmax
1
Load


First transmission
Retransmission
t
$t_0$-X
$t_0$
$t_0$+X
$t_0$+X+2$t_{prop}$
$t_0$+X+2$t_{prop}$ + B
Vulnerable period
Time-out
Backoff period B
Retransmission if necessary

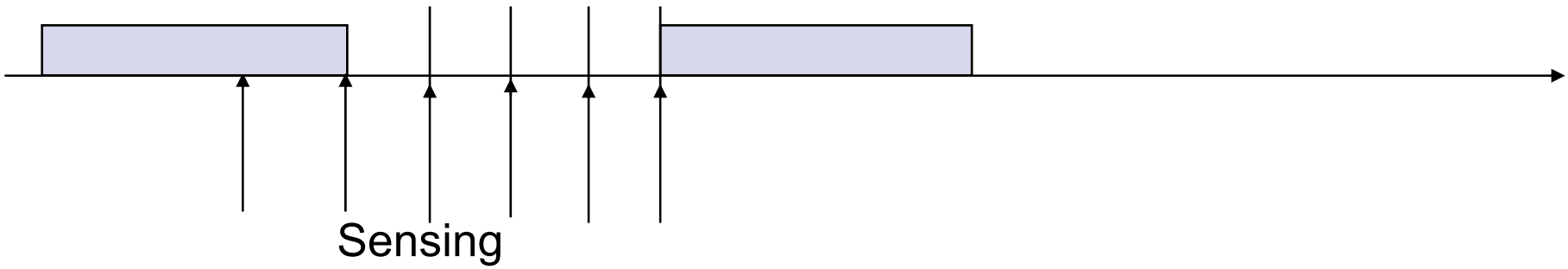

0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
S
0.368
0.184
Ge-G
Ge-2G
0.01563
0.03125
0.0625
0.125
0.25
0.5
1
2
4
8
G

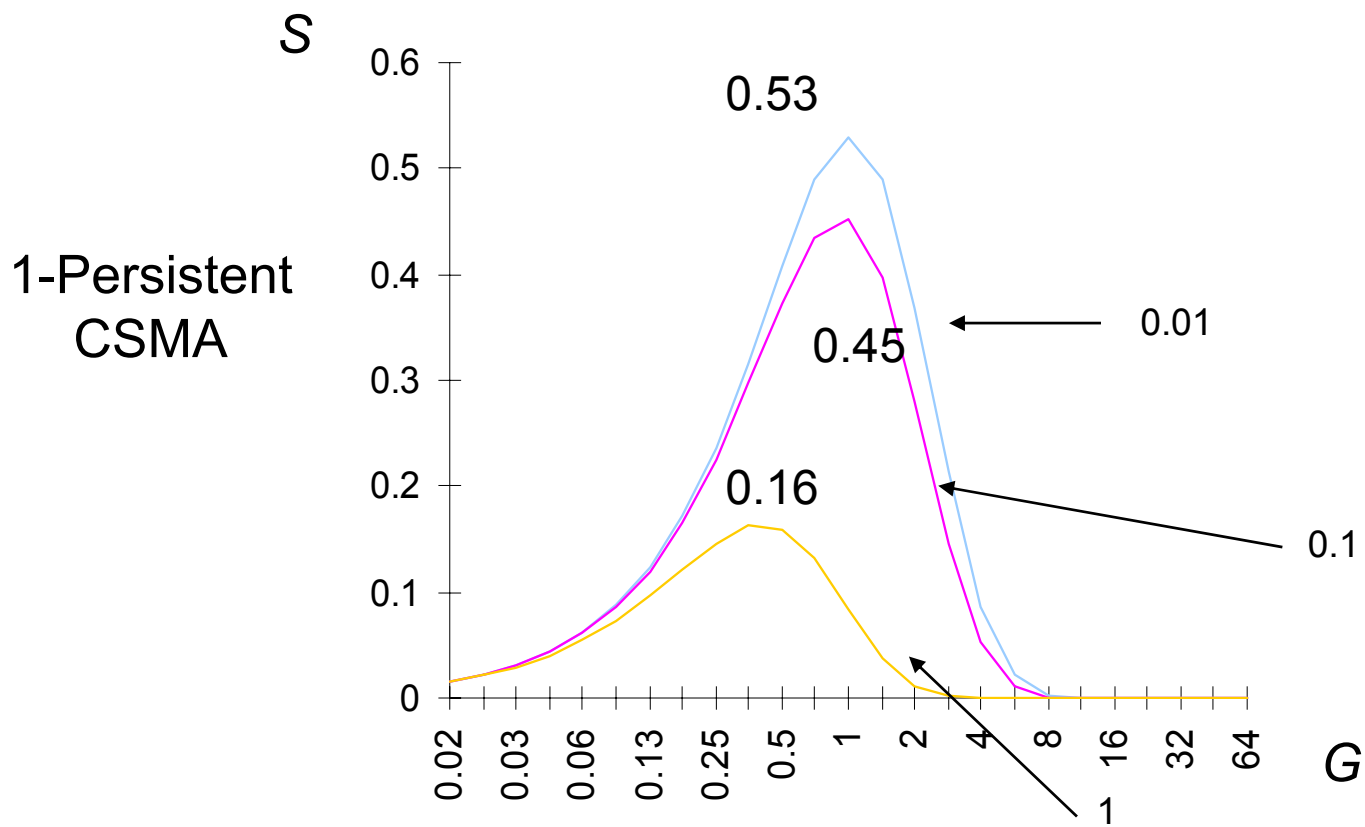

t
kX
(k+1)X
$t_0 + X + 2t_{prop}$
$t_0 + X + 2t_{prop} + B$
Vulnerable period
Time-out
Backoff period
B
Retransmission if necessary

Station A begins transmission at $t=0$

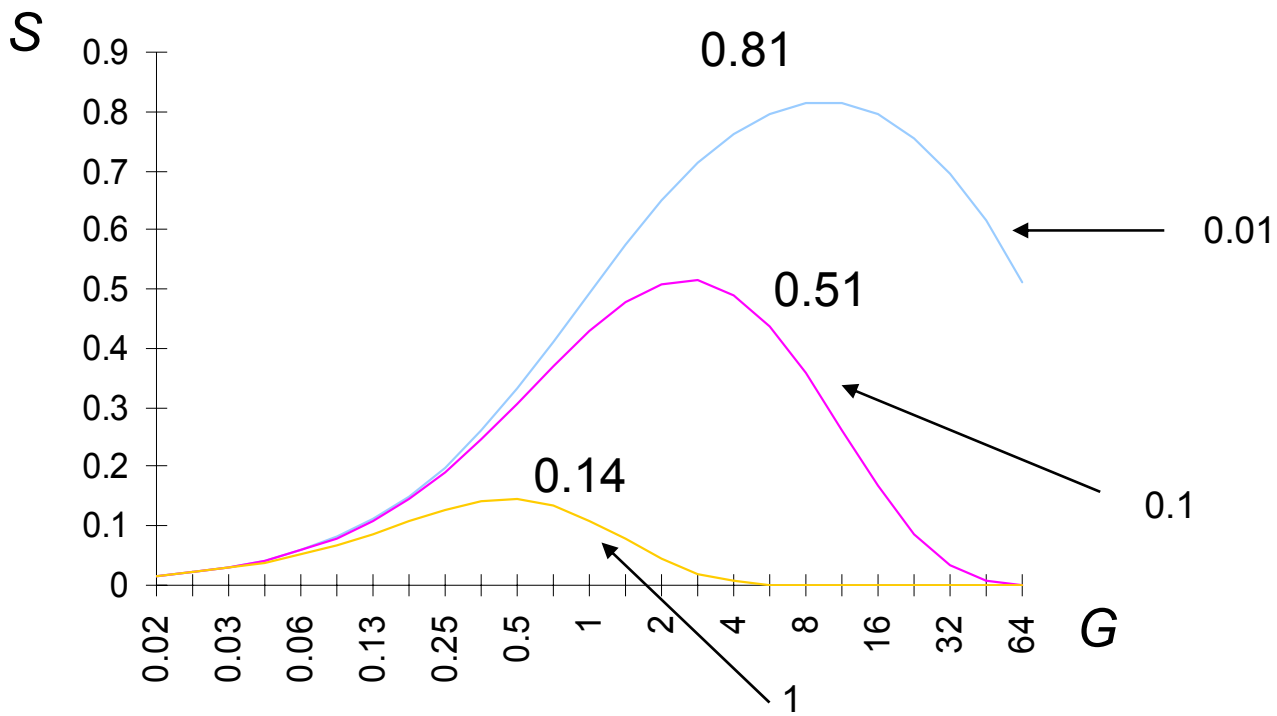


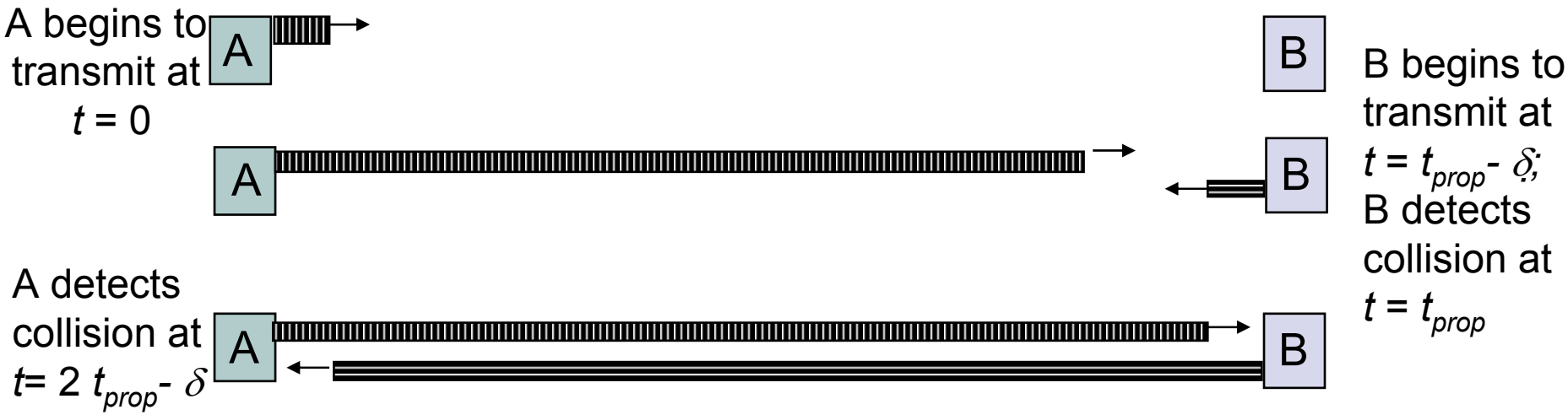

Station A captures channel at $t=t_{prop}$


Sensing

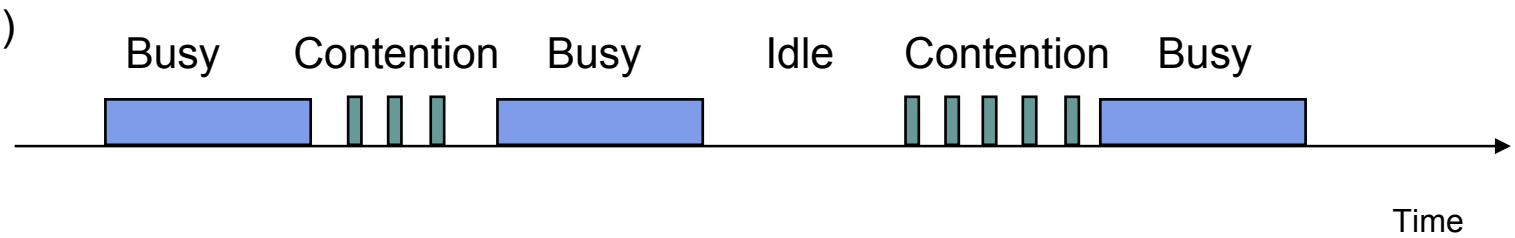

S
1-Persistent
CSMA
0.6
0.5
0.4
0.3
0.2
0.1
0
0.53
0.45
0.16
0.01
0.1
1
0.02
0.03
0.06
0.13
0.25
0.5
1
2
4
8
16
32
64
G

Non-Persistent CSMA

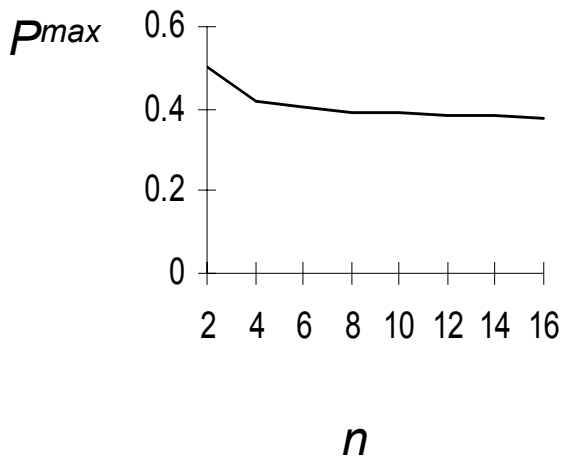


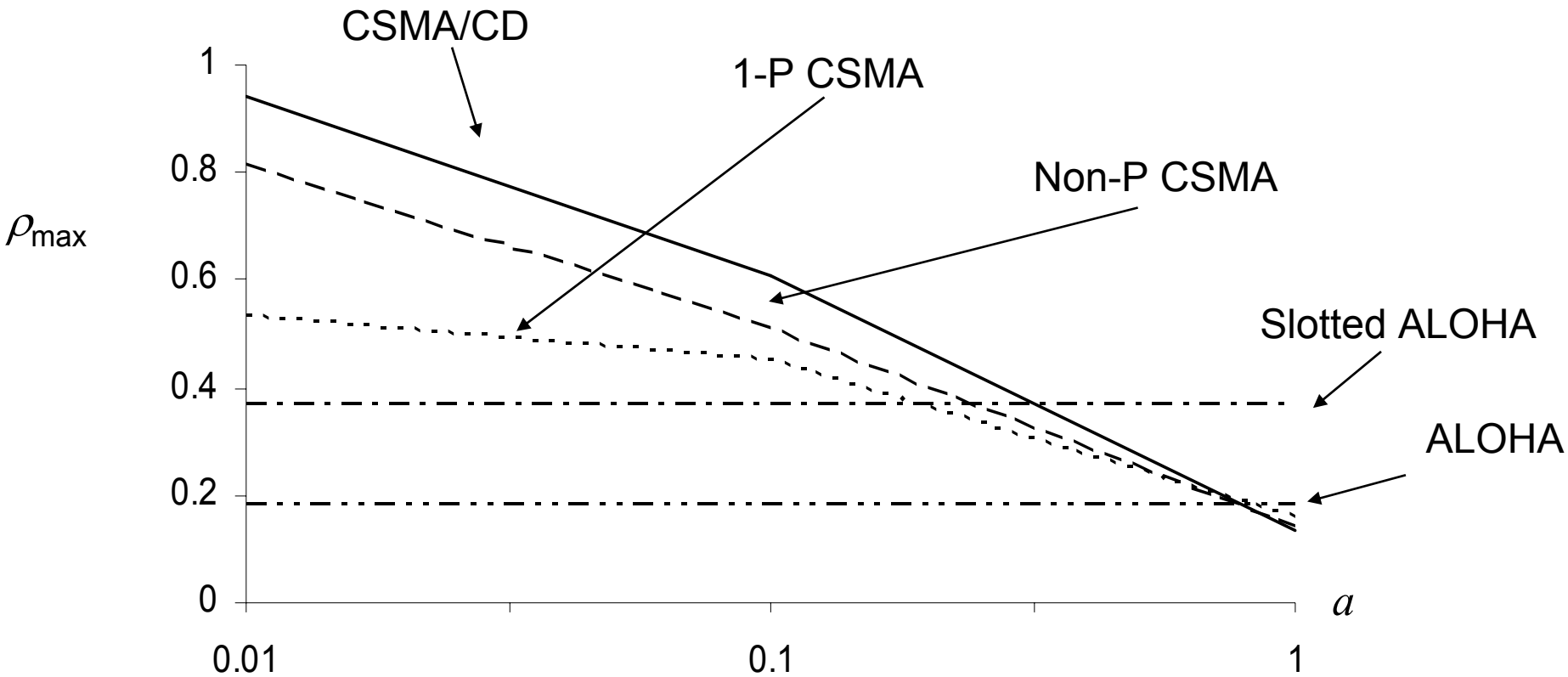

A begins to transmit at $t = 0$
A
B
B begins to transmit at $t = t_{prop} - \delta$;
B detects collision at $t = t_{prop}$
A
B
A detects collision at $t = 2\,t_{prop} - \delta$
A
B

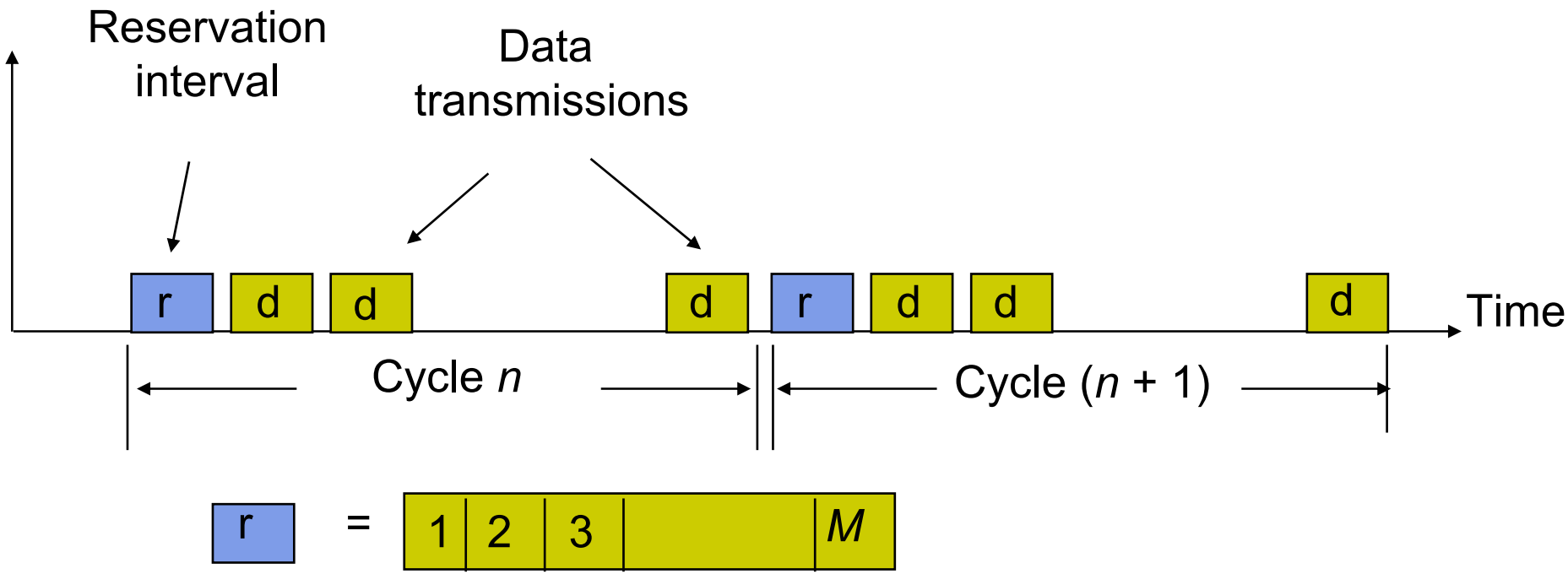
(a)

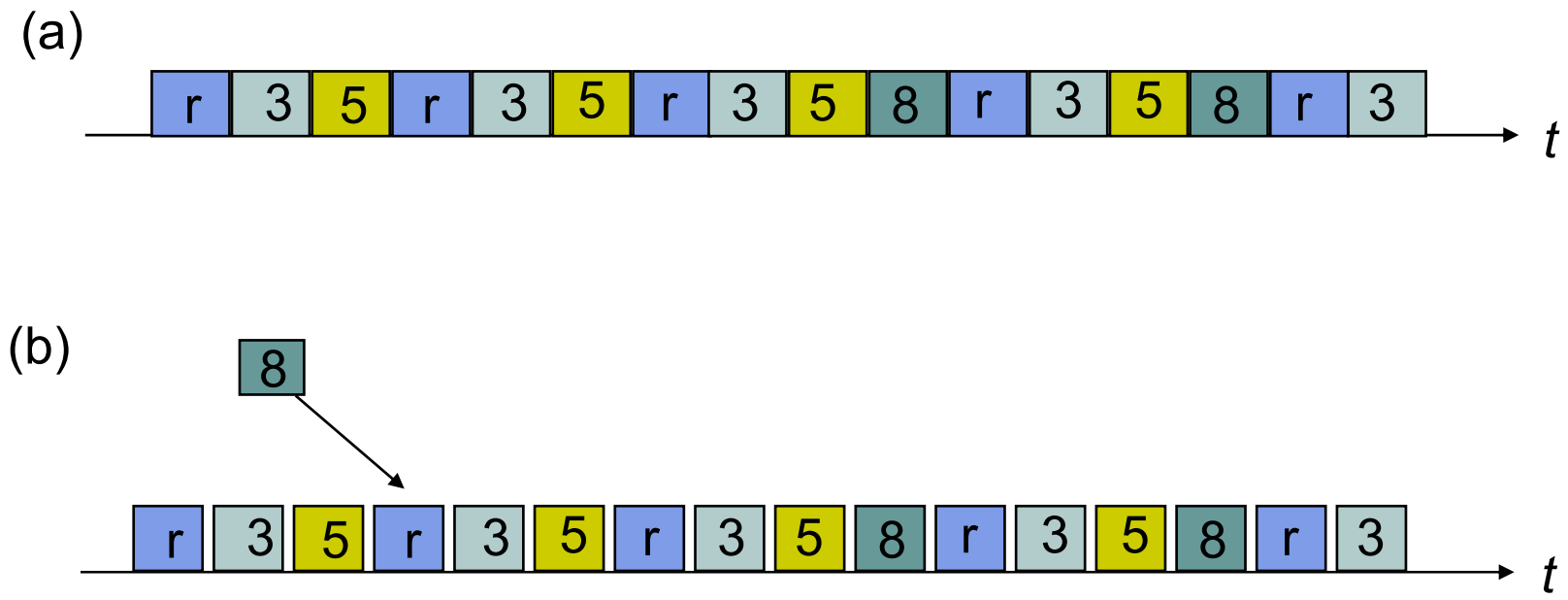

Busy
Contention
Busy
Idle
Contention
Busy
Time

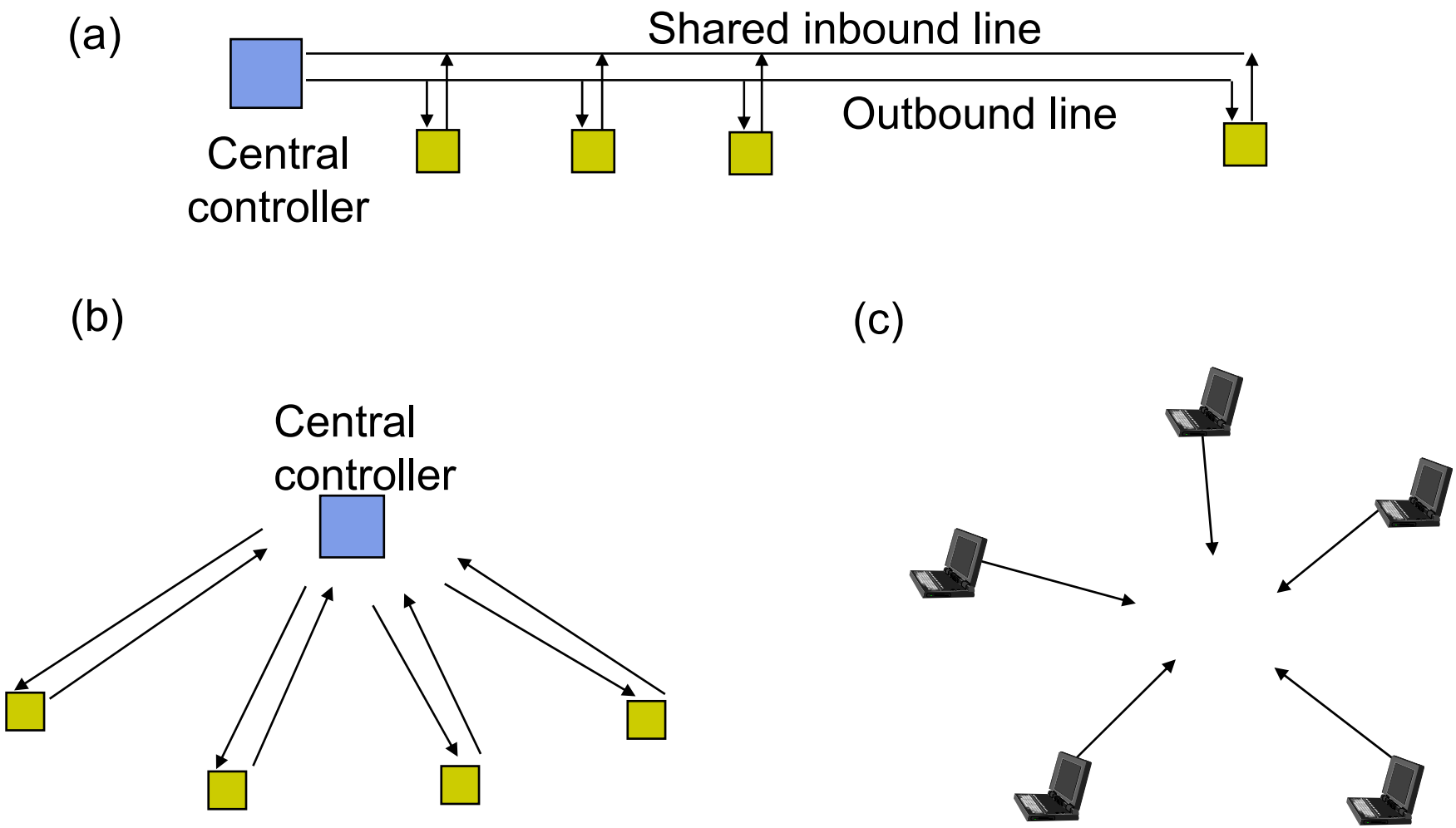
(b)

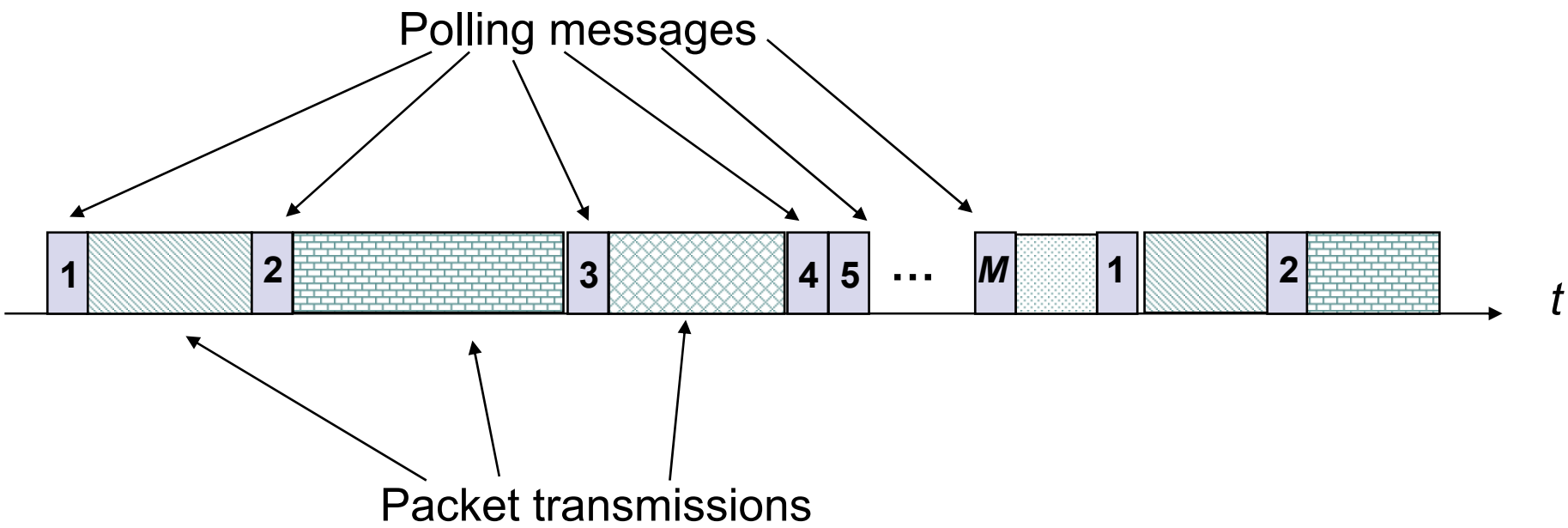

Pmax
0.6
0.4
0.2
0
2
4
6
8
10
12
14
16
n

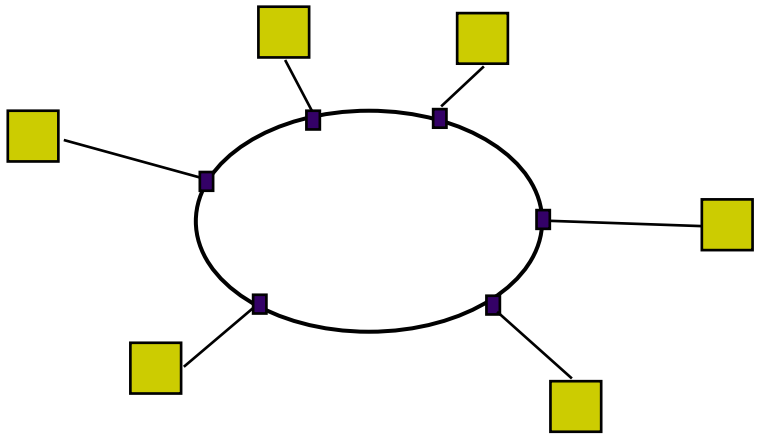

CSMA/CD
1-P CSMA
Non-P CSMA
Slotted ALOHA
ALOHA
1
0.8
0.6
0.4
0.2
0
$\rho_{max}$
$a$
0.01
0.1
1

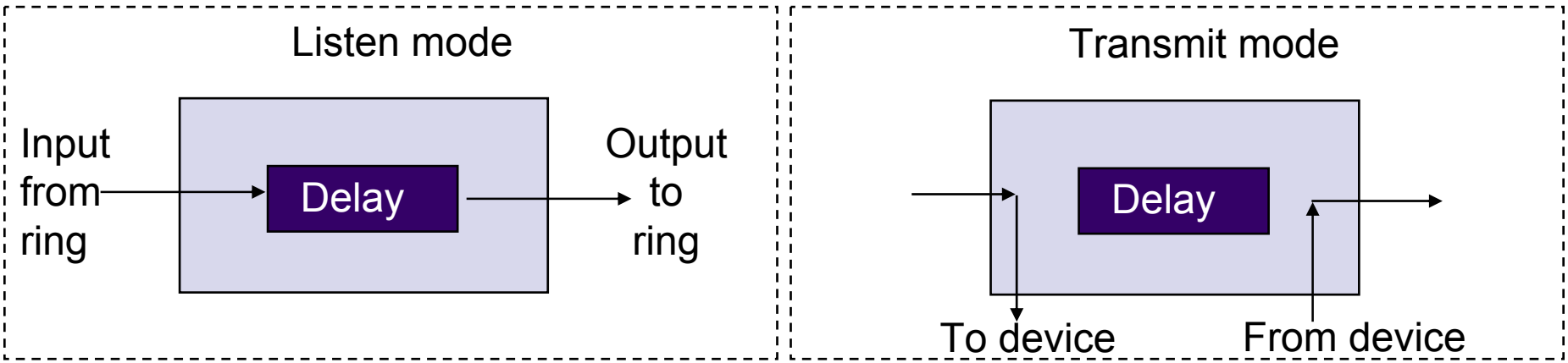

Reservation interval
Data transmissions
r
d
d
d
r
d
d
d
Time
Cycle n
Cycle (n + 1)
r
=
1
2
3
M

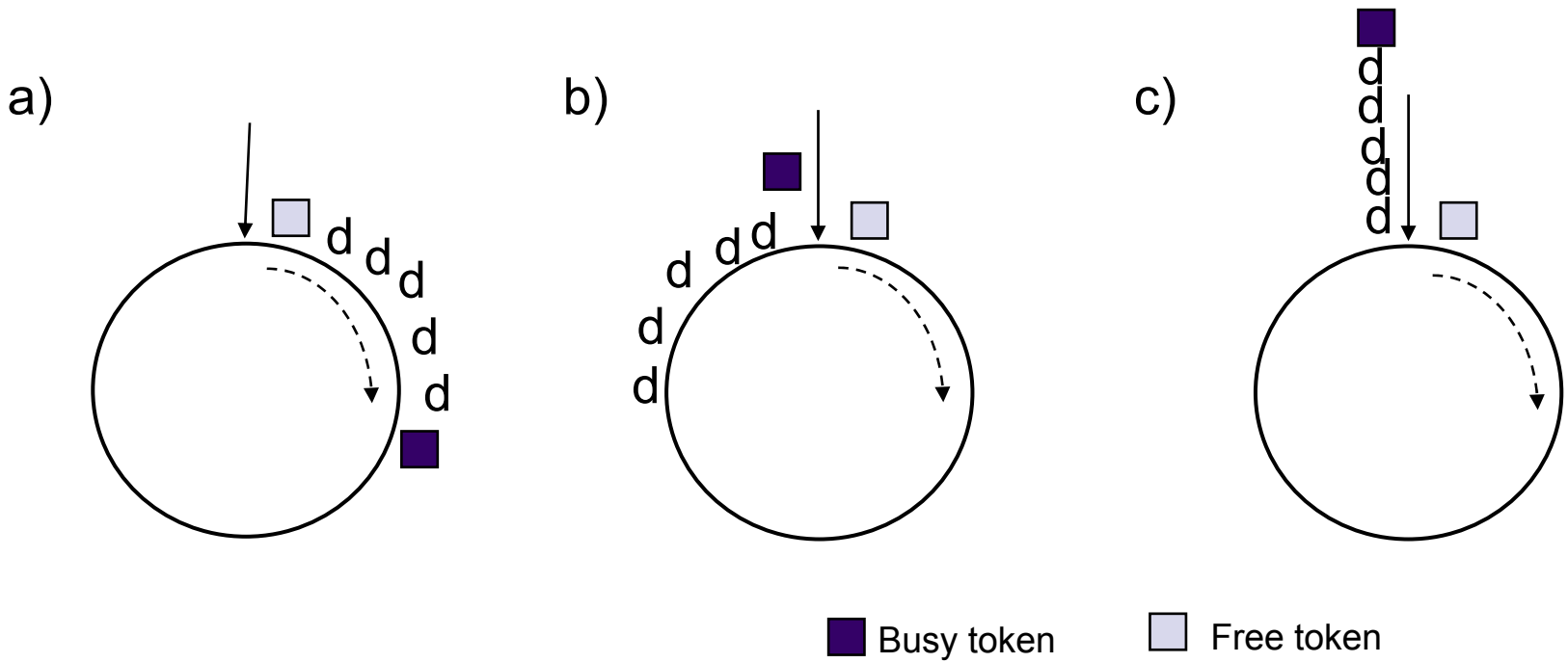

(a)
r 3 5 r 3 5 r 3 5 8 r 3 5 8 r 3
t
(b)
8
r 3 5 r 3 5 r 3 5 8 r 3 5 8 r 3
t

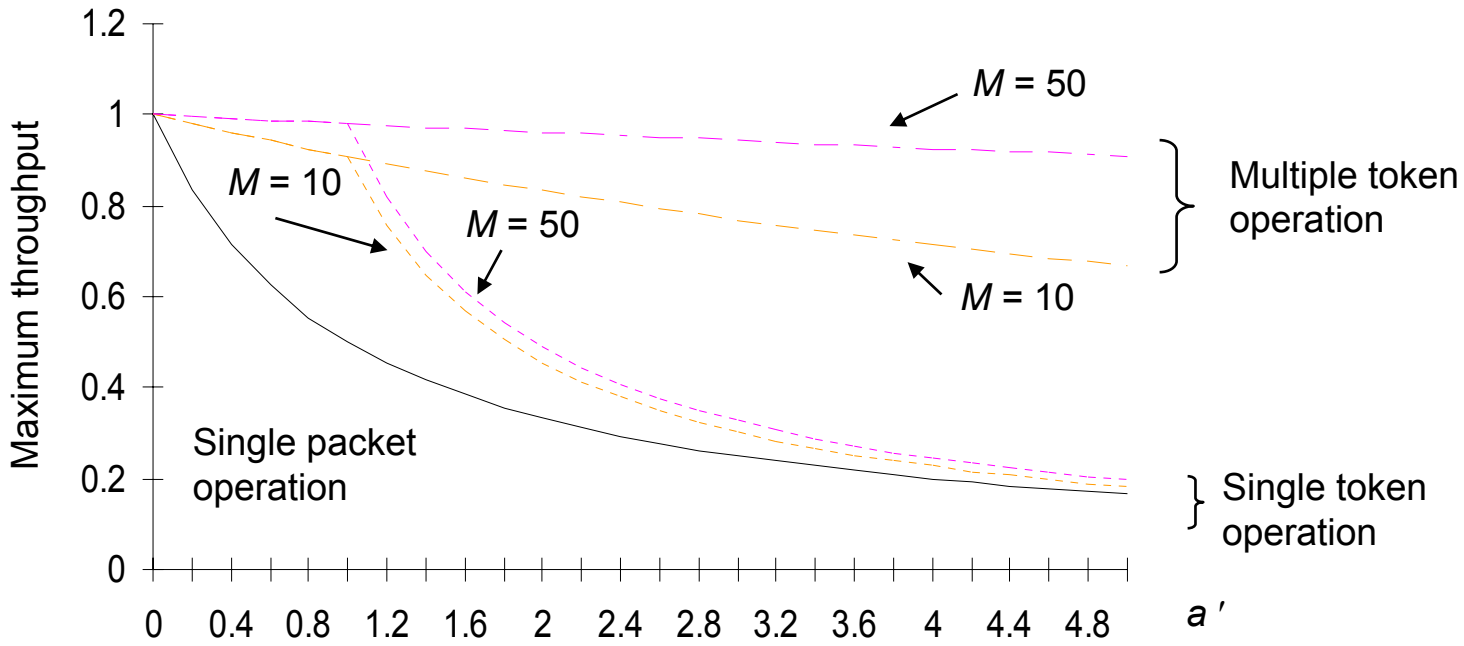

(a)
Shared inbound line
Outbound line
Central
controller
(b)
Central
controller
(c)

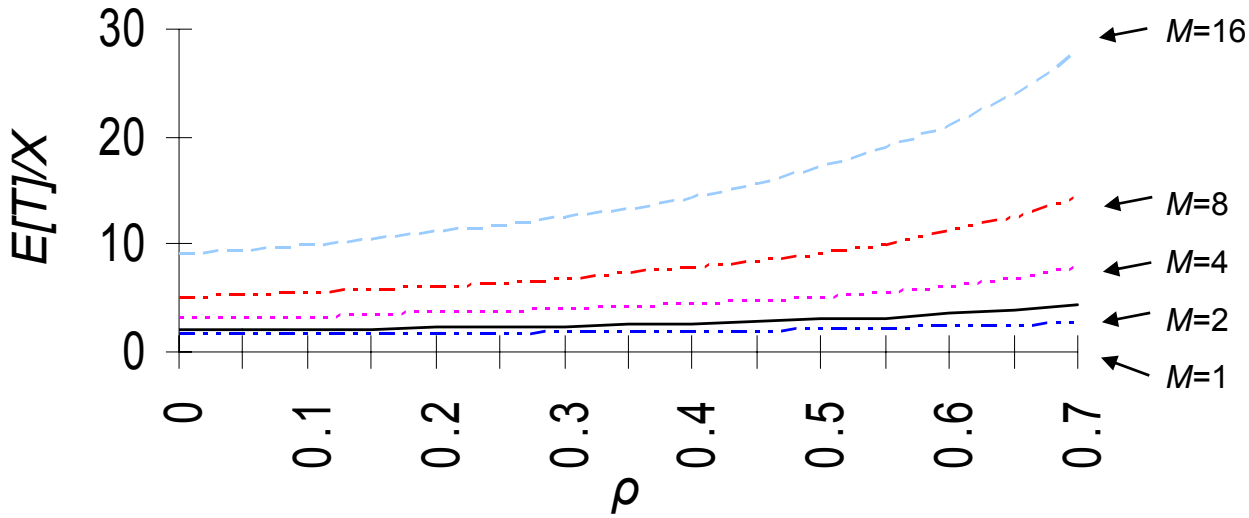

Polling messages
1
2
3
4
5
…
M
1
2
t
Packet transmissions

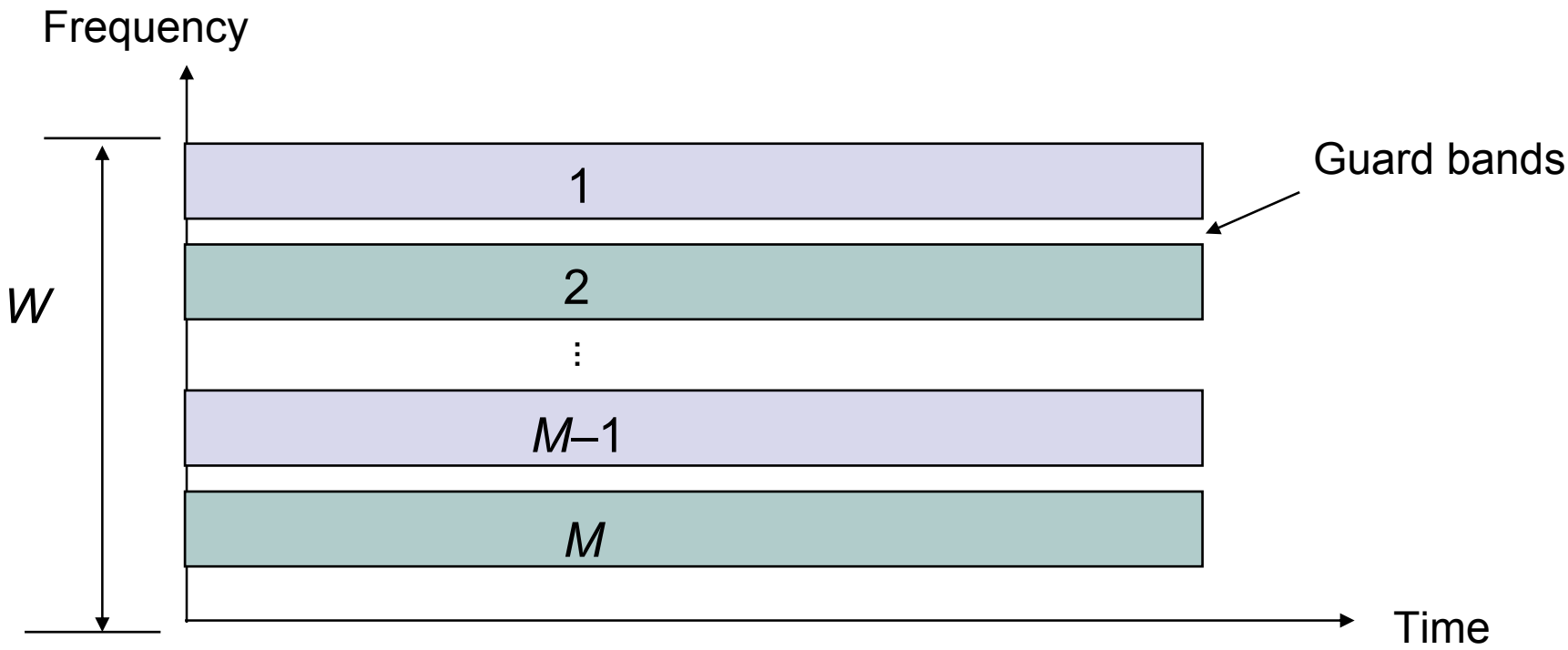


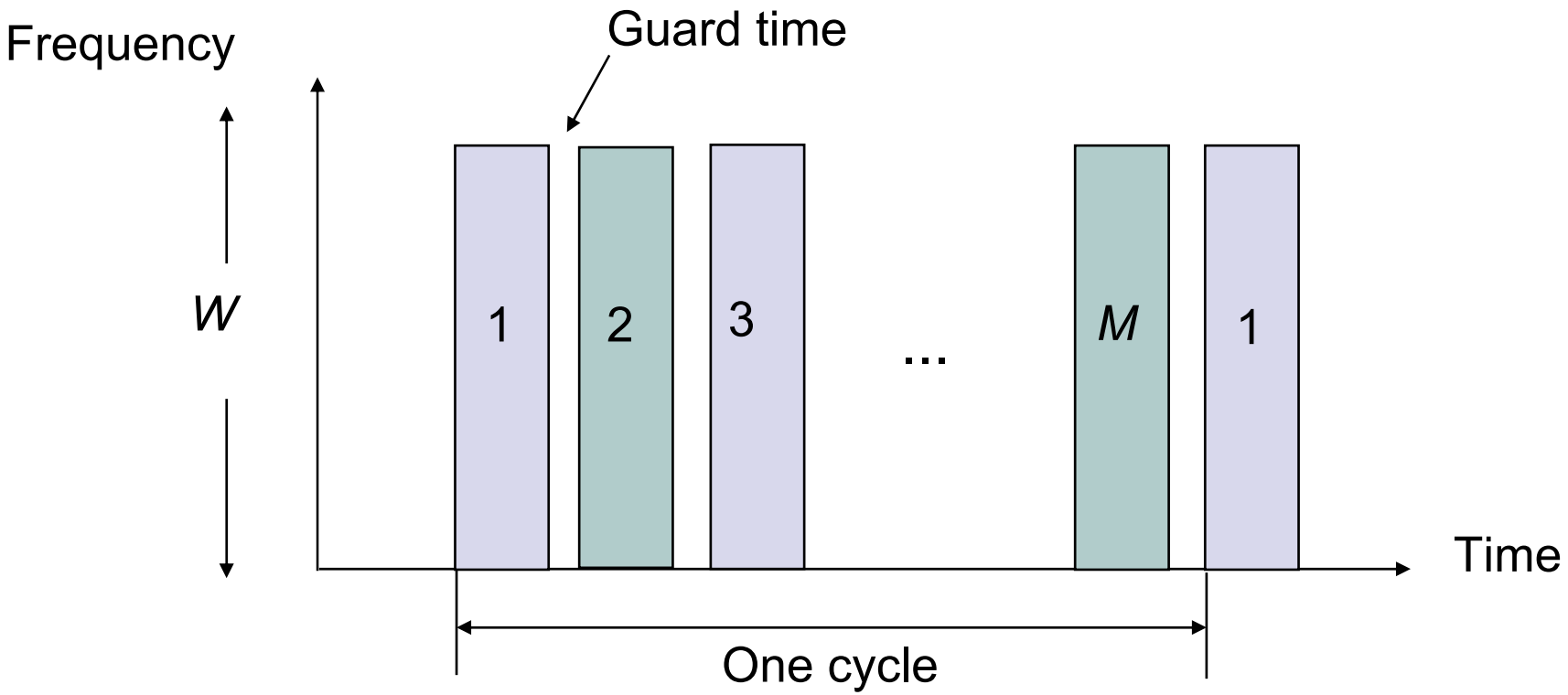

Listen mode
Input from ring
Delay
Output to ring
Transmit mode
Delay
To device
From device

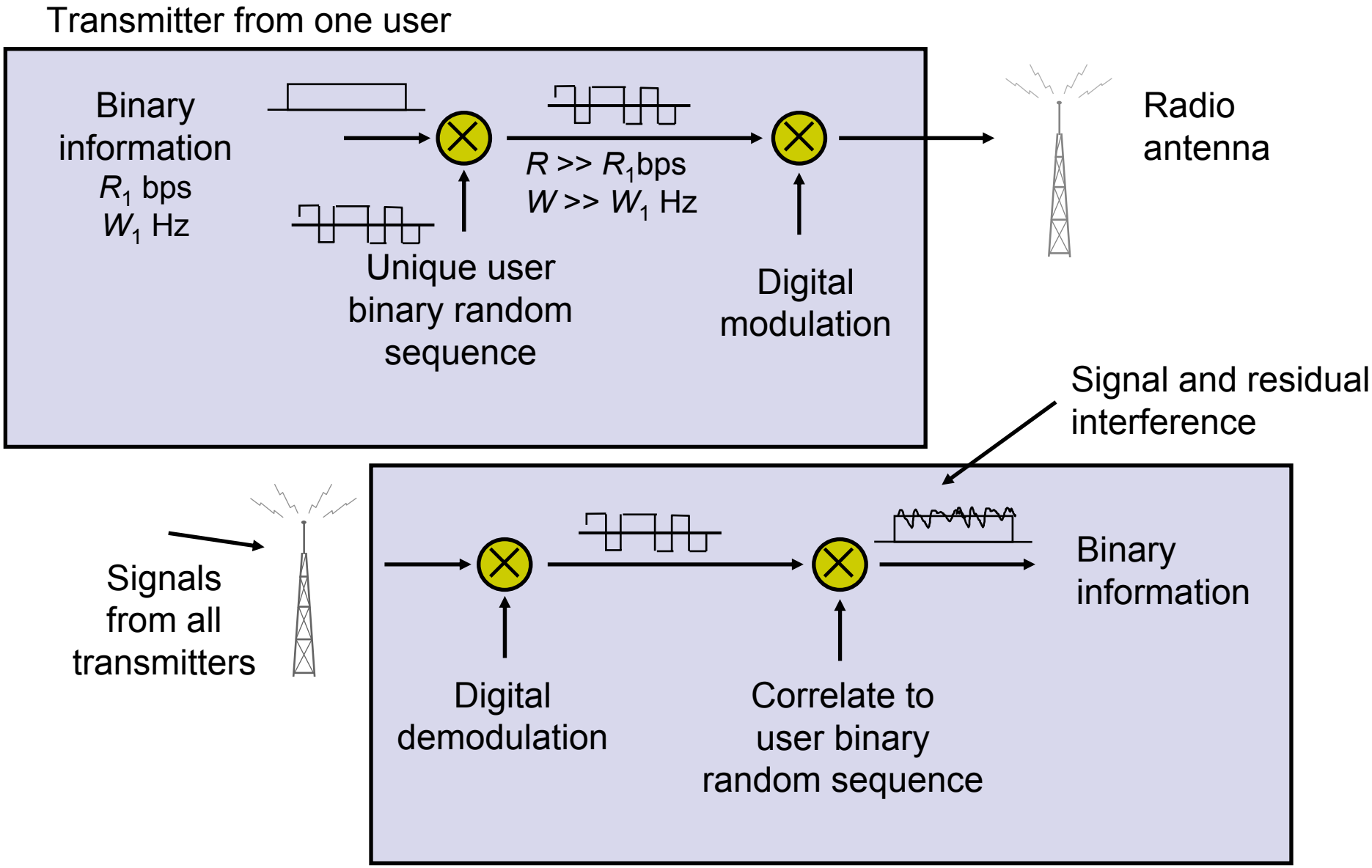

a)
d
d
d
d
d
b)
d
d
d
d
d
c)
d
d
d
d
d
Busy token
Free token

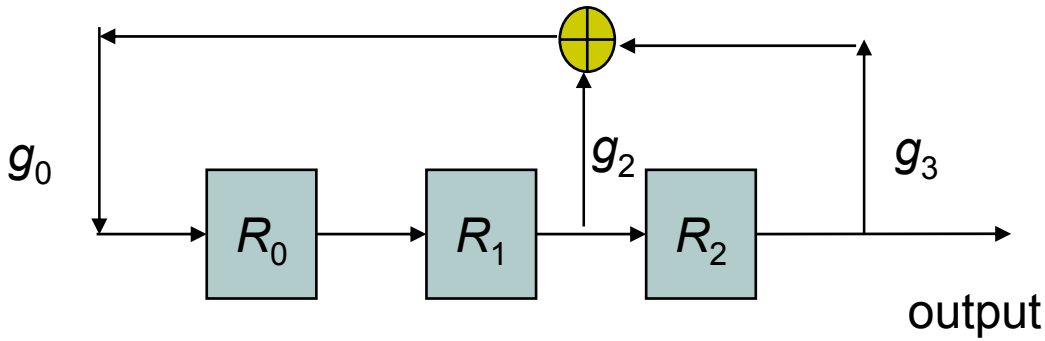

Maximum throughput
1.2
1
0.8
0.6
0.4
0.2
0
0
0.4
0.8
1.2
1.6
2
2.4
2.8
3.2
3.6
4
4.4
4.8
a'
M = 50
M = 10
M = 50
M = 10
Multiple token operation
Single packet operation
Single token operation


30
20
10
0
E[T]/X
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
ρ
M=16
M=8
M=4
M=2
M=1


Frequency
Guard bands
1
2
M–1
M
W
Time


Frequency
Guard time
W
1
2
3
...
M
1
Time
One cycle


Transmitter from one user
Binary information
$R_1$ bps
$W_1$ Hz
$R >> R_1$bps
$W >> W_1$ Hz
Unique user binary random sequence
Digital modulation
Radio antenna
Signal and residual interference
Signals from all transmitters
Digital demodulation
Correlate to user binary random sequence
Binary information

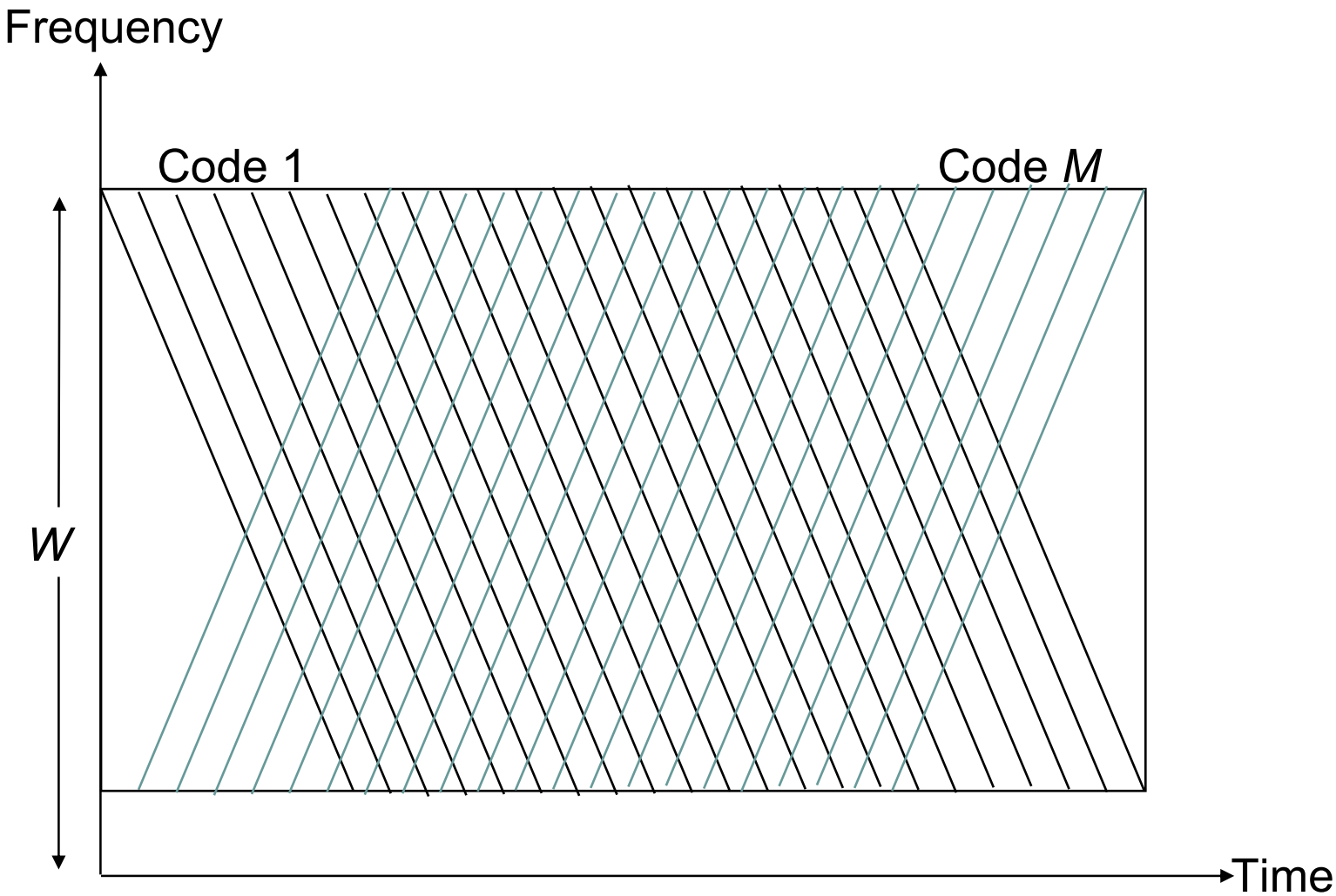



$g(x) = x^3 + x^2 + 1$

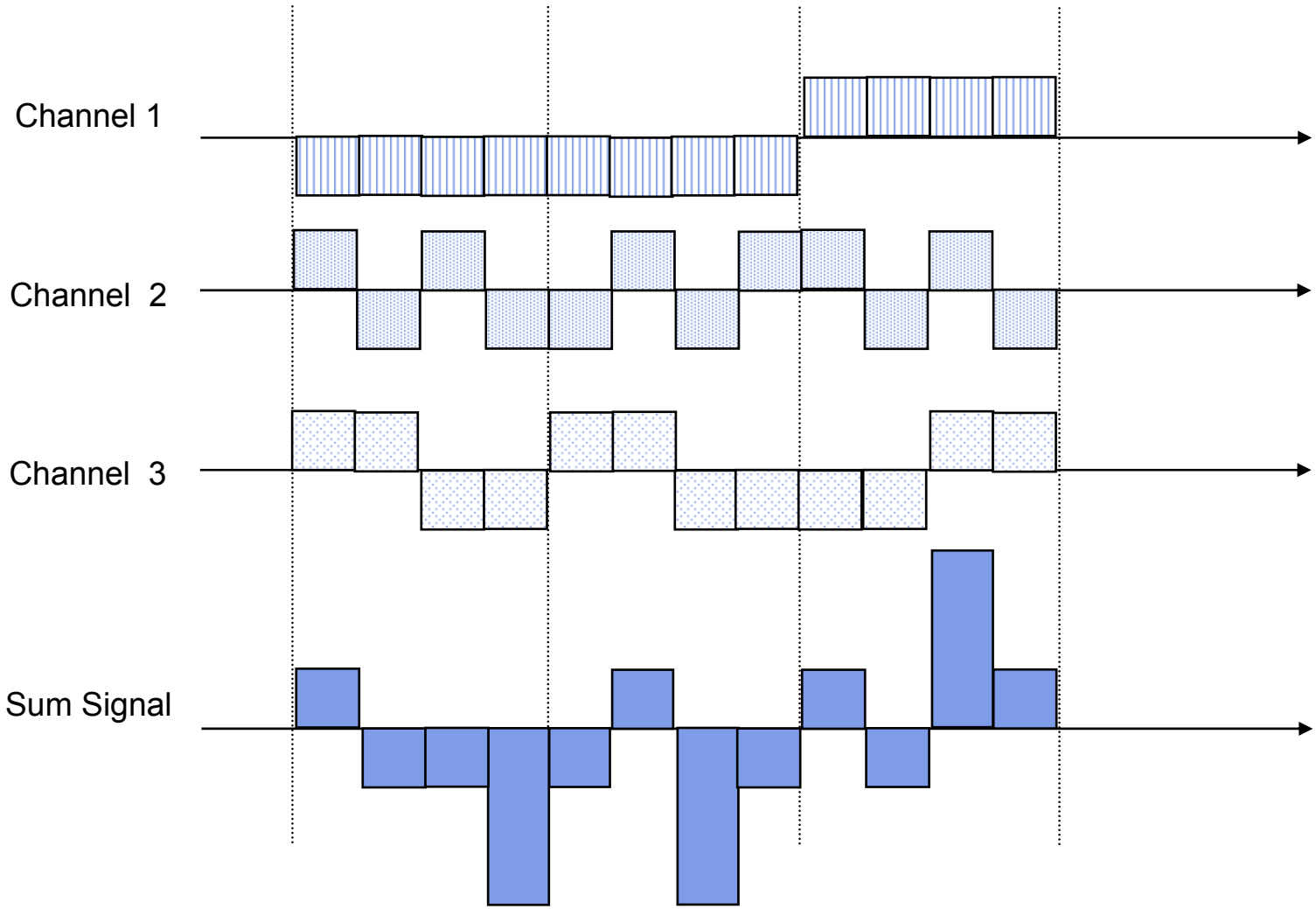
The coefficients of a primitive generator polynomial determine the feedback taps

| Time | $R_0$ | $R_1$ | $R_2$ |
|---|---|---|---|
| 0 | 1 | 0 | 0 |
| 1 | 0 | 1 | 0 |
| 2 | 1 | 0 | 1 |
| 3 | 1 | 1 | 0 |
| 4 | 1 | 1 | 1 |
| 5 | 0 | 1 | 1 |
| 6 | 0 | 0 | 1 |
| 7 | 1 | 0 | 0 |

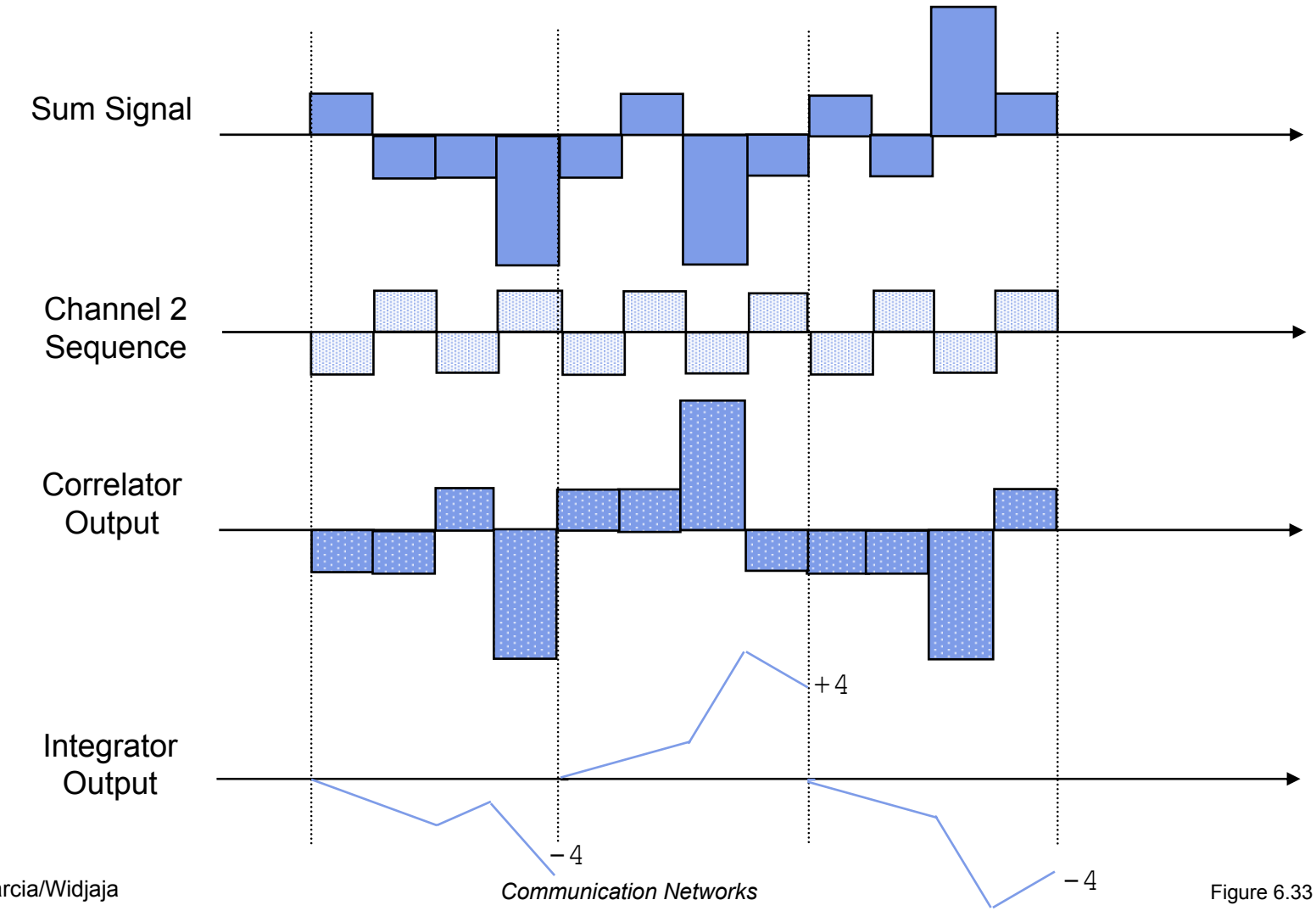
Sequence repeats from here onwards


Frequency
Code 1
Code M
W
Time

Channel 1: `110 -> +1+1+1 -> (-1,-1,-1,-1),(-1,-1,-1,-1),(+1,+1,+1,+1)`
Channel 2: `010 -> -1+1-1 -> (+1,-1,+1,-1),(-1,+1,-1,+1),(+1,-1,+1,-1)`
Channel 3: `001 -> -1-1+1 -> (+1,+1,-1,-1),(+1,+1,-1,-1),(-1,-1,+1,+1)`
Sum Signal: `(+1,-1,-1,-3),(-1,+1,-3,-1),(+1,-1,+3,+1)`

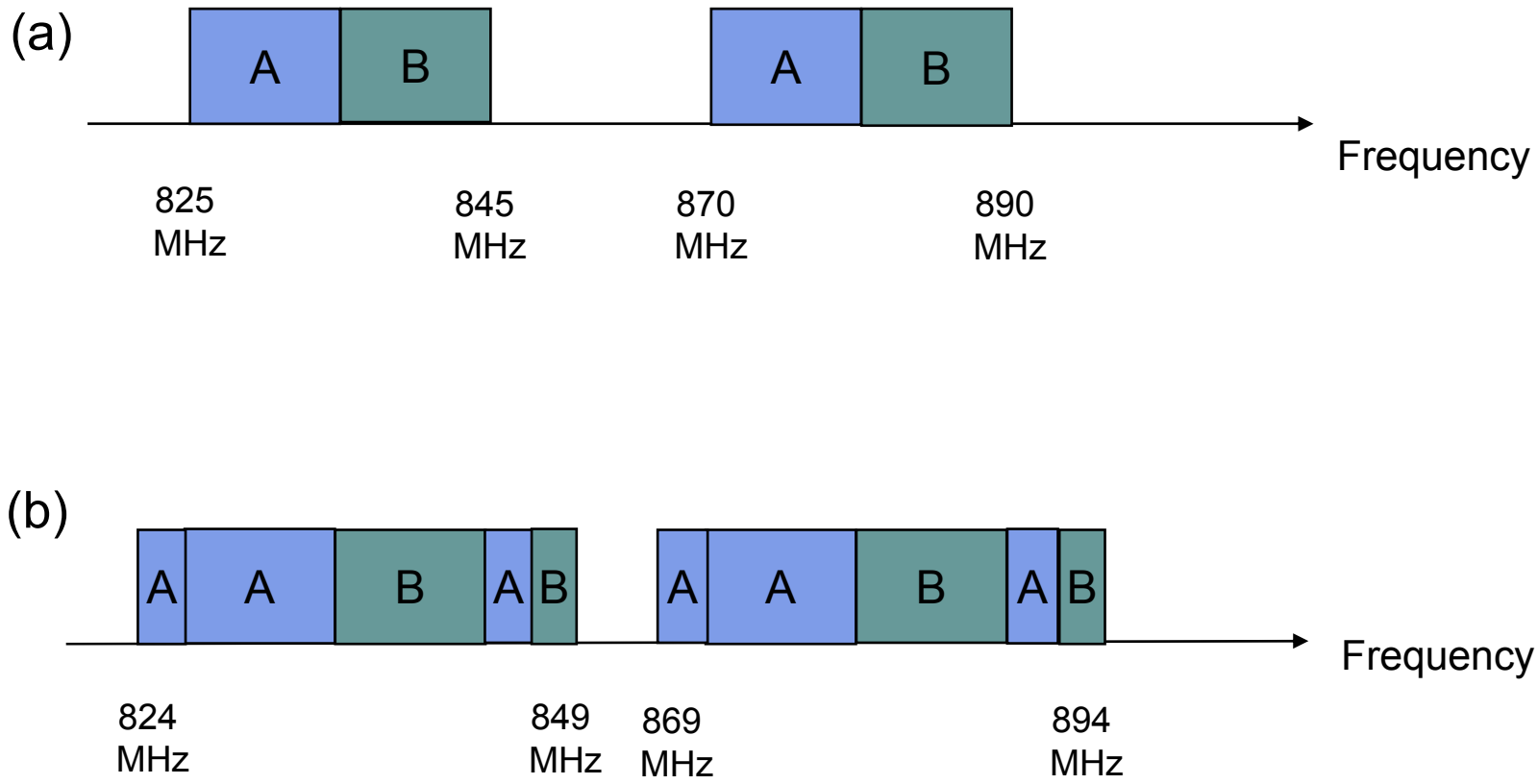


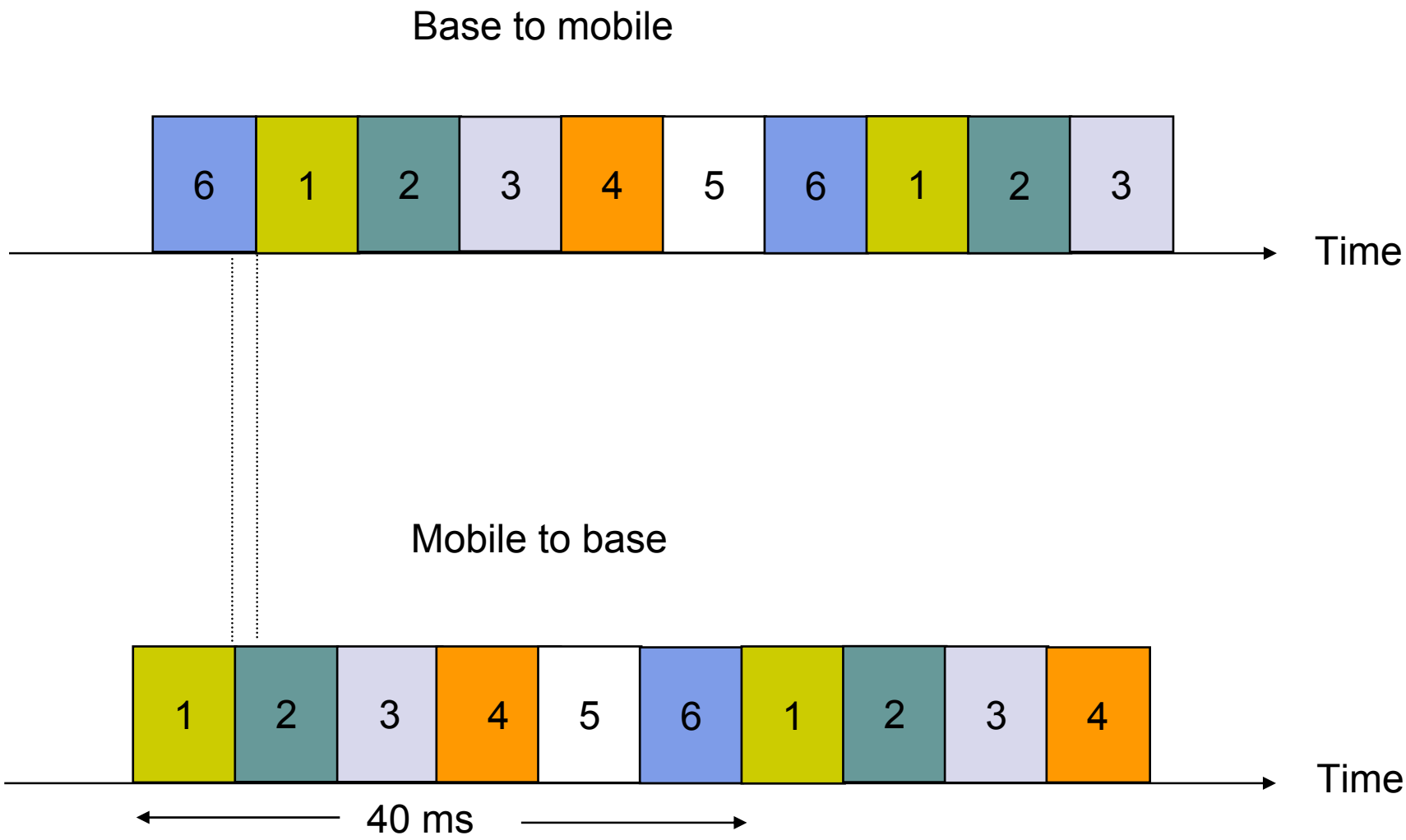
| | |
|---|---|
| Sum Signal: | (+1,-1,-1,-3),(-1,+1,-3,-1),(+1,-1,+3,+1) |
| Channel 2 Sequence: | (-1,+1,-1,+1),(-1,+1,-1,+1),(-1,+1,-1,+1) |
| Correlator Output: | (-1,-1,+1,-3),(+1,+1,+3,-1),(-1,-1,-3,+1) |
| Integrated Output: | -4, +4, -4 |
| Binary Output: | 0, 1, 0 |

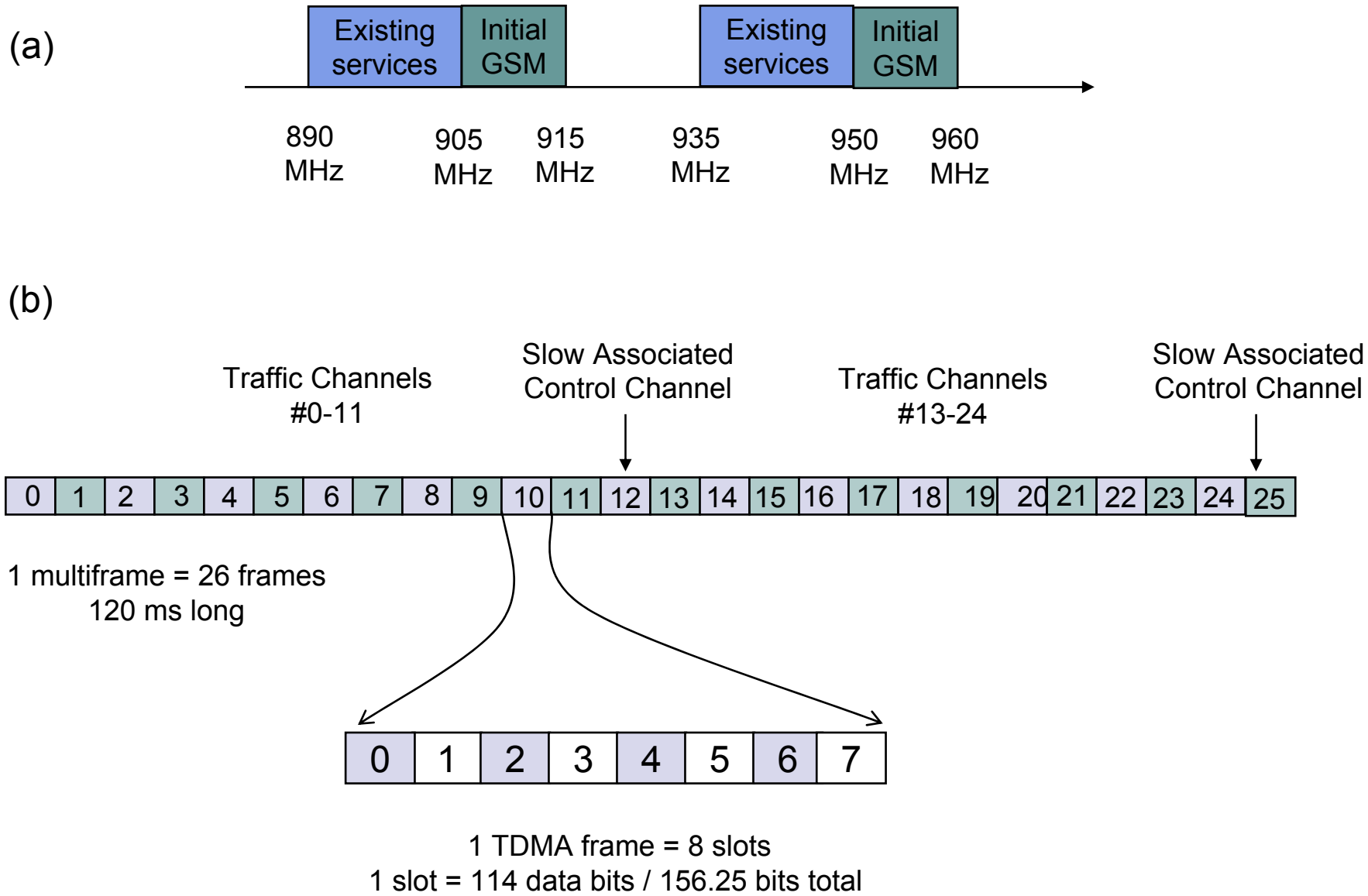


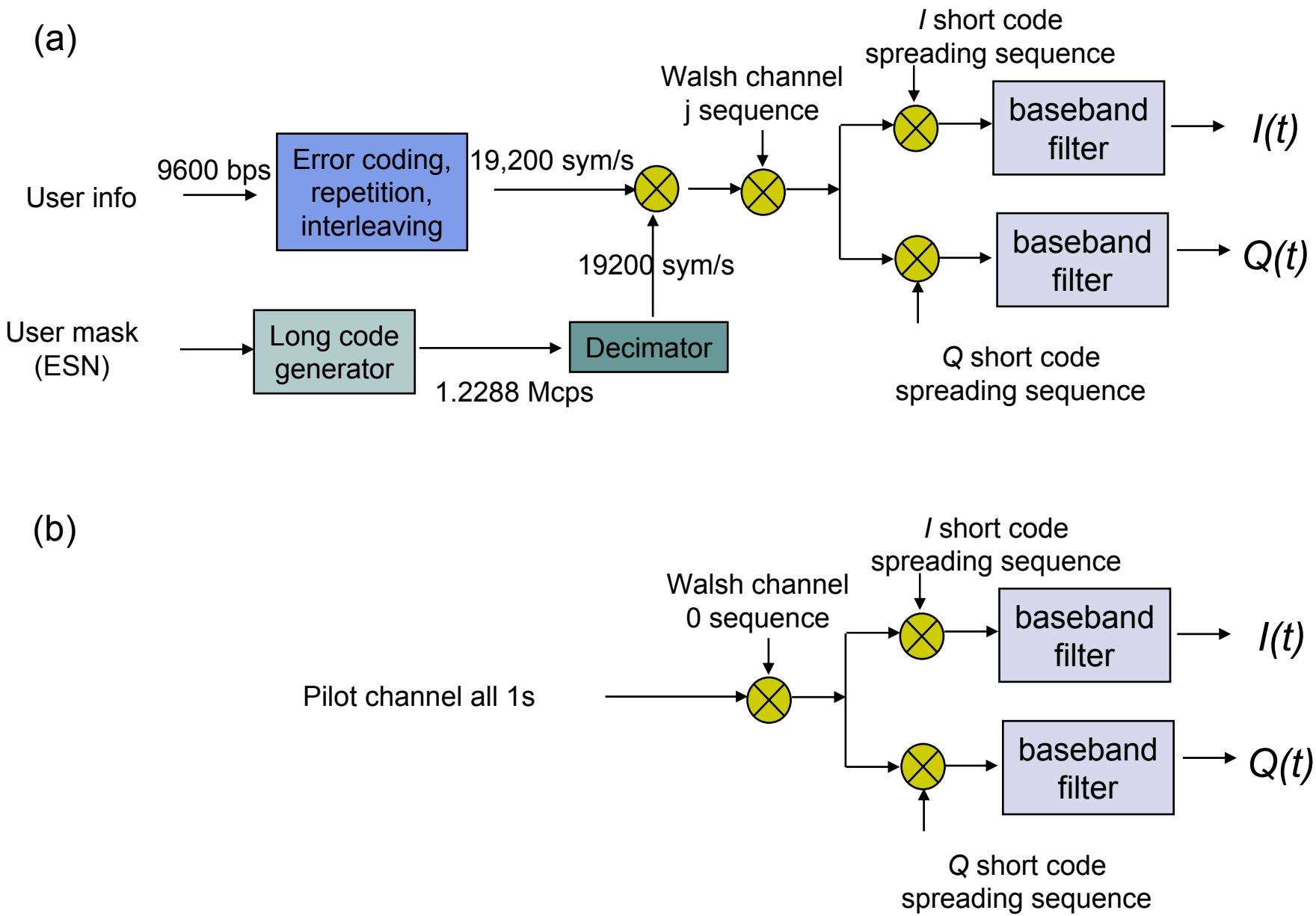
$$W_1 = \begin{bmatrix} 0 \end{bmatrix} \qquad W_2 = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix} \qquad W_4 = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 \end{bmatrix}$$

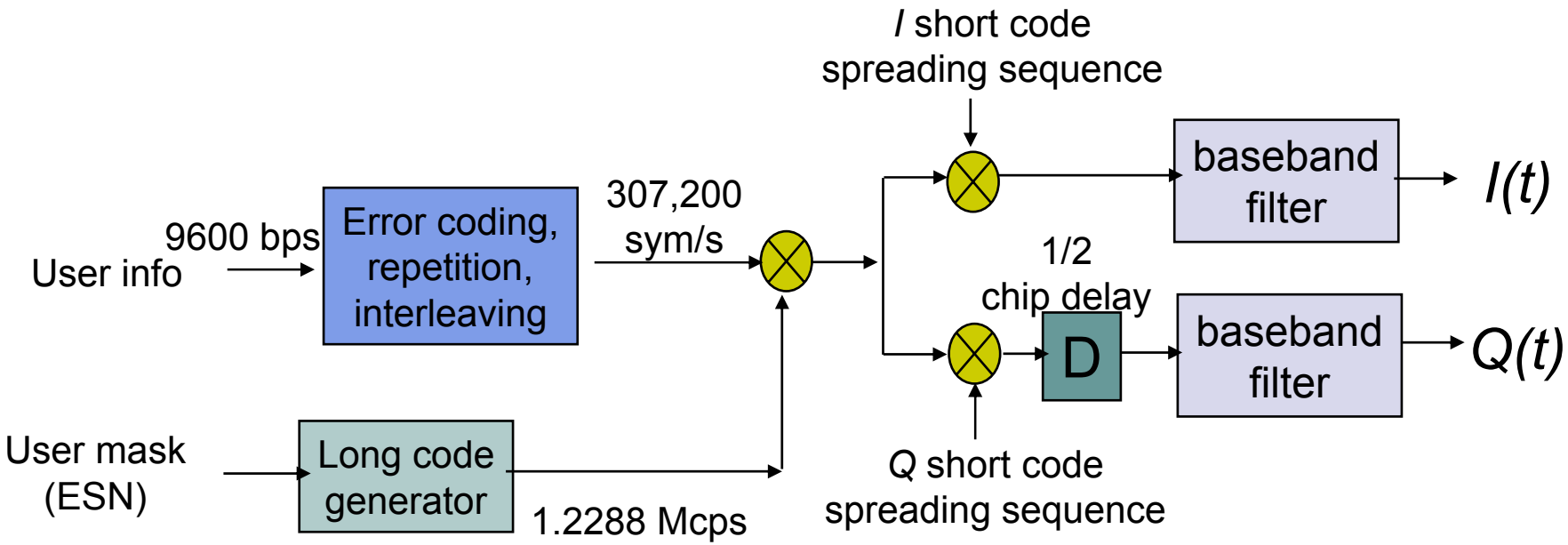
$$W_8 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 1 & 0 & 1 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 & 1 & 0 & 0 & 1 \end{bmatrix}$$

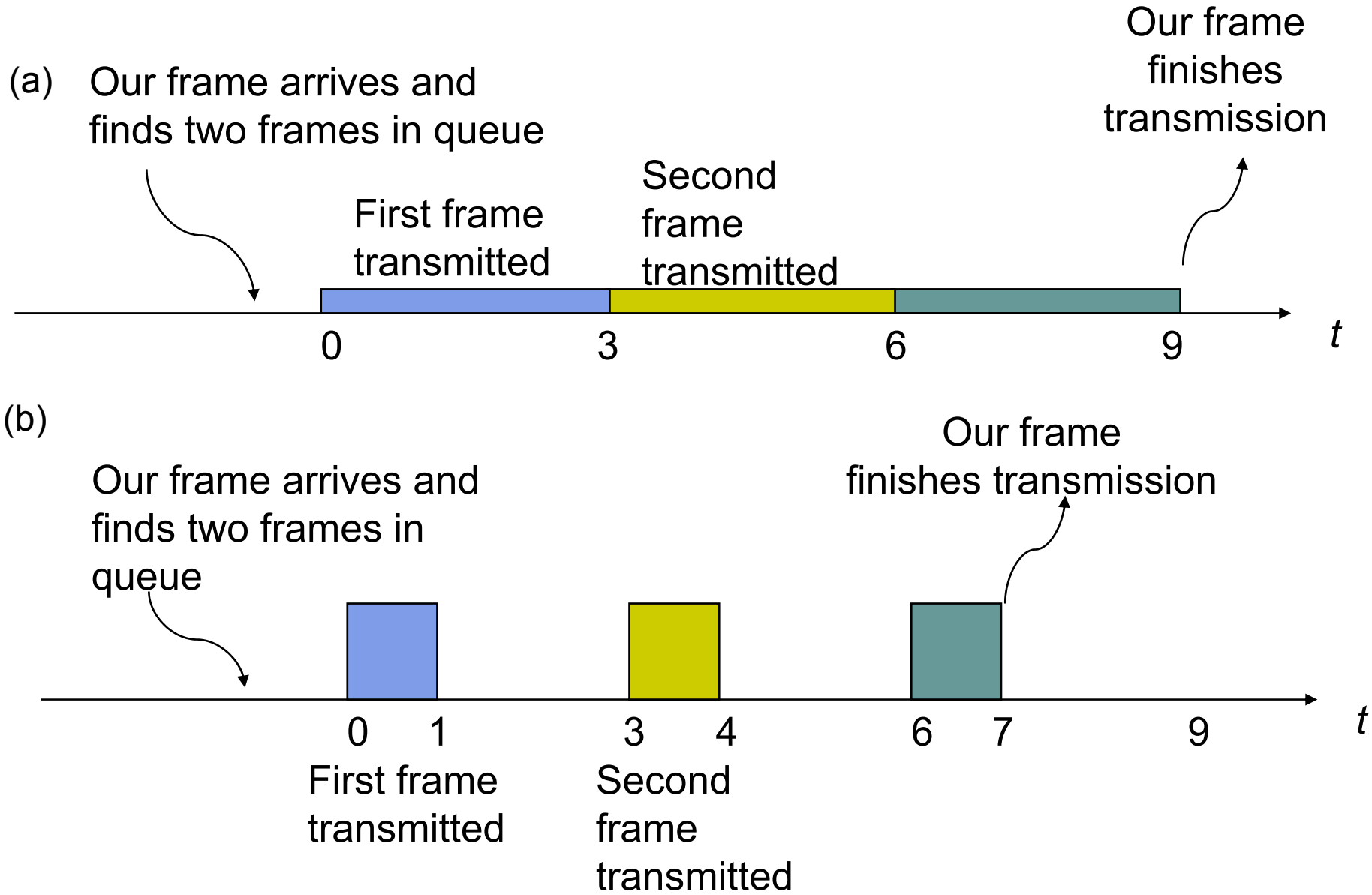

(a)
A
B
A
B
Frequency
825
MHz
845
MHz
870
MHz
890
MHz
(b)
A
A
B
A
B
A
A
B
A
B
Frequency
824
MHz
849
MHz
869
MHz
894
MHz

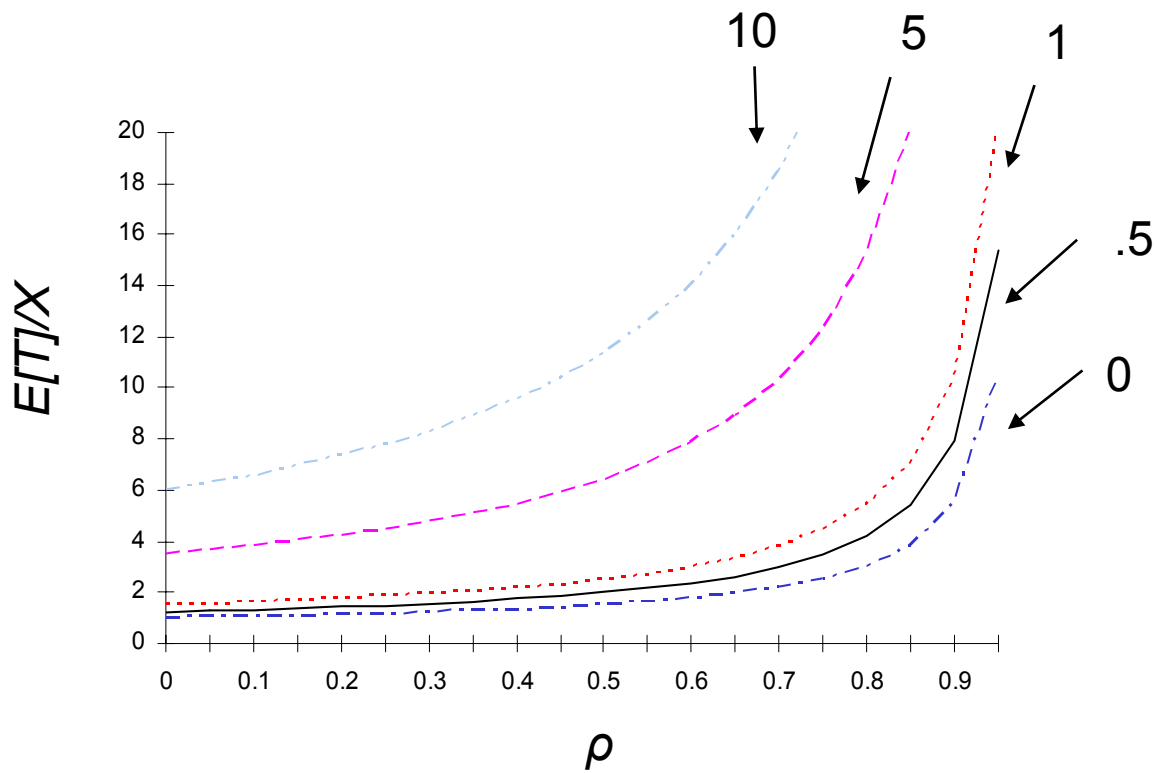

Base to mobile
6
1
2
3
4
5
6
1
2
3
Time
Mobile to base
1
2
3
4
5
6
1
2
3
4
Time
40 ms


(a)
Existing services
Initial GSM
Existing services
Initial GSM
890 MHz
905 MHz
915 MHz
935 MHz
950 MHz
960 MHz
(b)
Traffic Channels #0-11
Slow Associated Control Channel
Traffic Channels #13-24
Slow Associated Control Channel
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
1 multiframe = 26 frames
120 ms long
0 1 2 3 4 5 6 7
1 TDMA frame = 8 slots
1 slot = 114 data bits / 156.25 bits total

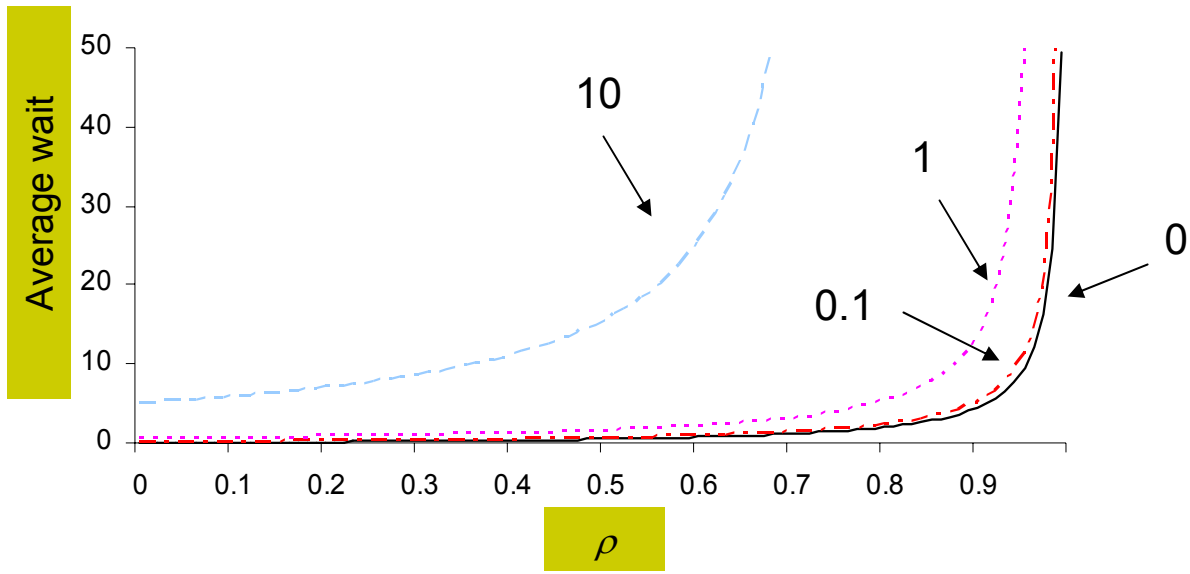

(a)
I short code spreading sequence
Walsh channel j sequence
baseband filter
I(t)
User info
9600 bps
Error coding, repetition, interleaving
19,200 sym/s
baseband filter
Q(t)
19200 sym/s
User mask (ESN)
Long code generator
Decimator
1.2288 Mcps
Q short code spreading sequence
(b)
I short code spreading sequence
Walsh channel 0 sequence
baseband filter
I(t)
Pilot channel all 1s
baseband filter
Q(t)
Q short code spreading sequence

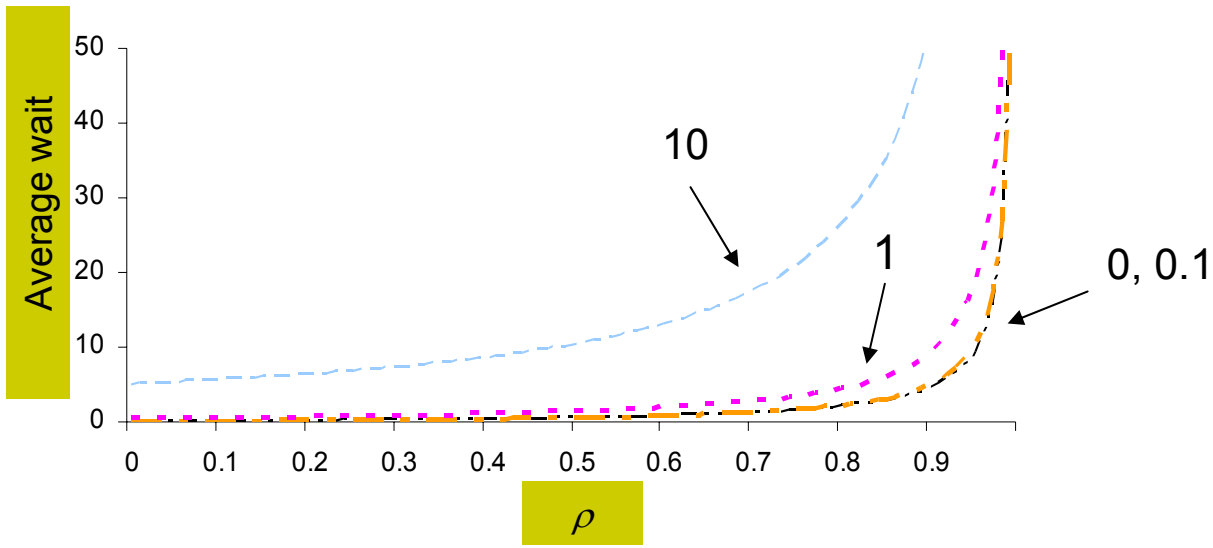

I short code
spreading sequence
baseband
filter
I(t)
9600 bps
User info
Error coding,
repetition,
interleaving
307,200
sym/s
1/2
chip delay
D
baseband
filter
Q(t)
User mask
(ESN)
Long code
generator
1.2288 Mcps
Q short code
spreading sequence

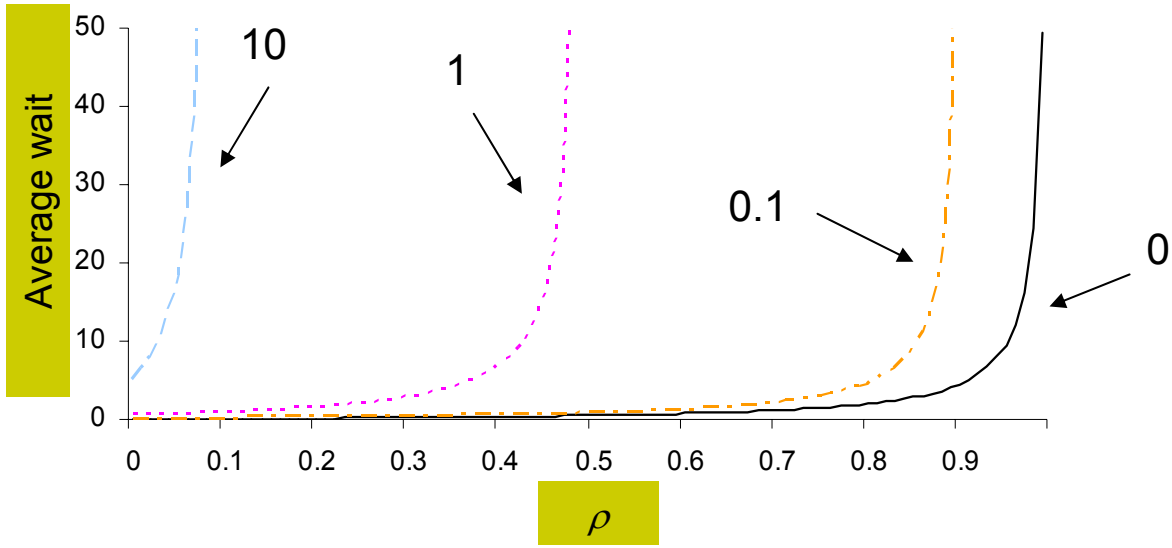

(a)
Our frame arrives and finds two frames in queue
First frame transmitted
Second frame transmitted
Our frame finishes transmission
0
3
6
9
t
(b)
Our frame arrives and finds two frames in queue
Our frame finishes transmission
0
1
3
4
6
7
9
t
First frame transmitted
Second frame transmitted



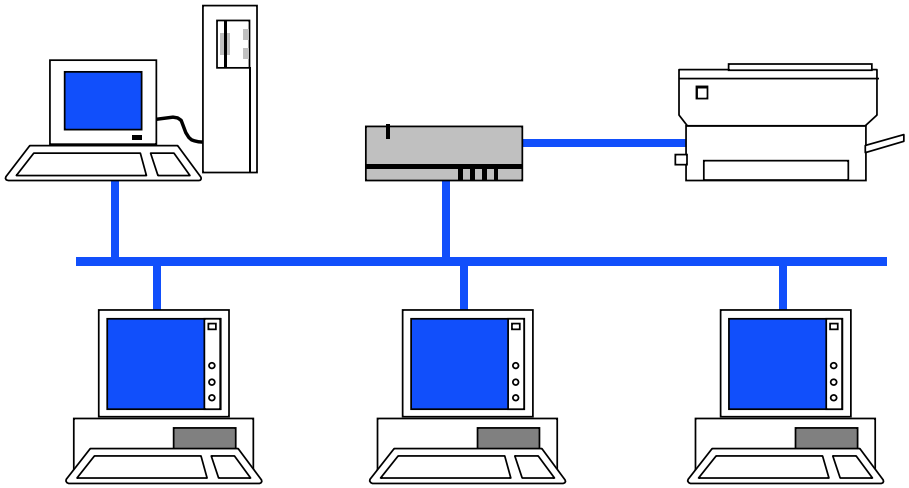

$$a' = \frac{\tau'}{X}$$


Average wait
50
40
30
20
10
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
ρ
10
1
0.1
0

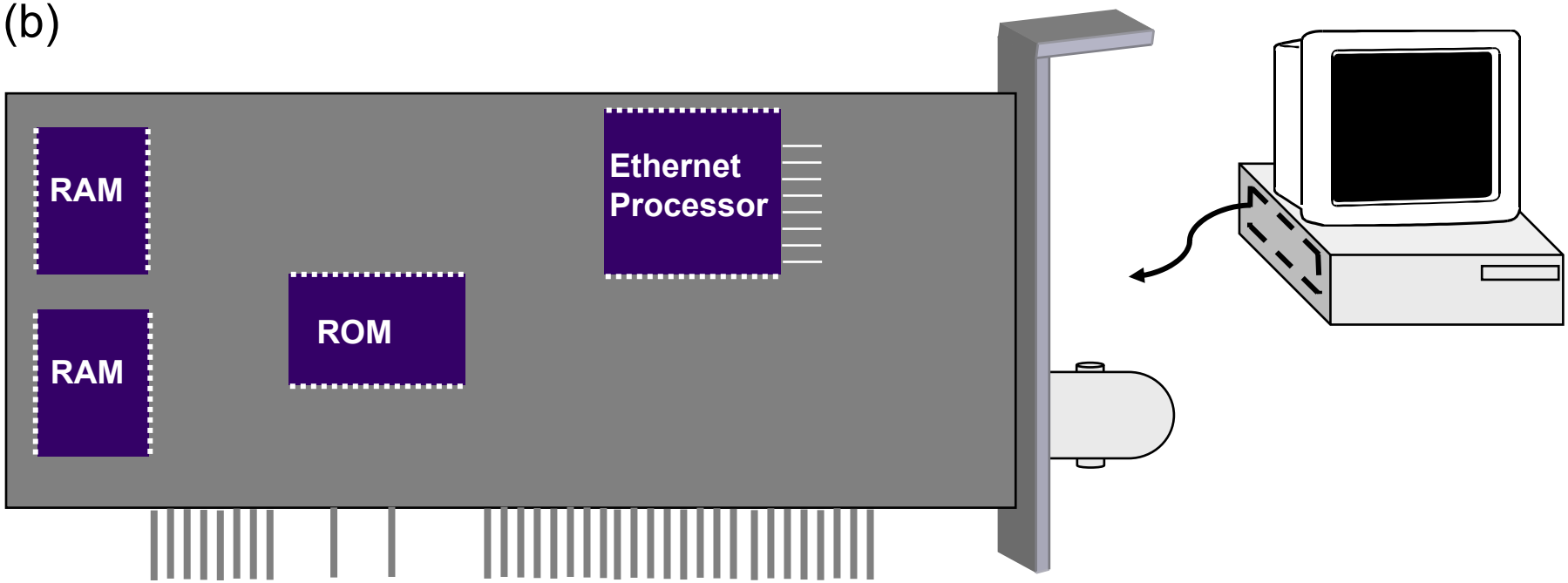

Average wait
50
40
30
20
10
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
ρ
10
1
0, 0.1

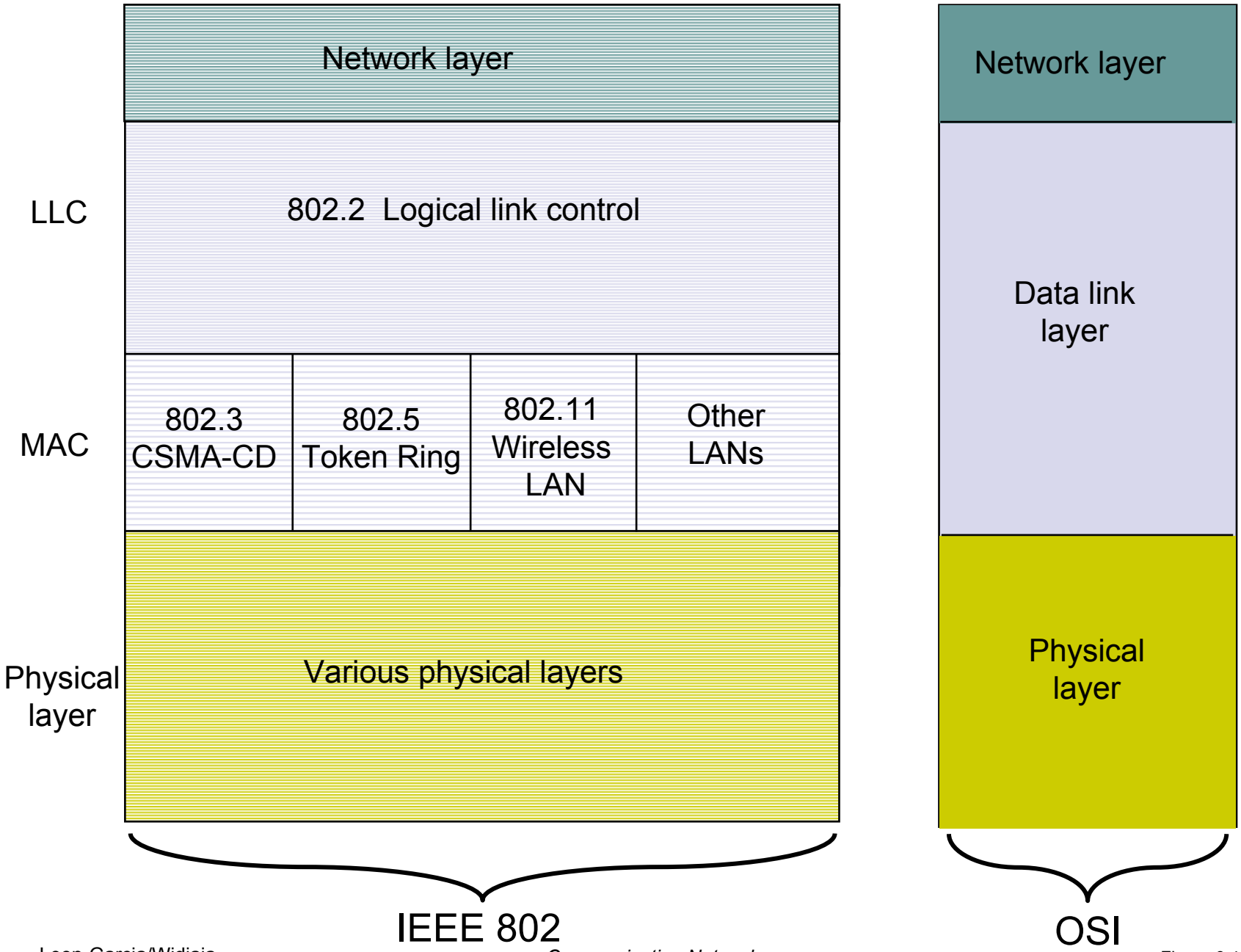

Average wait
50
40
30
20
10
0
10
1
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
ρ

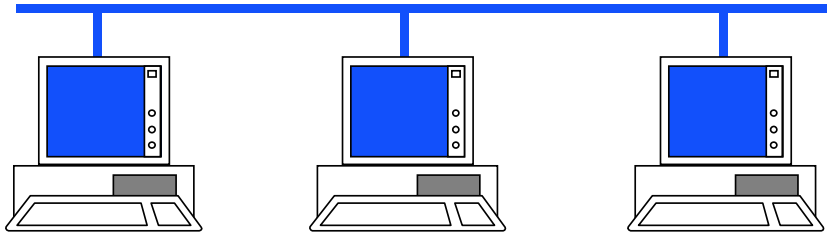
(a)



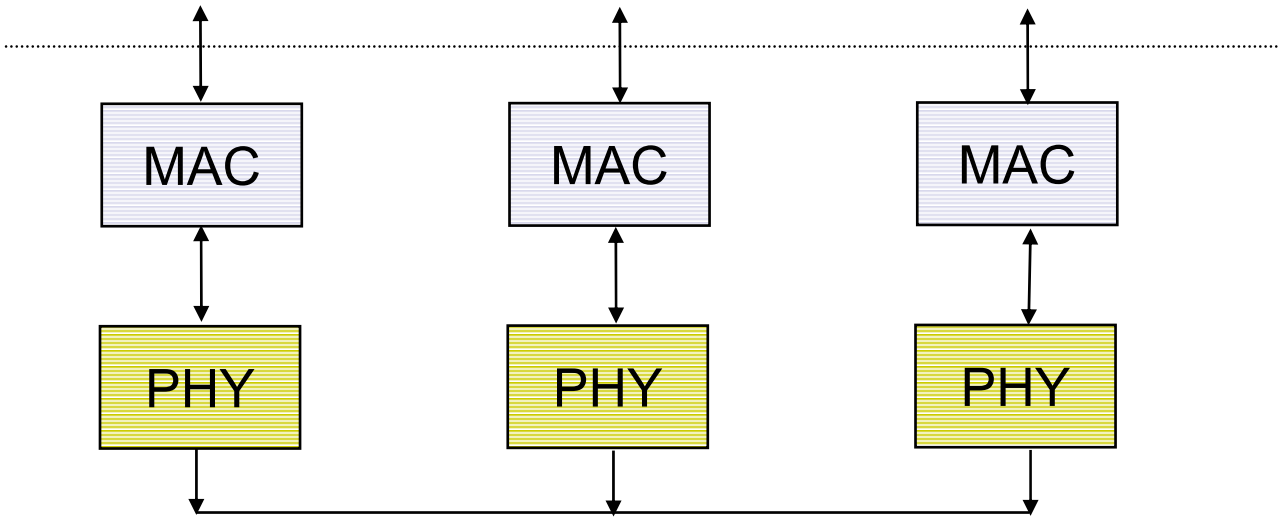
(b)

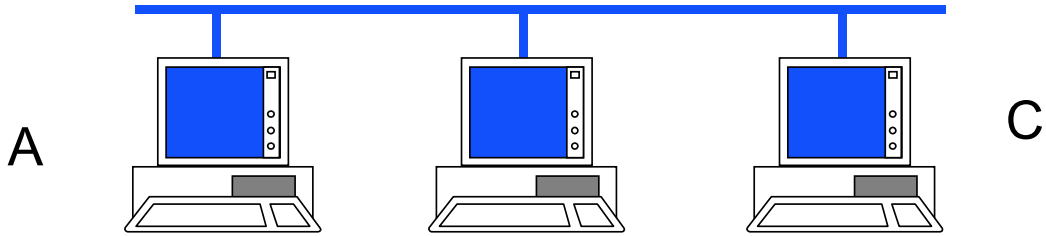


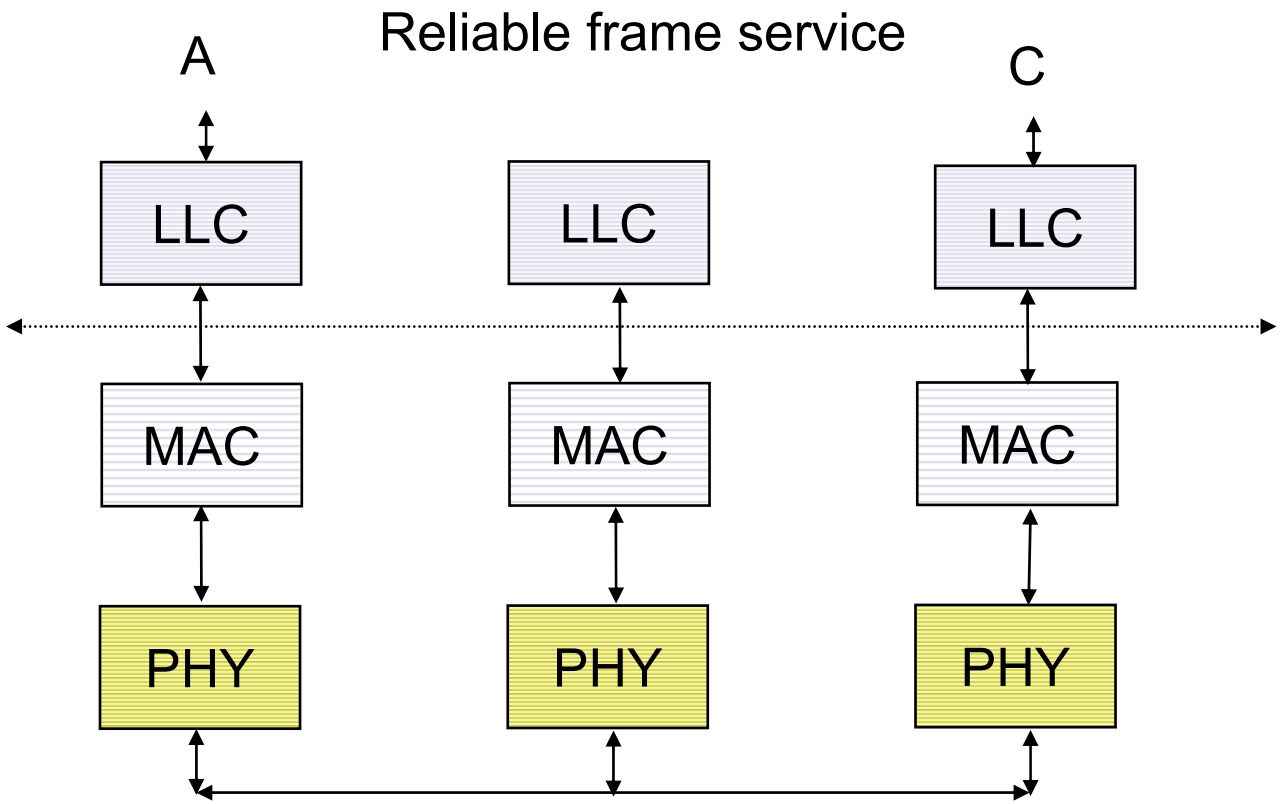

Network layer
LLC
802.2 Logical link control
MAC
802.3 CSMA-CD
802.5 Token Ring
802.11 Wireless LAN
Other LANs
Physical layer
Various physical layers
IEEE 802
Network layer
Data link layer
Physical layer
OSI

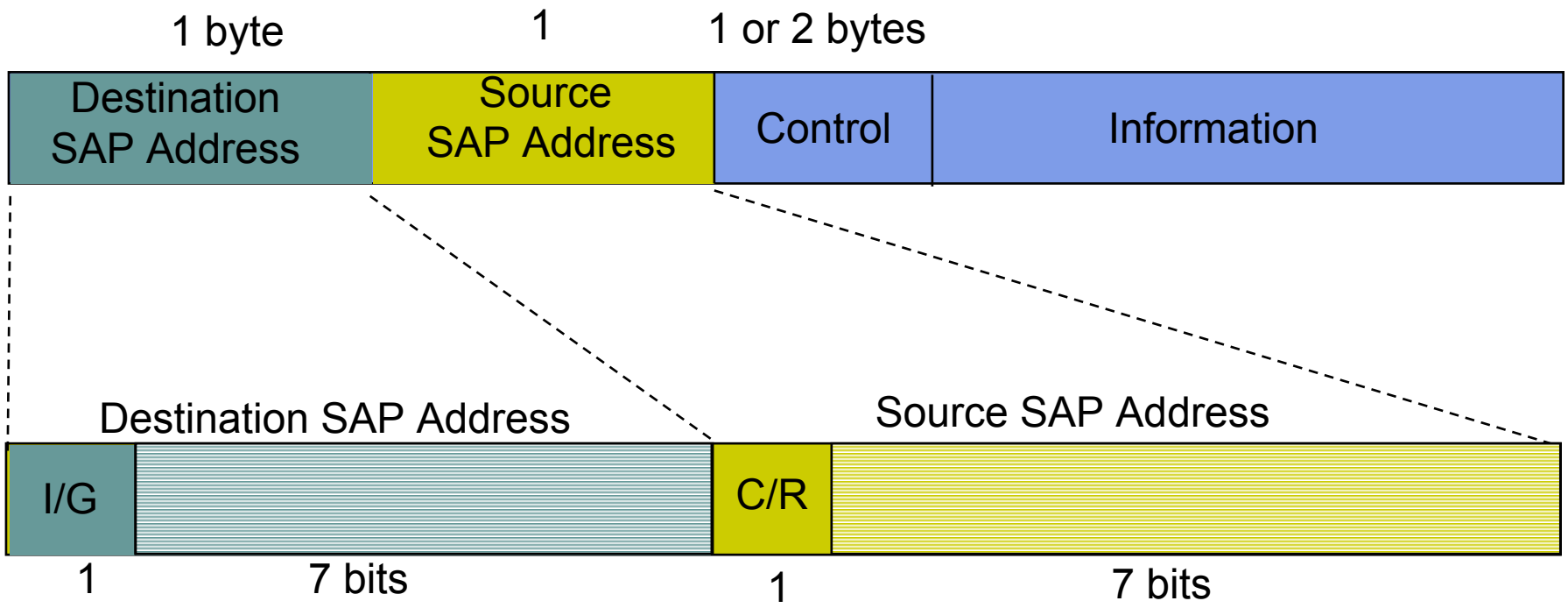


Unreliable Datagram Service

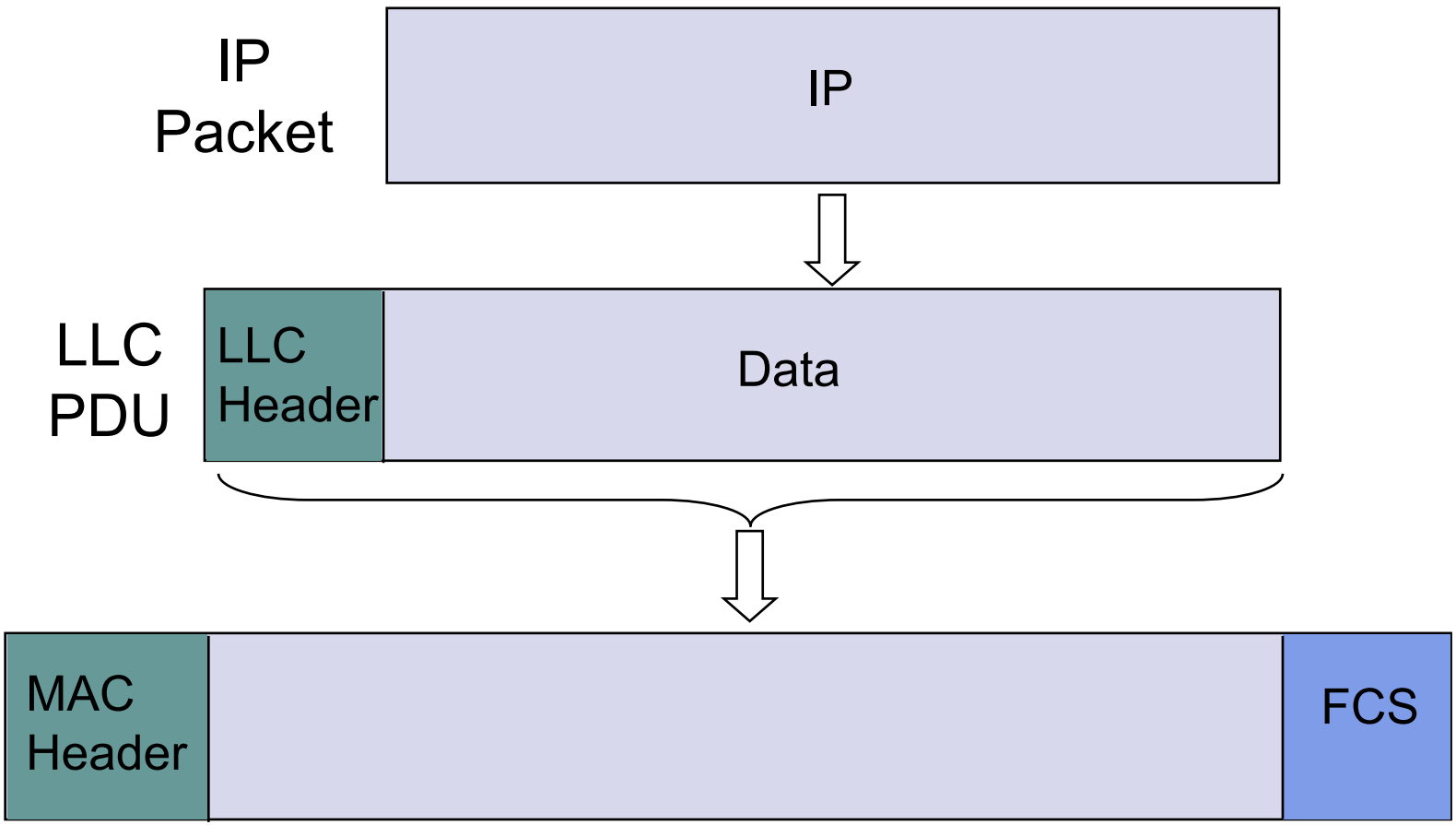


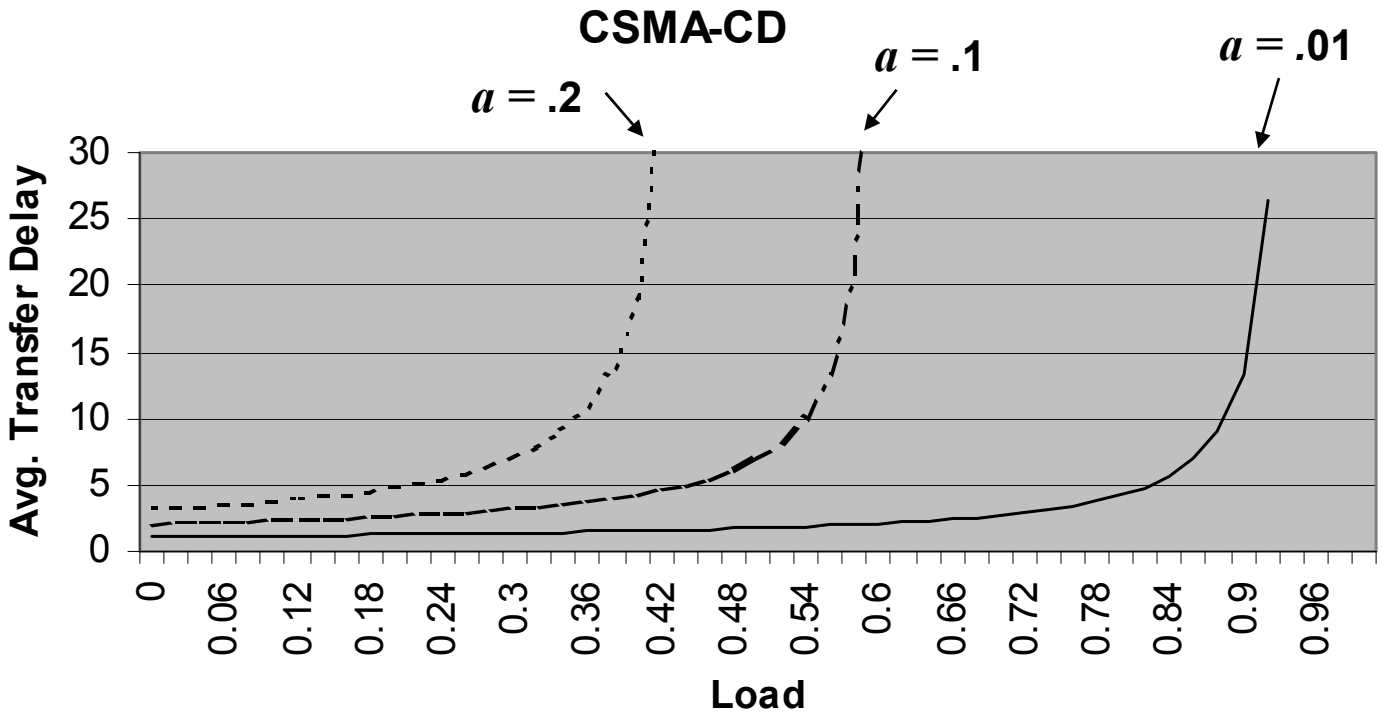

A
C

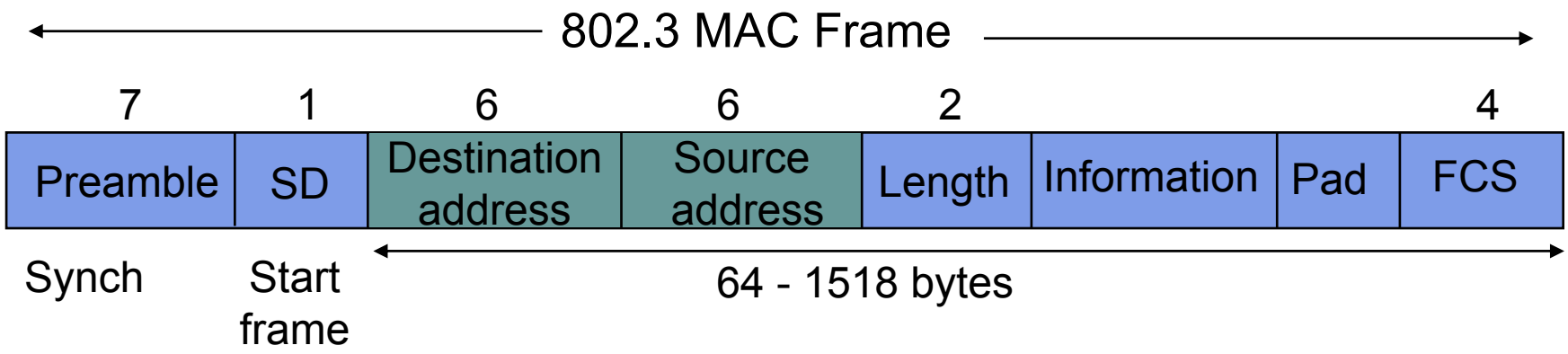

Reliable frame service
A
C
LLC
LLC
LLC
MAC
MAC
MAC
PHY
PHY
PHY

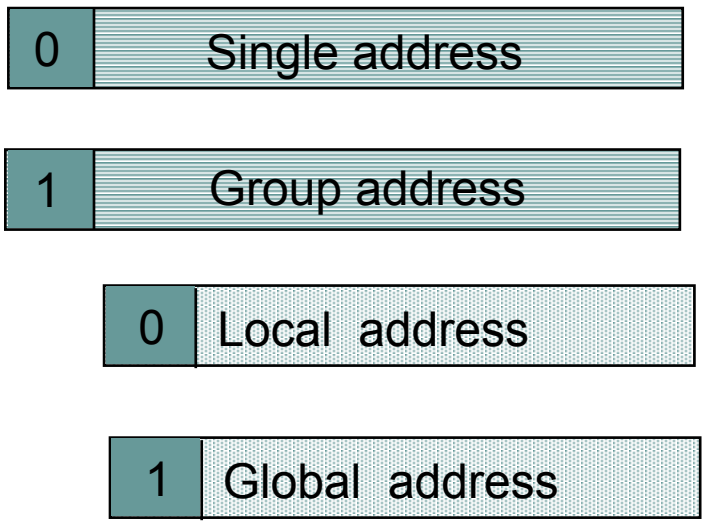



I/G = Individual or group address
C/R = Command or response frame


IP
Packet
IP
LLC
PDU
LLC
Header
Data
MAC
Header
FCS

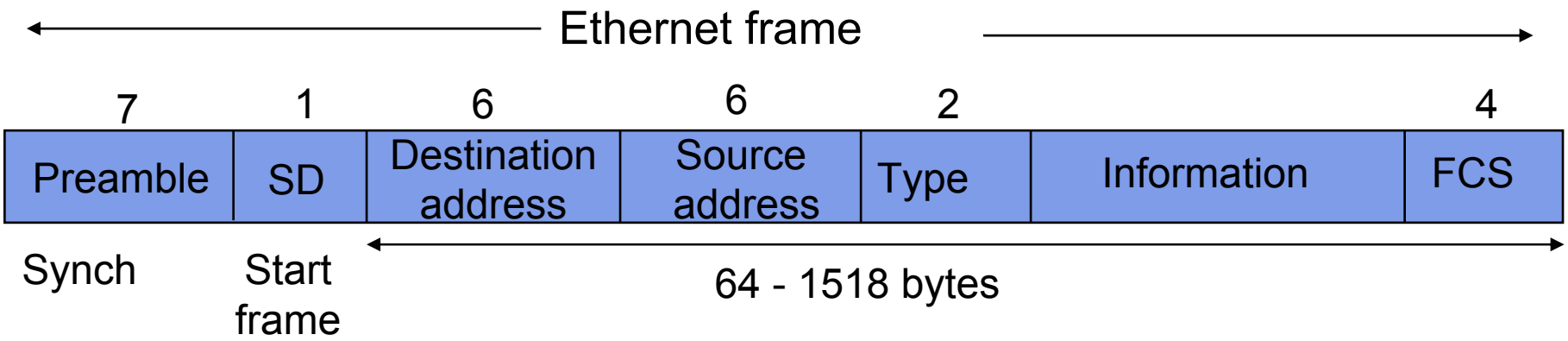

CSMA-CD
a = .2
a = .1
a = .01
Avg. Transfer Delay
30
25
20
15
10
5
0
0
0.06
0.12
0.18
0.24
0.3
0.36
0.42
0.48
0.54
0.6
0.66
0.72
0.78
0.84
0.9
0.96
Load

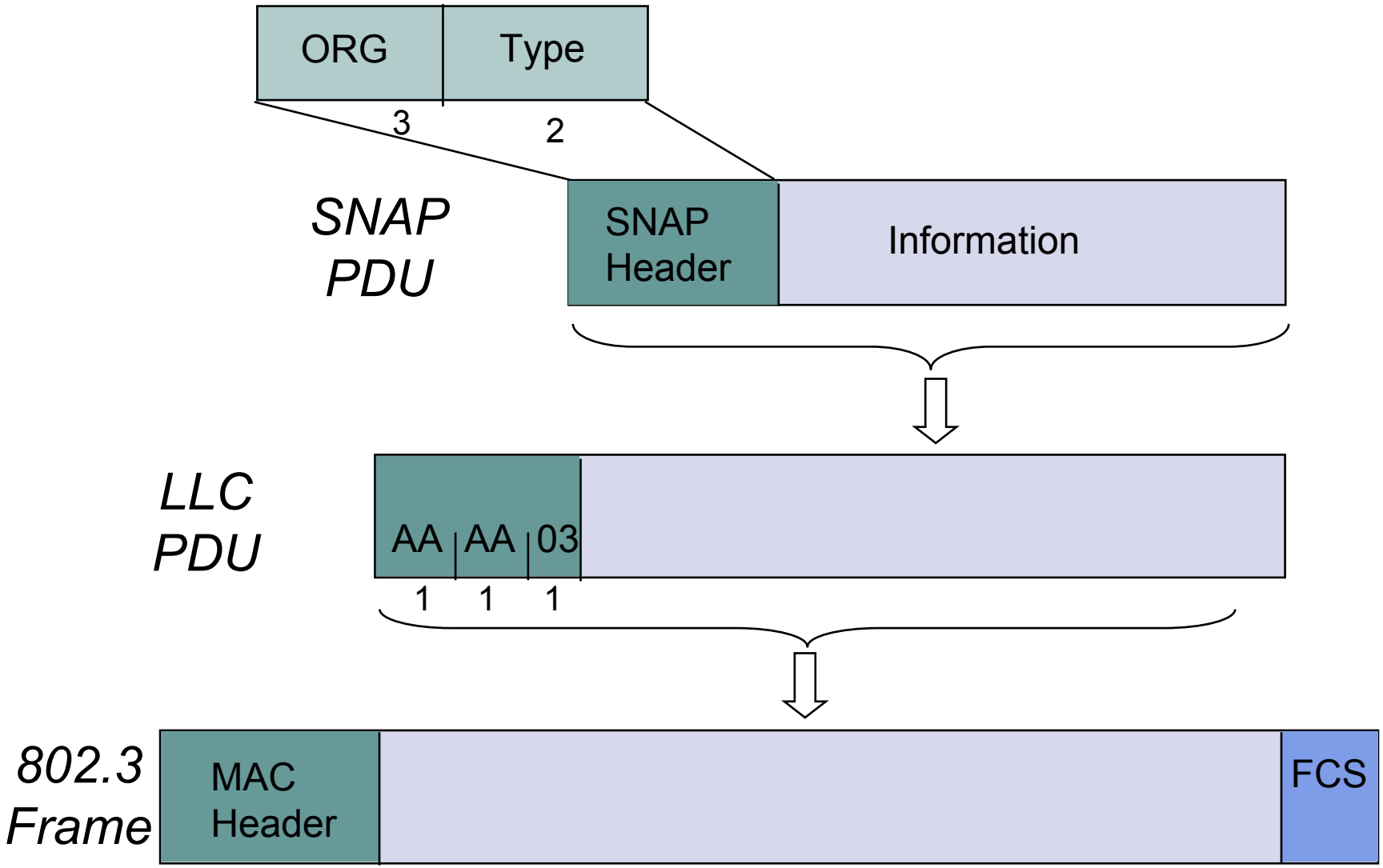


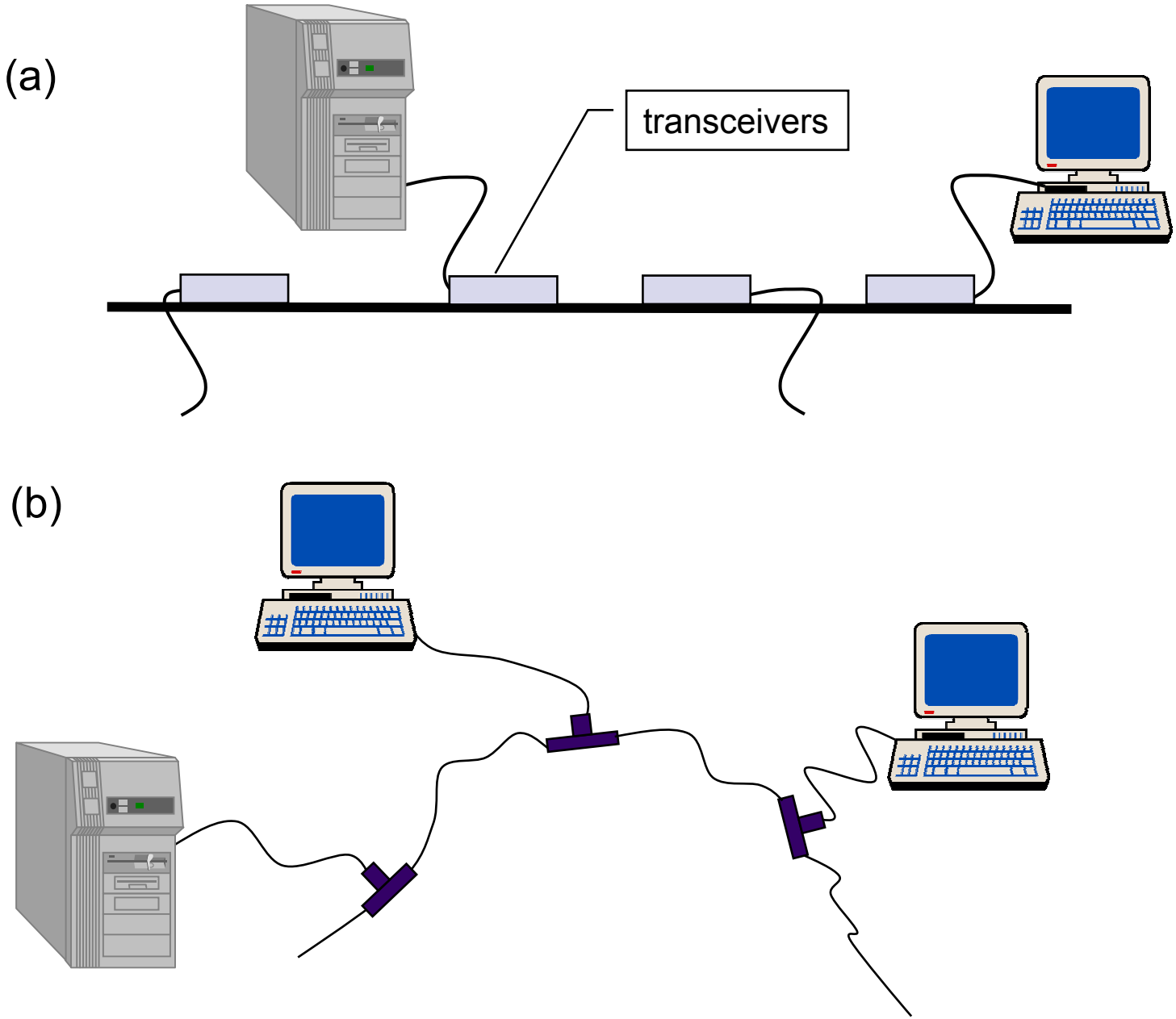



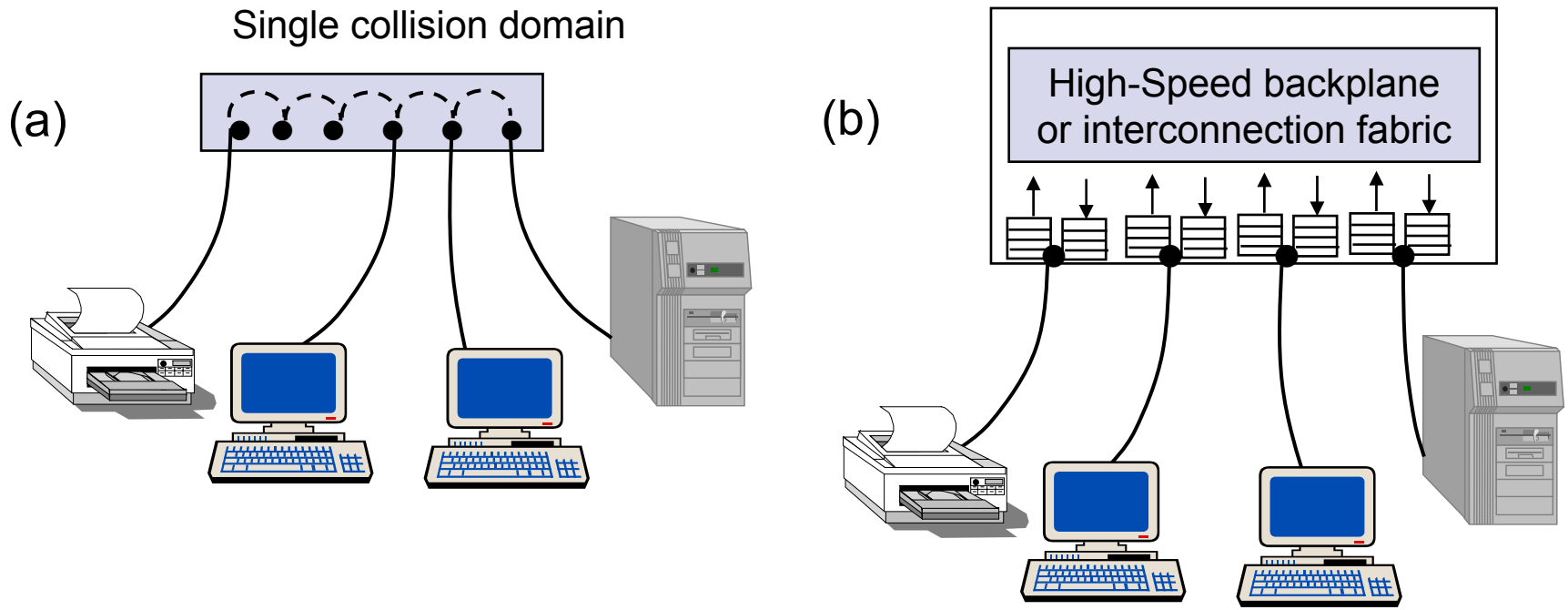

- Destination address is either single address or group address (broadcast = 111...111)

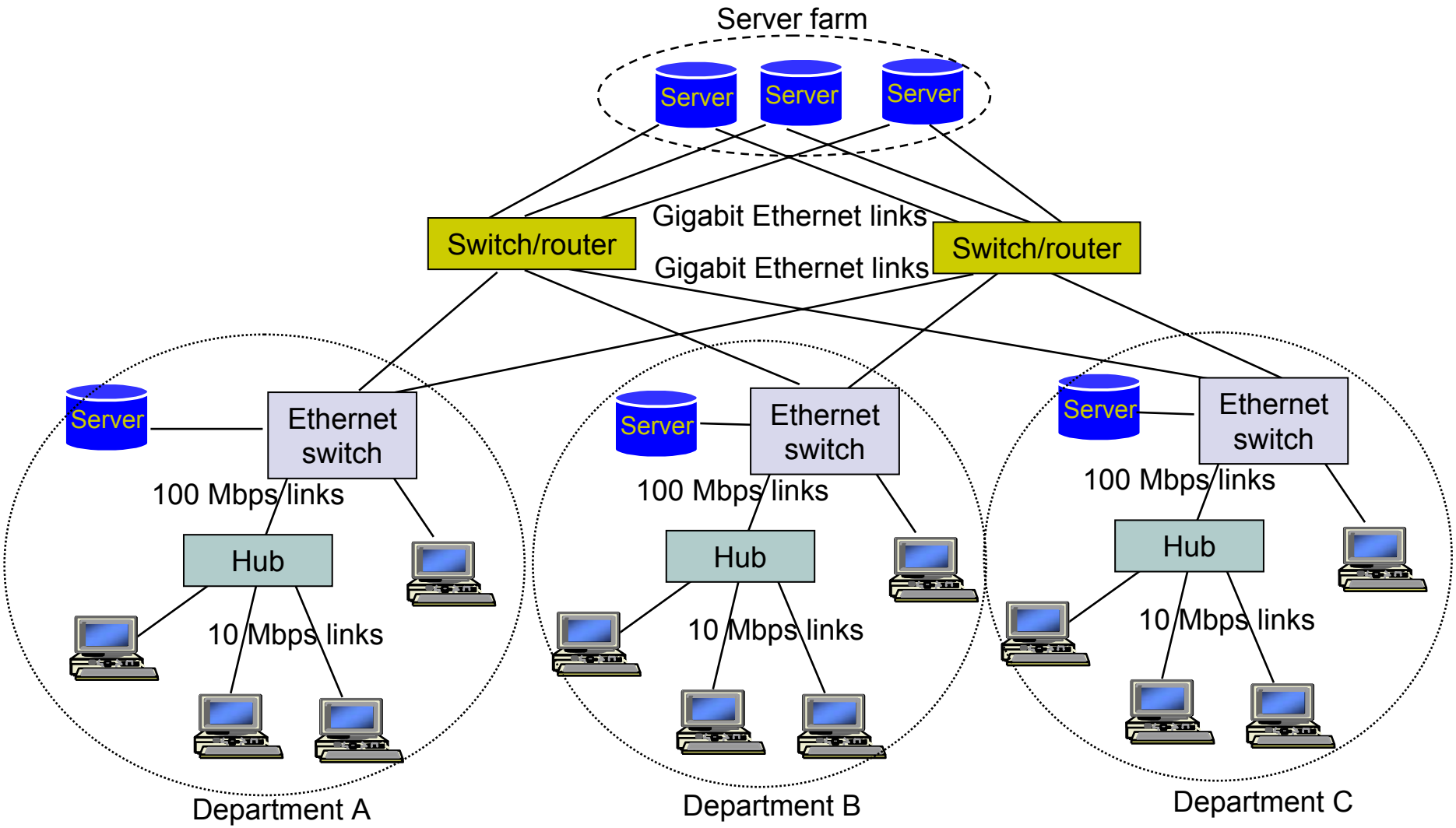
- Addresses are defined on local or universal basis
- $2^{46}$ possible global addresses

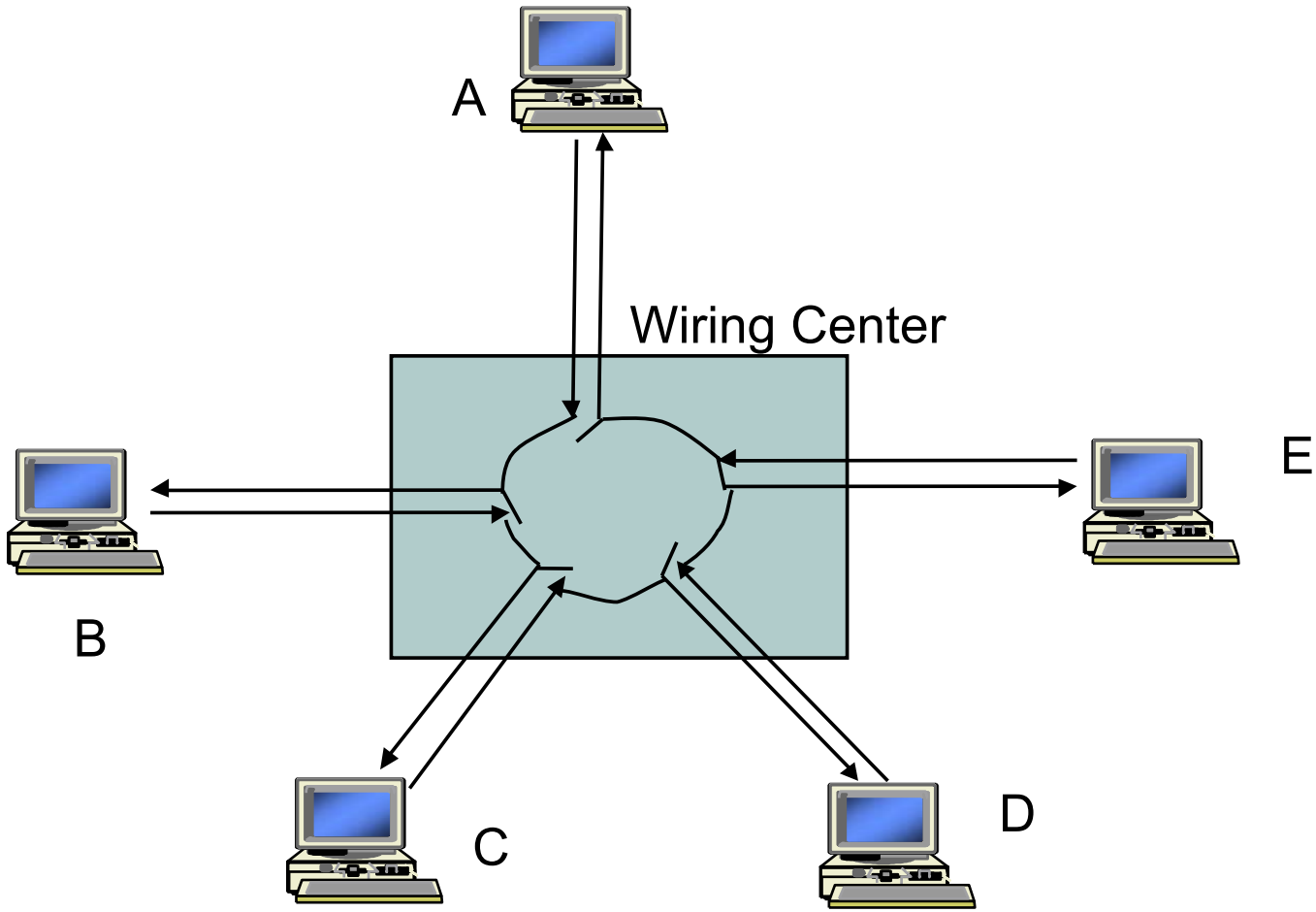

Ethernet frame
7
1
6
6
2
4
Preamble
SD
Destination address
Source address
Type
Information
FCS
Synch
Start frame
64 - 1518 bytes


ORG
Type
3
2
SNAP PDU
SNAP Header
Information
LLC PDU
AA
AA
03
1
1
1
802.3 Frame
MAC Header
FCS

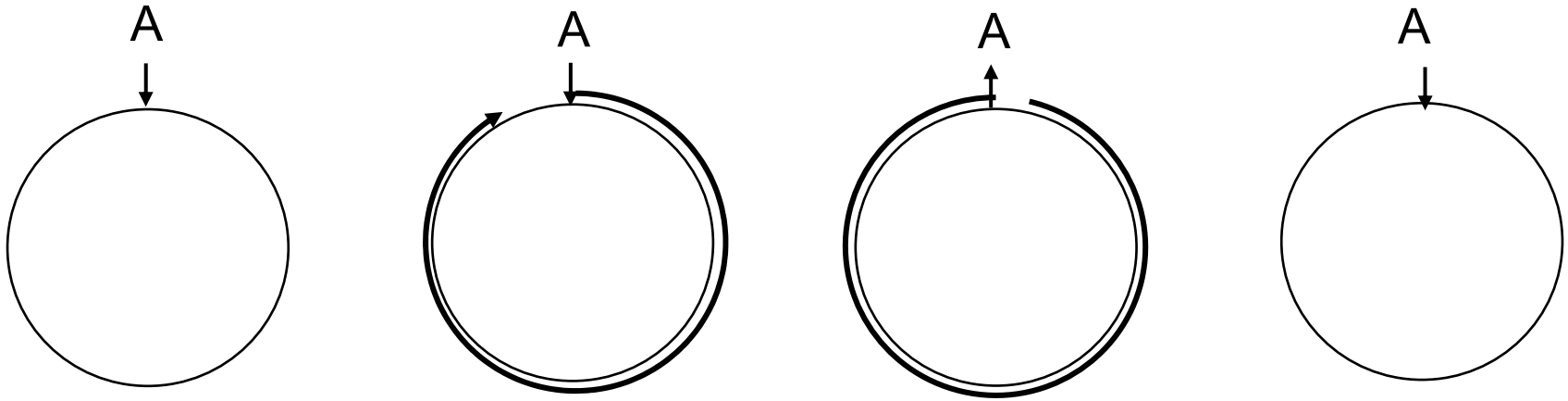

(a)
transceivers
(b)


Single collision domain
(a)
(b)
High-Speed backplane
or interconnection fabric


Server farm
Server
Server
Server
Gigabit Ethernet links
Gigabit Ethernet links
Switch/router
Switch/router
Server
Ethernet switch
100 Mbps links
Hub
10 Mbps links
Department A
Server
Ethernet switch
100 Mbps links
Hub
10 Mbps links
Department B
Server
Ethernet switch
100 Mbps links
Hub
10 Mbps links
Department C


A
Wiring Center
B
E
C
D

(a) Low Latency Ring



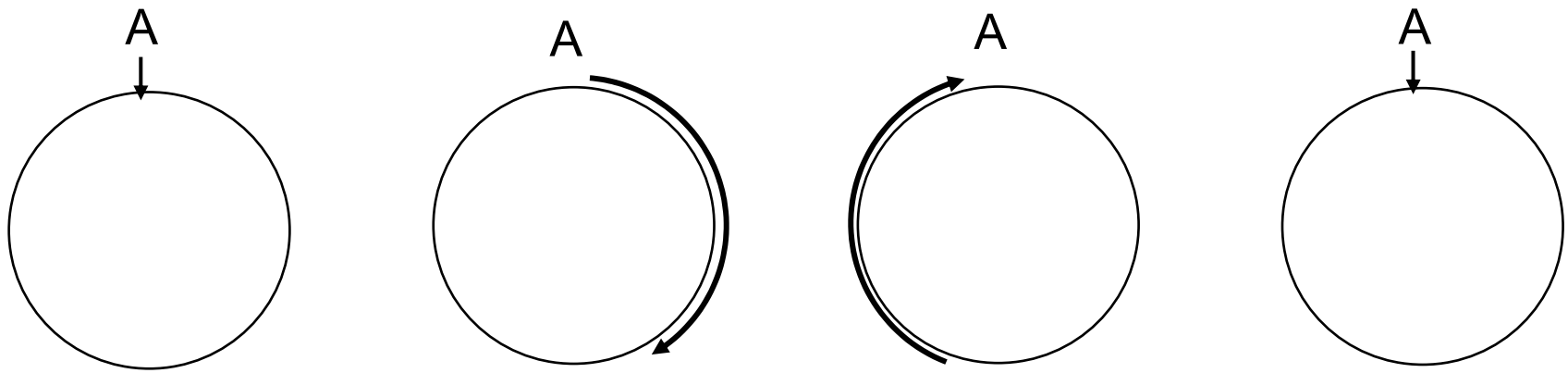

$t$ = 0, A begins frame

$t$ = 90, return of first bit

$t$ = 400, transmit last bit

$t$ = 490, reinsert token

(b) High Latency Ring



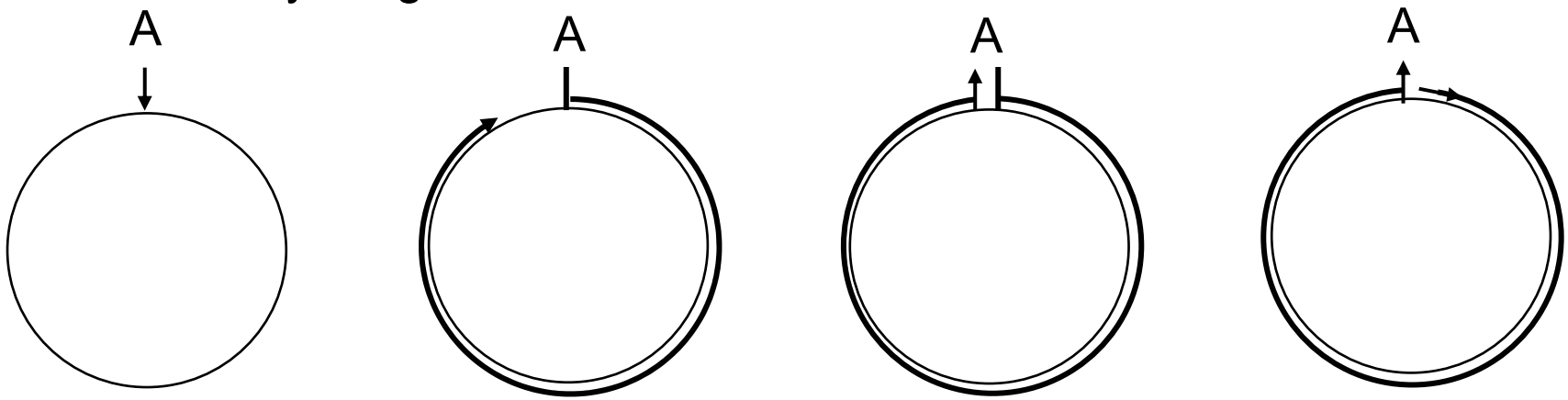

$t$ = 0, A begins frame

$t$ = 400, last bit of frame enters ring

$t$ = 840, return of first bit

$t$ = 1240, reinsert token

(a) Low Latency Ring



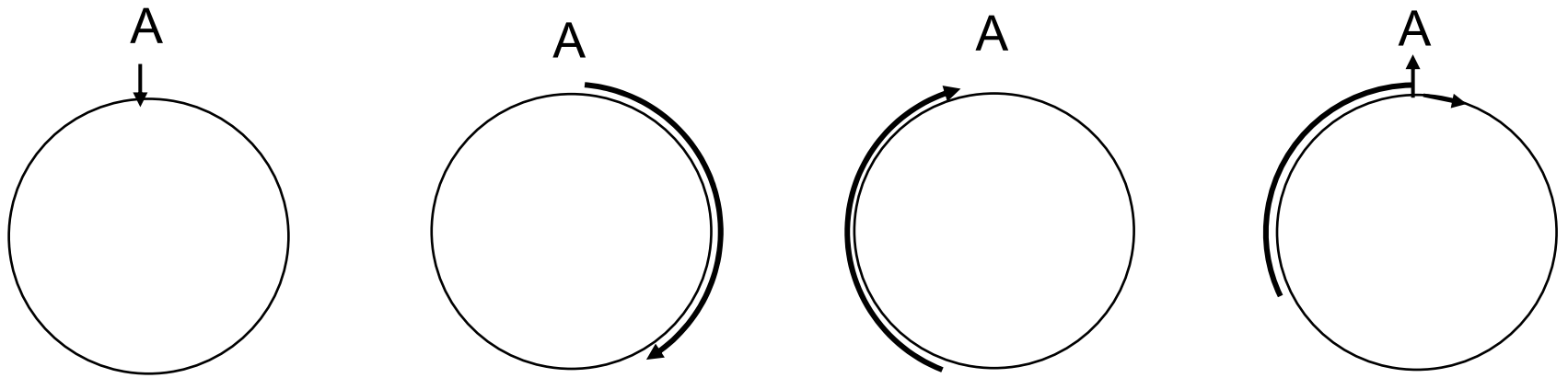

$t$ = 0, A begins frame

$t$ = 90, return of first bit

$t$ = 210, return of header

$t$ = 400, last bit enters ring, reinsert token

(b) High Latency Ring




$t$ = 0, A begins frame

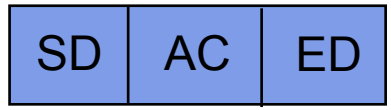
$t$ = 400, transmit last bit

$t$ = 840, arrival first frame bit

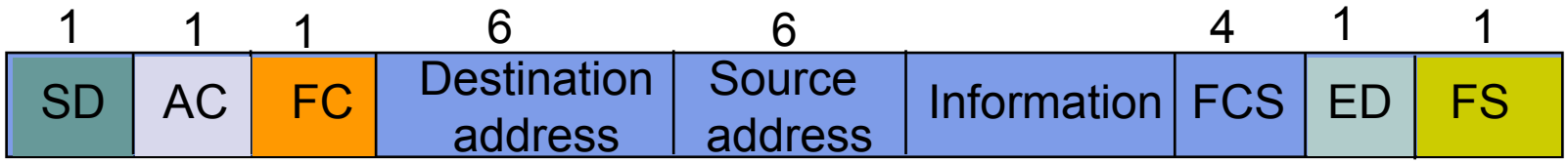
$t$ = 960, reinsert token

Figure 6.60

## Token frame format



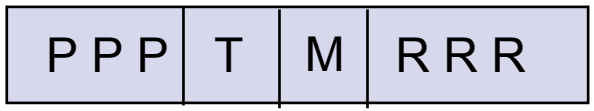

## Data frame format




**Starting delimiter**


J, K nondata symbols (line code)

**Access control**




PPP=priority; T=token bit
M=monitor bit; RRR=reservation

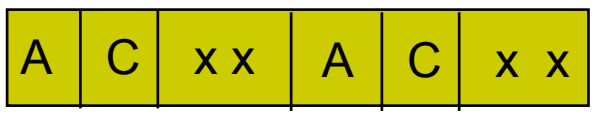
**Frame control**


FF = frame type
ZZZZZZ = control bits

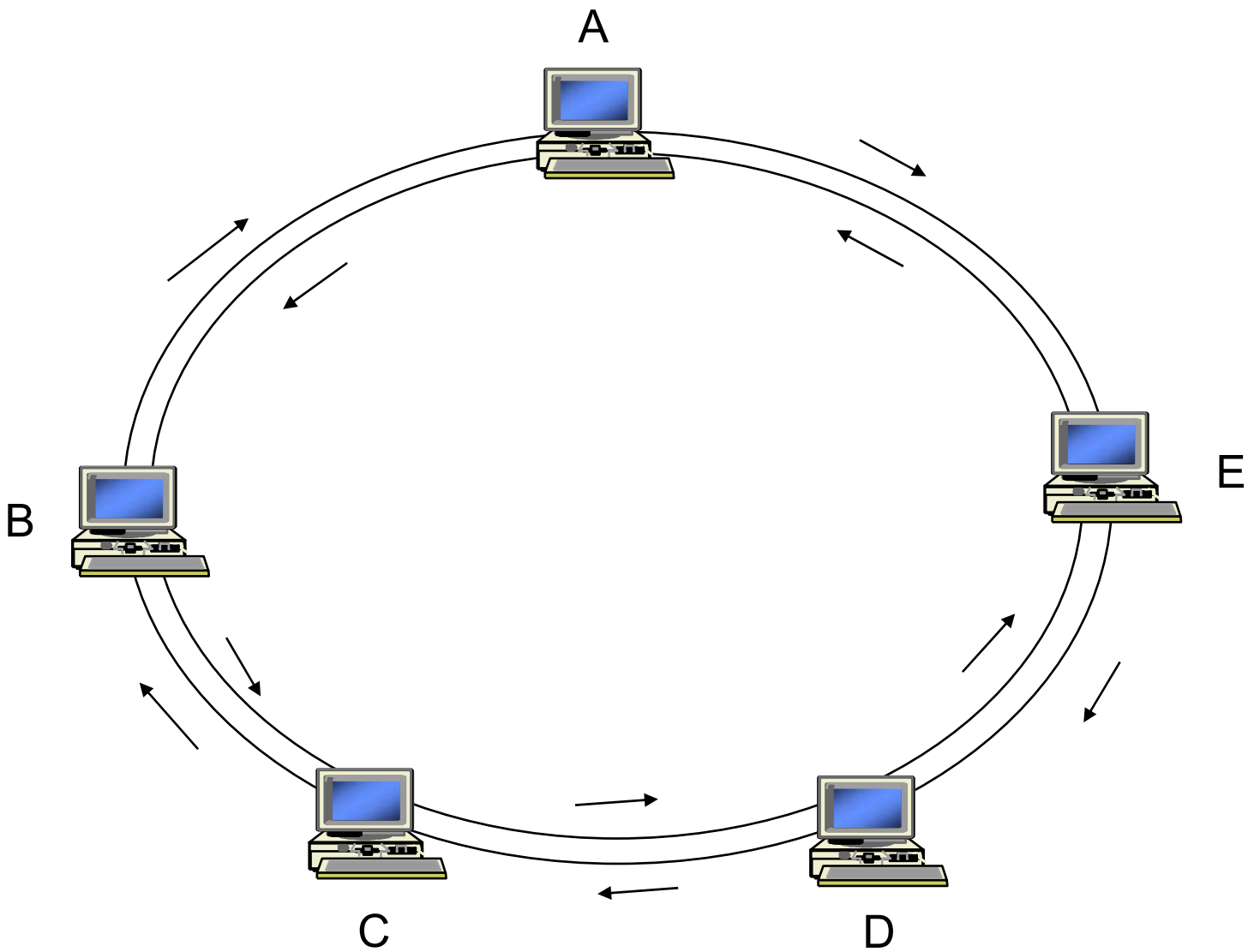
**Ending delimiter**


I = intermediate-frame bit
E = error-detection bit

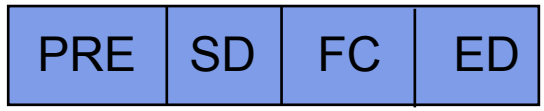
**Frame status**



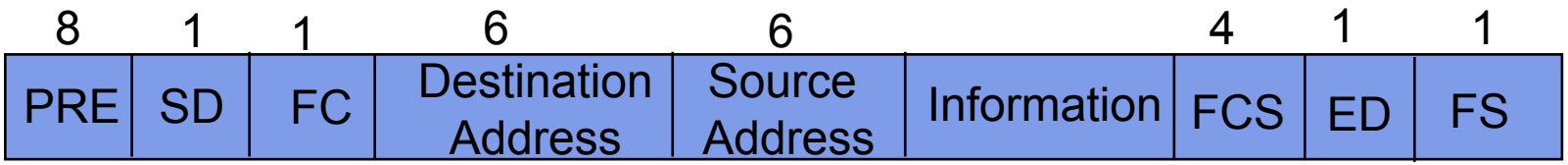

A = address-recognized bit
xx = undefined
C = frame-copied bit


A
B
C
D
E

Token Frame Format



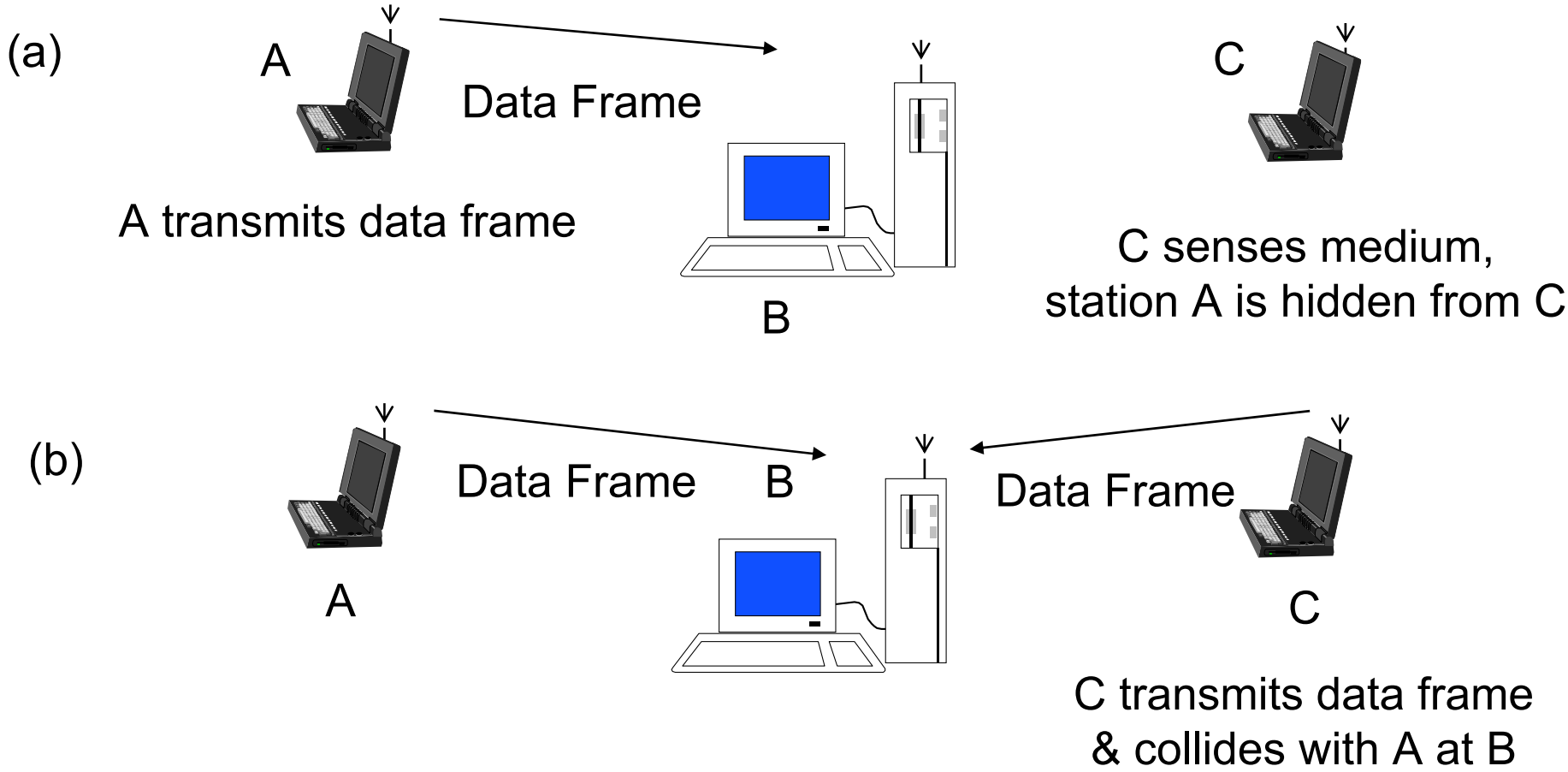

Data Frame Format

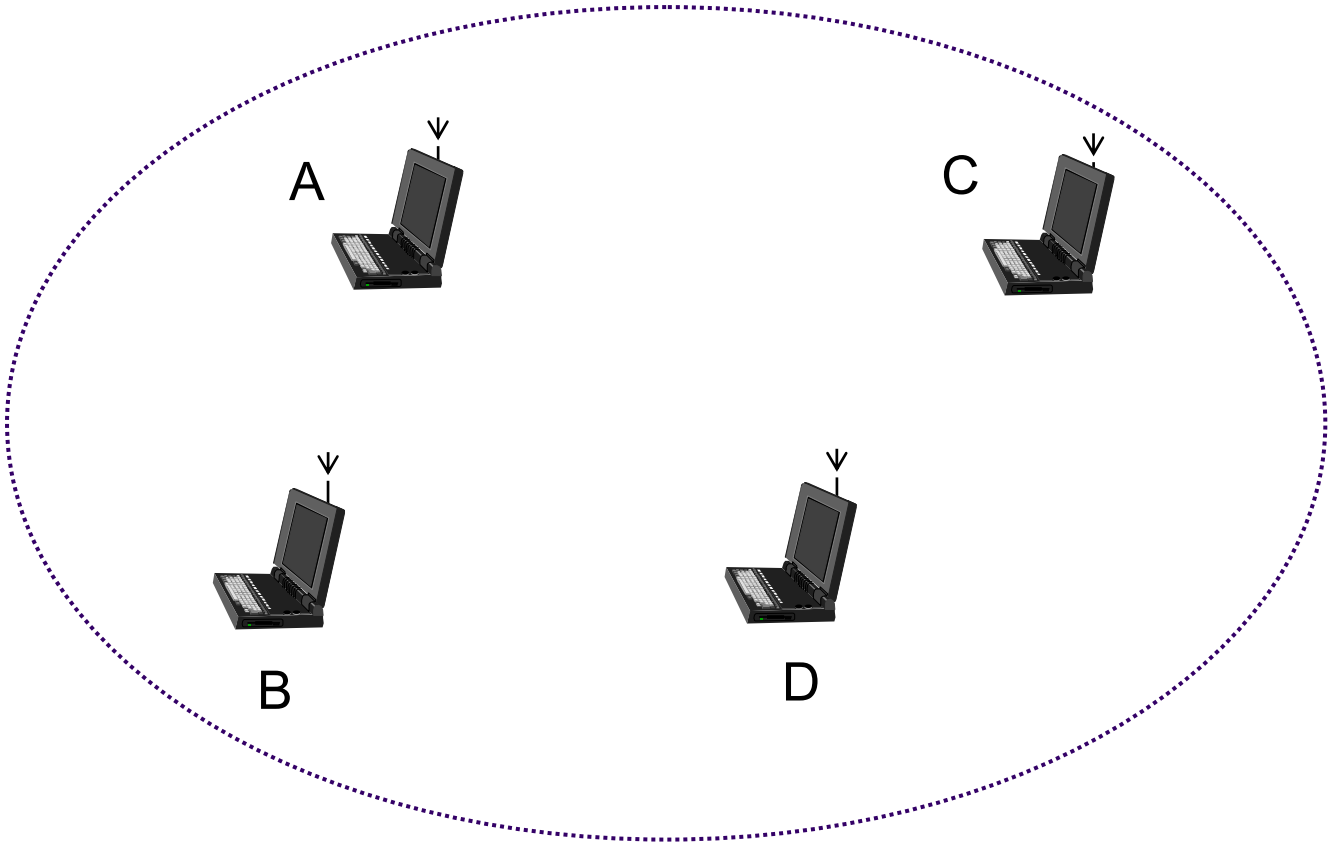


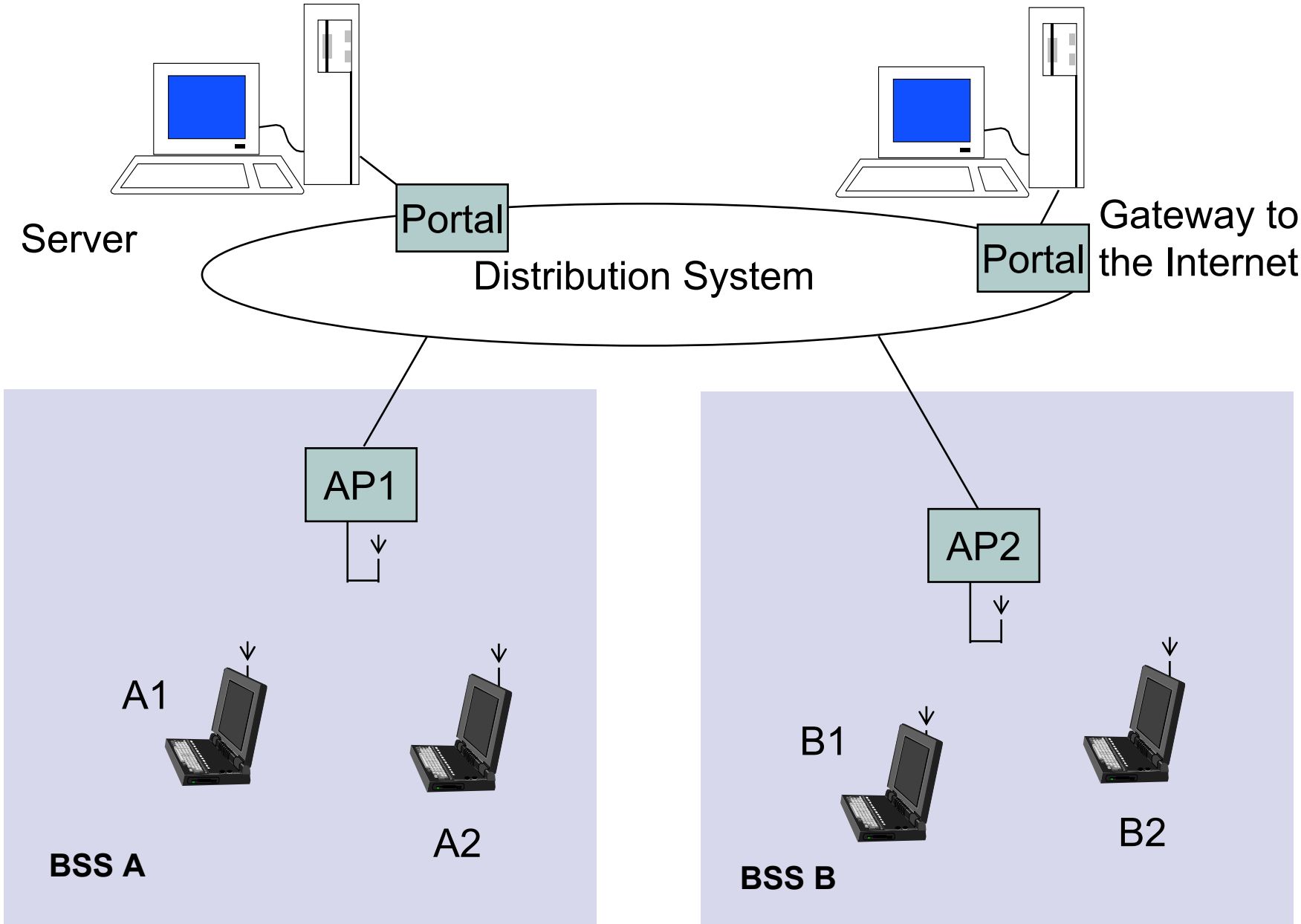

Preamble

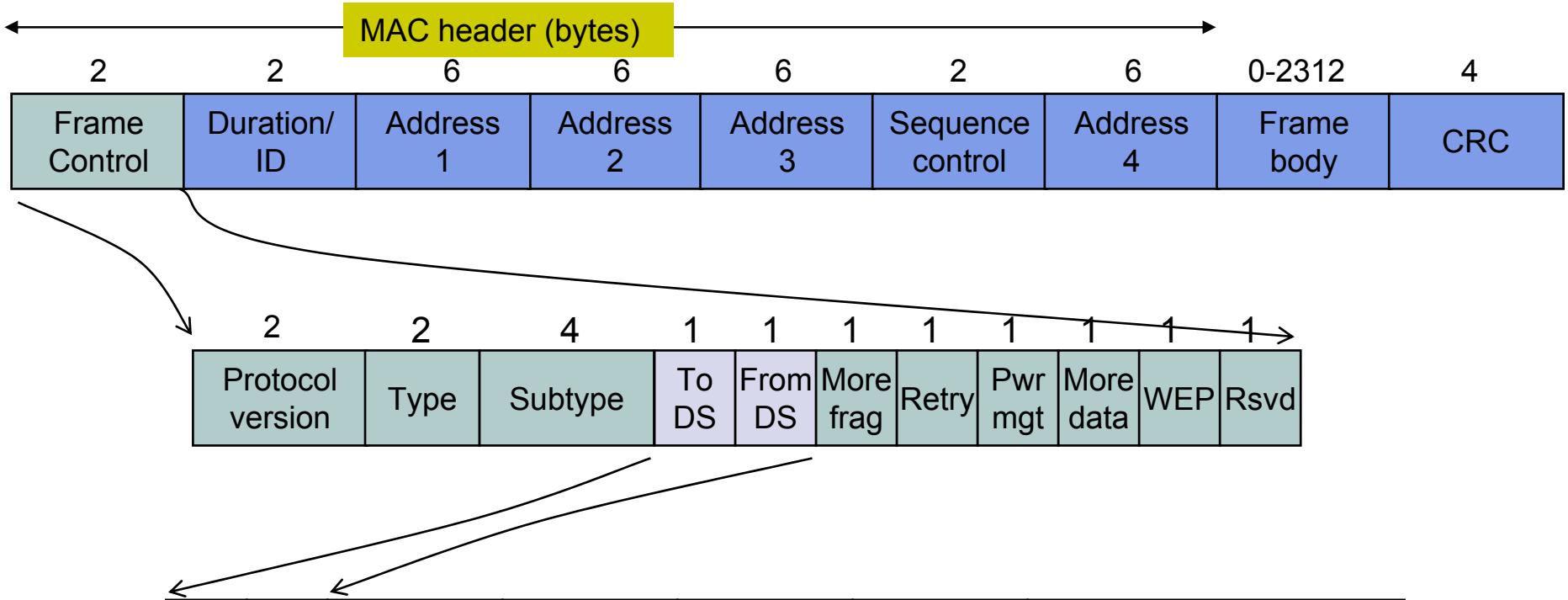
Frame control CLFFZZZZ

C = synch/asynch
L = address length (16 or 48 bits)
FF = LLC/MAC control/reserved frame type

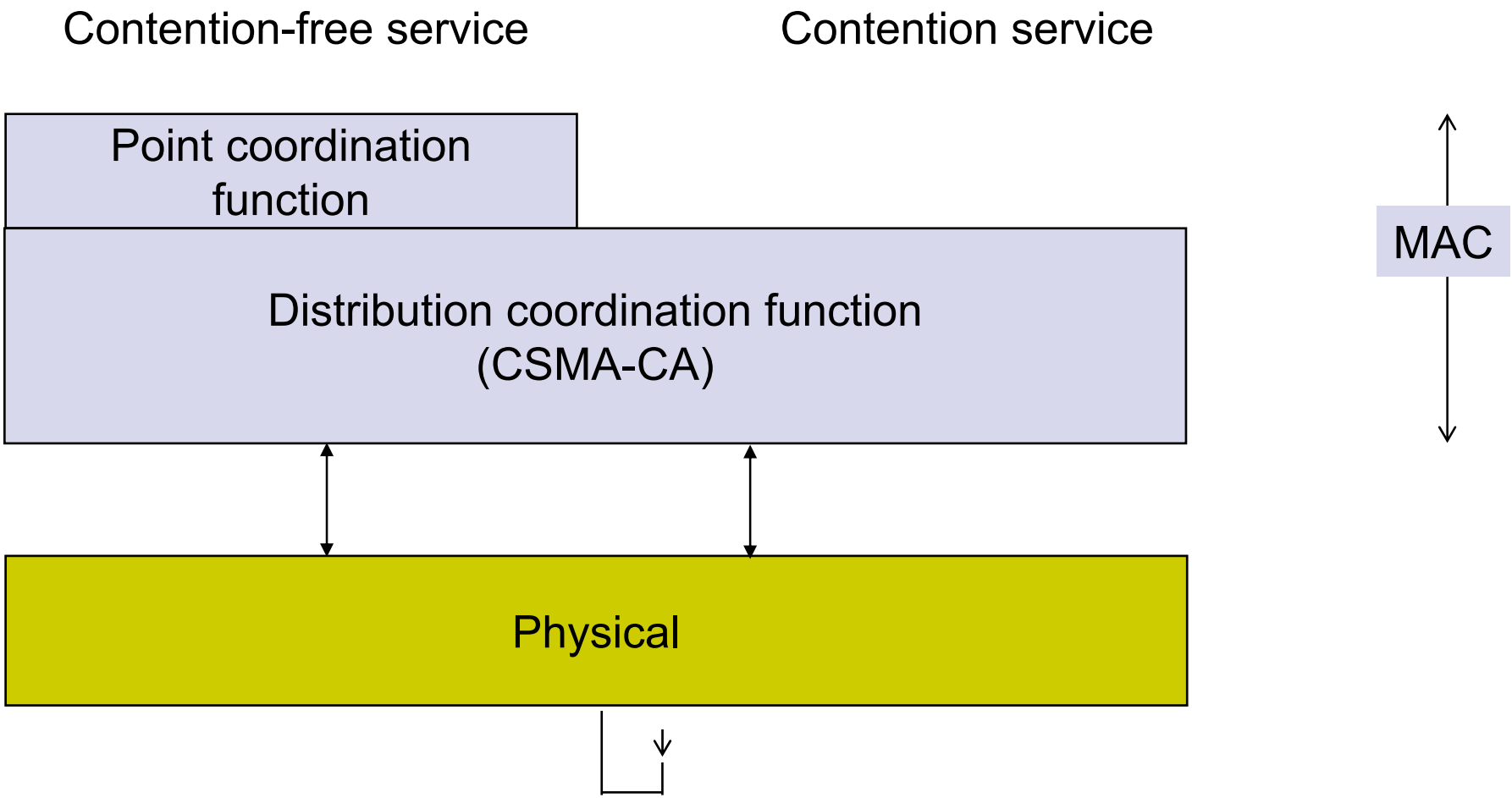

(a)
A
Data Frame
C
A transmits data frame
B
C senses medium,
station A is hidden from C
(b)
Data Frame
B
Data Frame
A
C
C transmits data frame
& collides with A at B

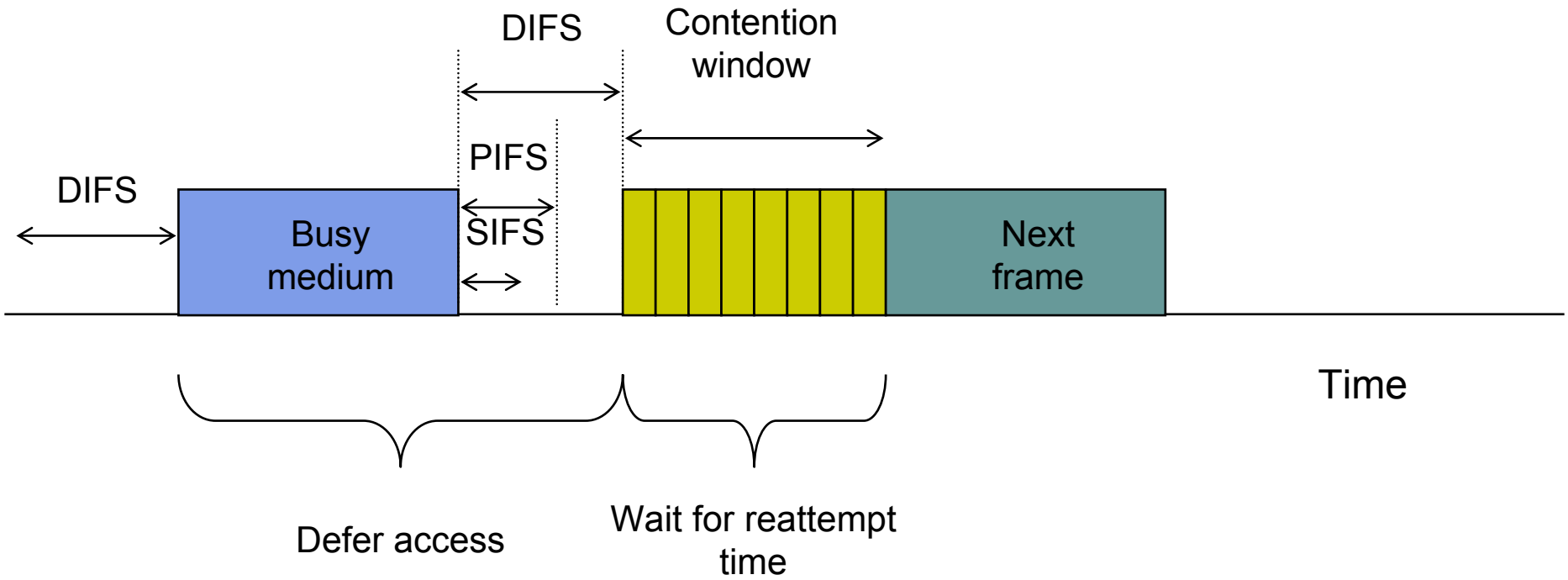

A
C
B
D

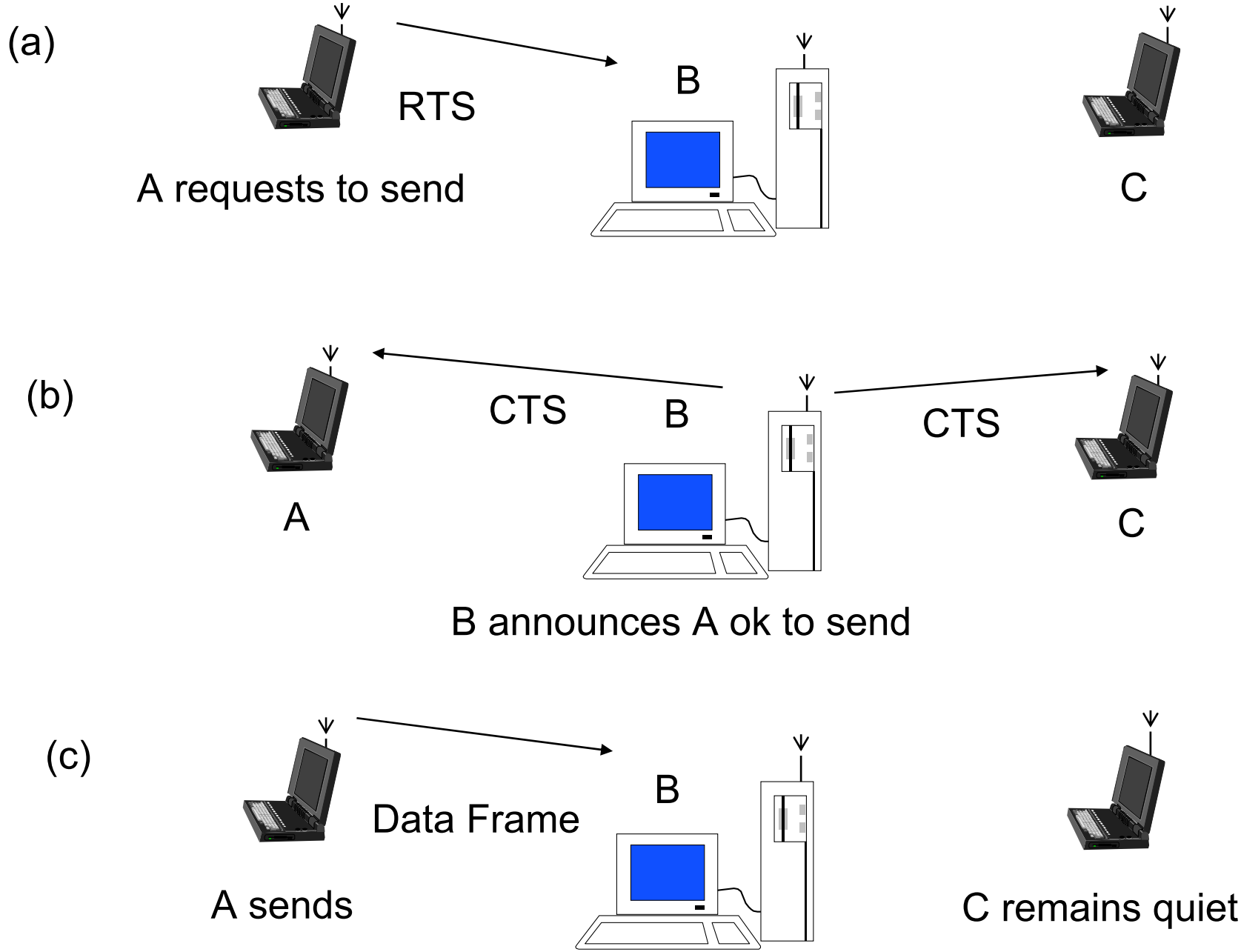

Server
Portal
Distribution System
Portal
Gateway to
the Internet
AP1
AP2
A1
A2
B1
B2
BSS A
BSS B

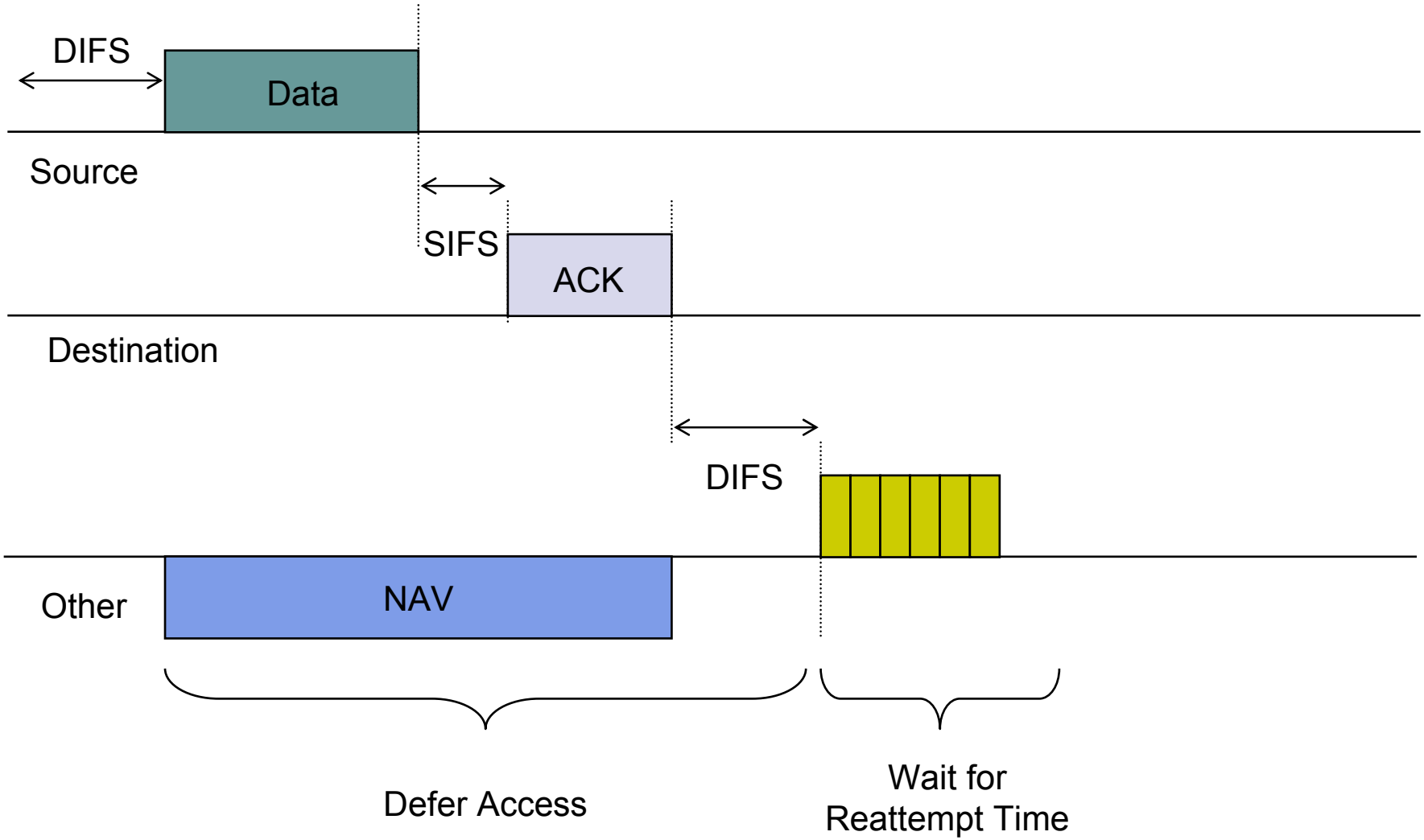


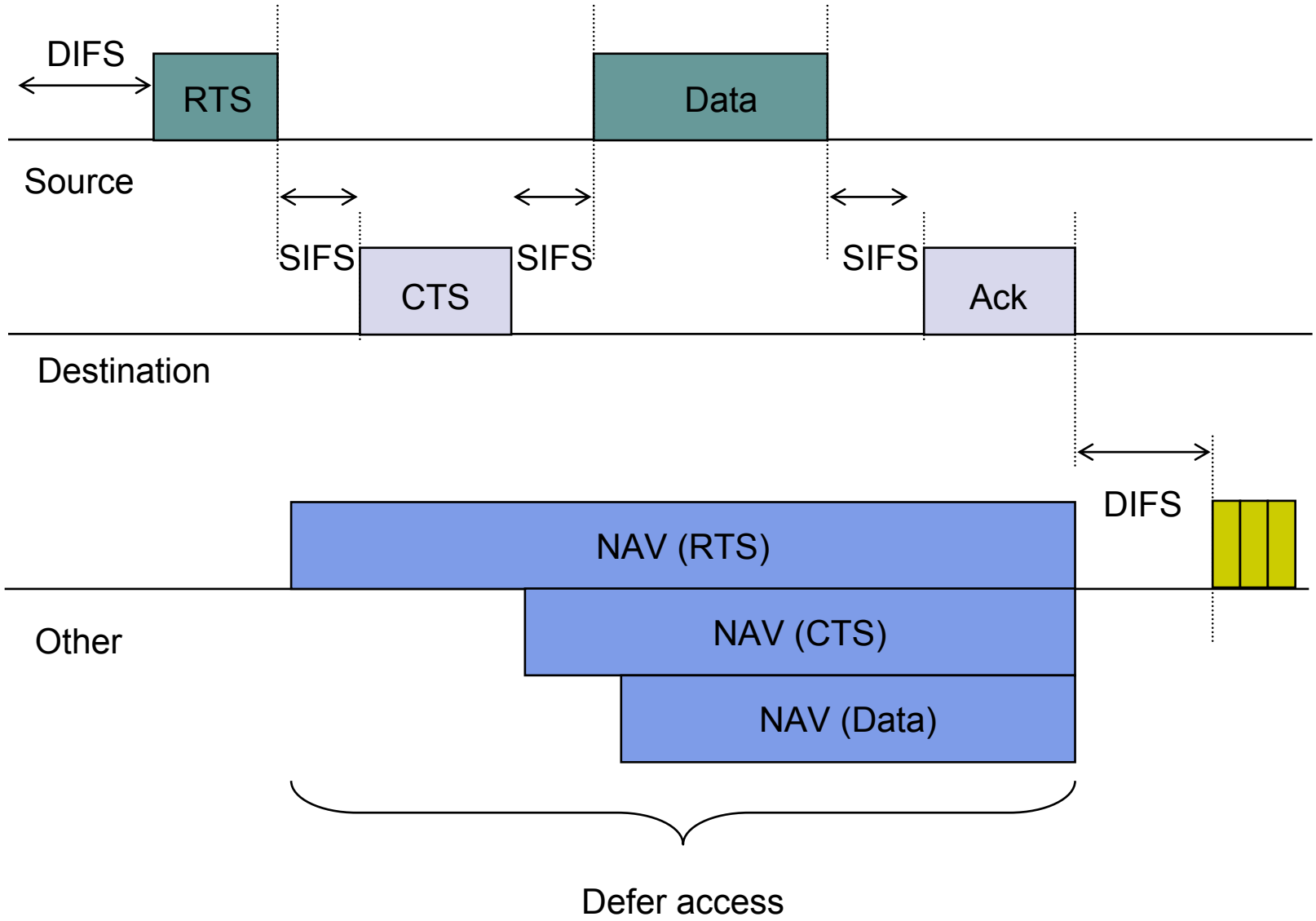

| To DS | From DS | Address 1 | Address 2 | Address 3 | Address 4 | Meaning |
|---|---|---|---|---|---|---|
| 0 | 0 | Destination address | Source address | BSSID | N/A | Data frame from station to station within a BSS |
| 0 | 1 | Destination address | BSSID | Source address | N/A | Data frame exiting the DS |
| 1 | 0 | BSSID | Source address | Destination address | N/A | Data frame destined for the DS |
| 1 | 1 | Receiver address | Transmitter address | Destination address | Source address | WDS frame being distributed from AP to AP |

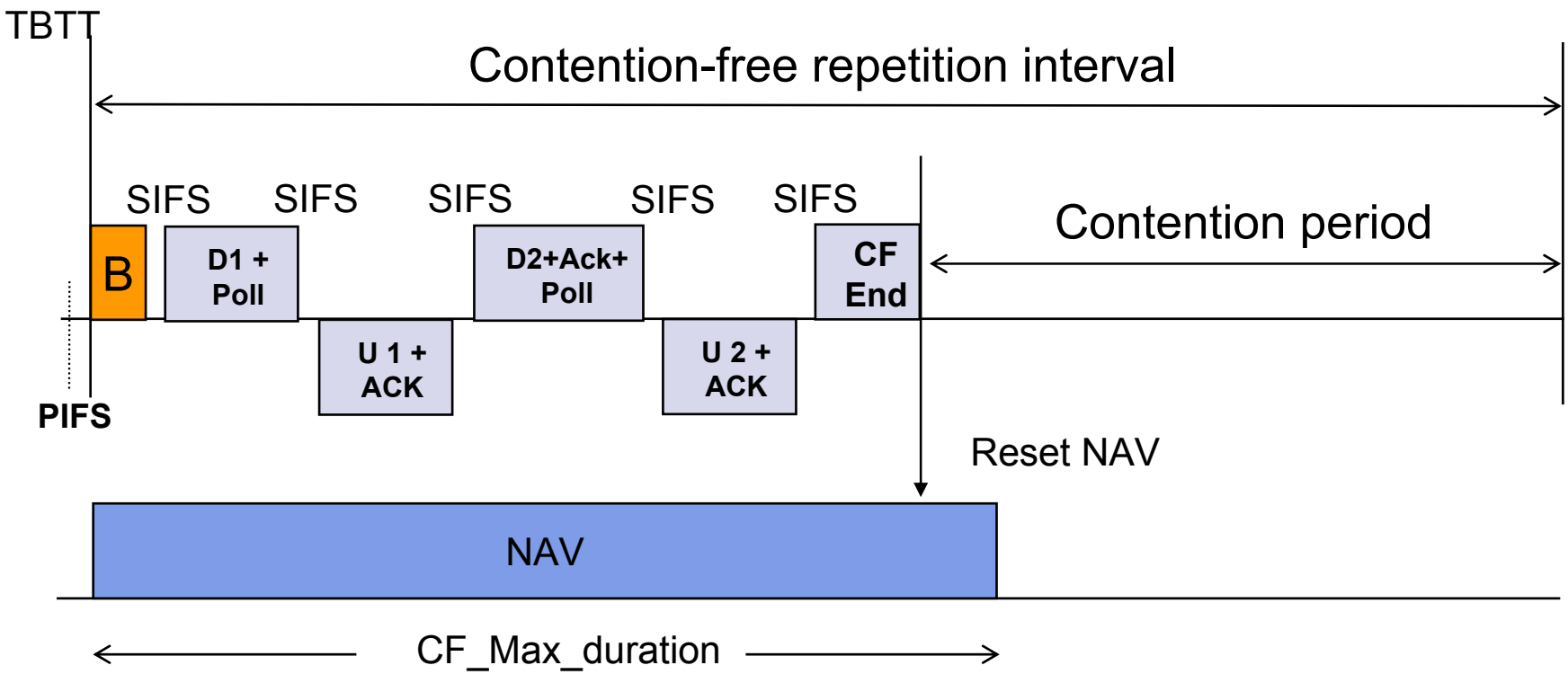

Contention-free service
Contention service
Point coordination function
Distribution coordination function (CSMA-CA)
Physical
MAC


DIFS
Contention window
PIFS
DIFS
SIFS
Busy medium
Next frame
Time
Defer access
Wait for reattempt time

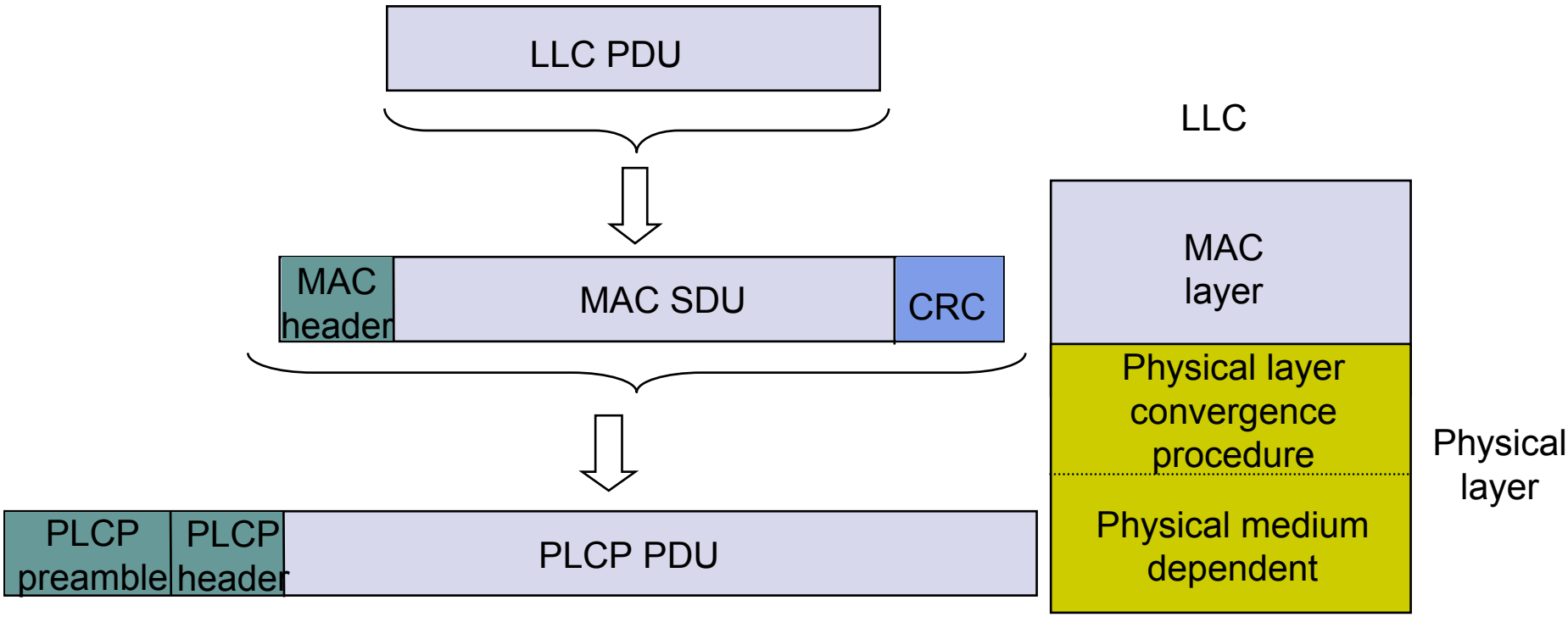

(a)
RTS
B
A requests to send
C
(b)
CTS
B
CTS
A
C
B announces A ok to send
(c)
Data Frame
B
A sends
C remains quiet

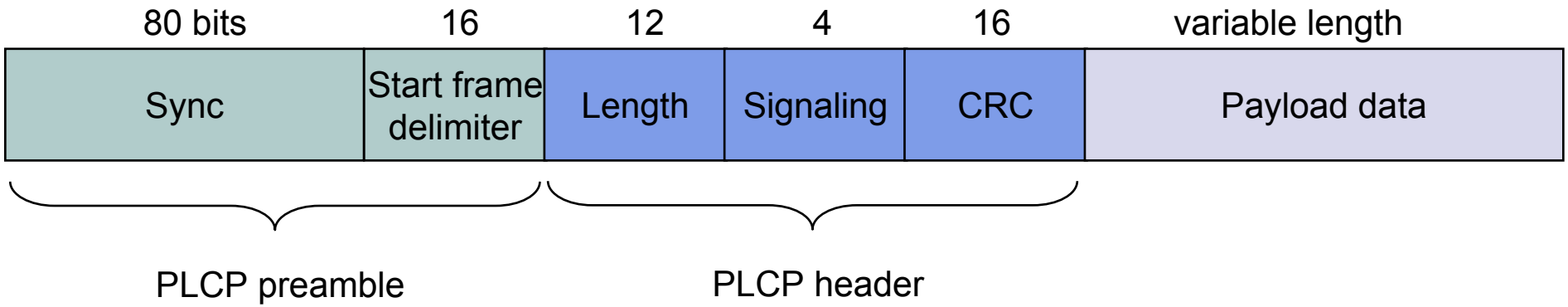

DIFS
Data
Source
SIFS
ACK
Destination
DIFS
Other
NAV
Defer Access
Wait for
Reattempt Time


DIFS
RTS
Data
Source
SIFS
CTS
SIFS
SIFS
Ack
Destination
DIFS
NAV (RTS)
NAV (CTS)
NAV (Data)
Other
Defer access

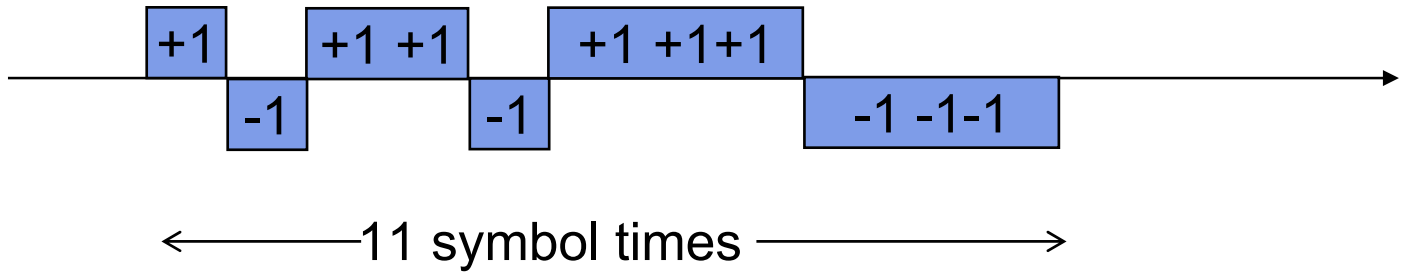



D1, D2 = frame sent by point coordinator
U1, U2 = frame sent by polled station
TBTT = target beacon transmission time
B = beacon frame

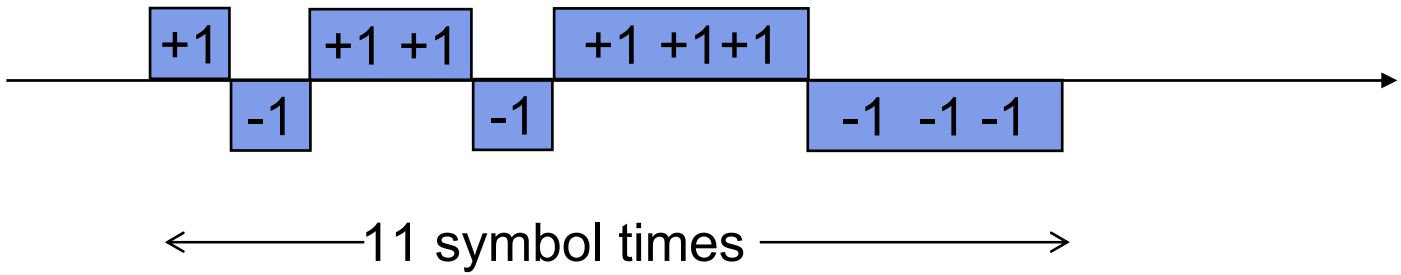

LLC PDU
LLC
MAC header
MAC SDU
CRC
MAC layer
Physical layer convergence procedure
Physical medium dependent
Physical layer
PLCP preamble
PLCP header
PLCP PDU


80 bits
16
12
4
16
variable length
Sync
Start frame delimiter
Length
Signaling
CRC
Payload data
PLCP preamble
PLCP header

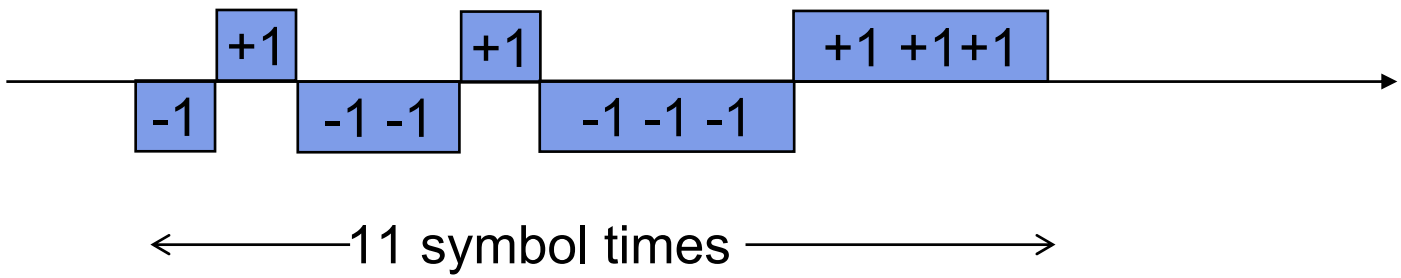
11-chip Barker sequence:

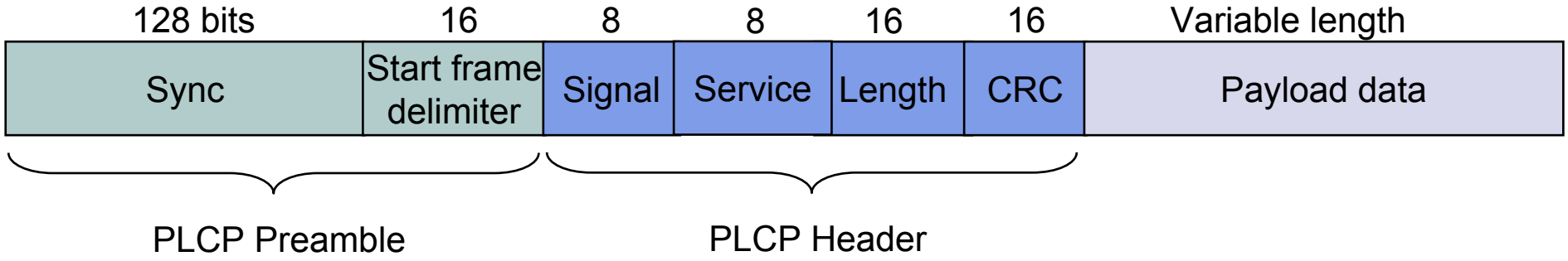


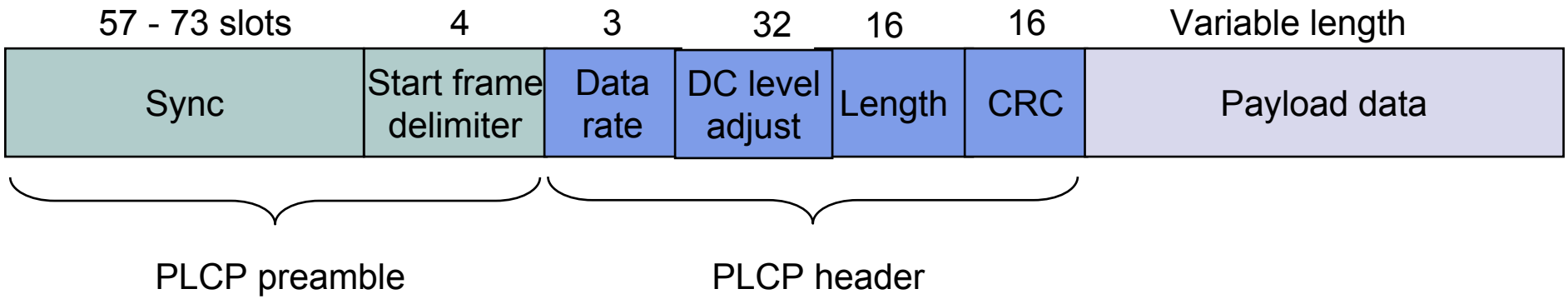

To transmit +1, send:

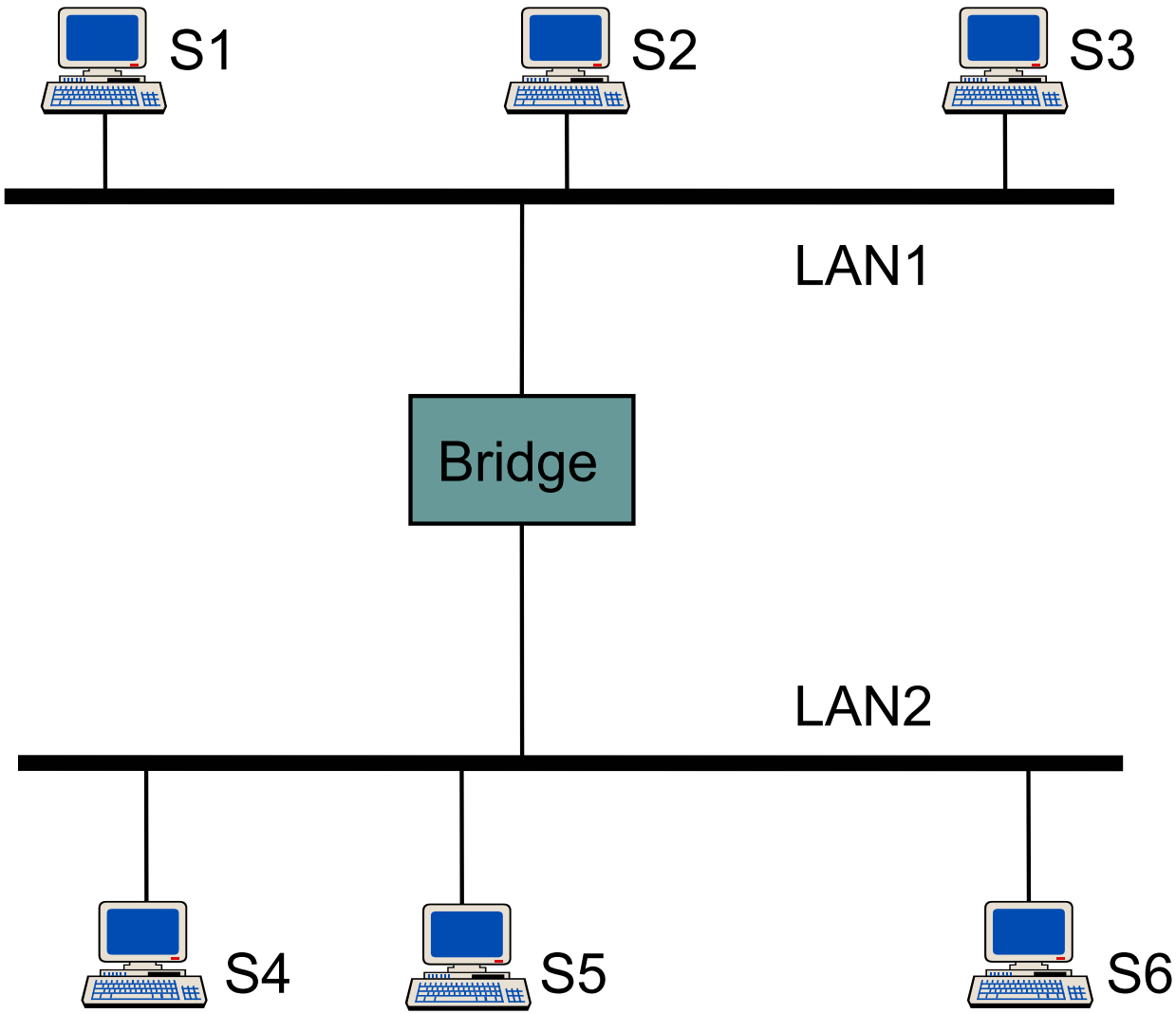


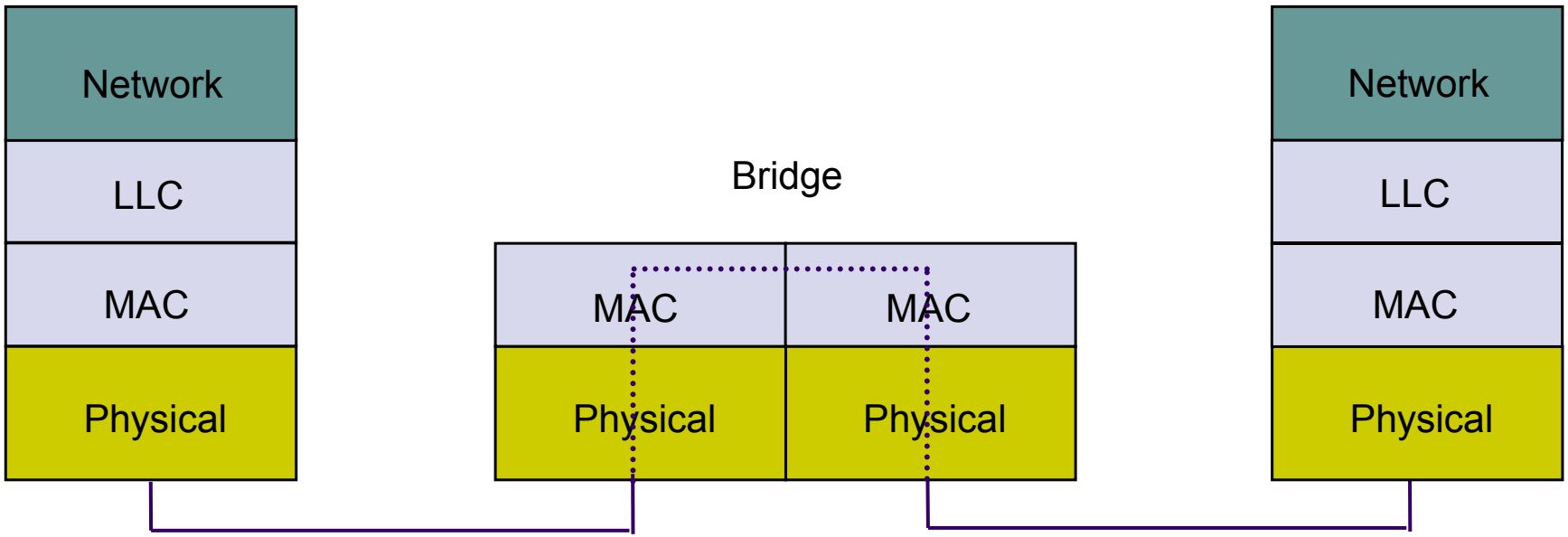

To transmit -1, send:

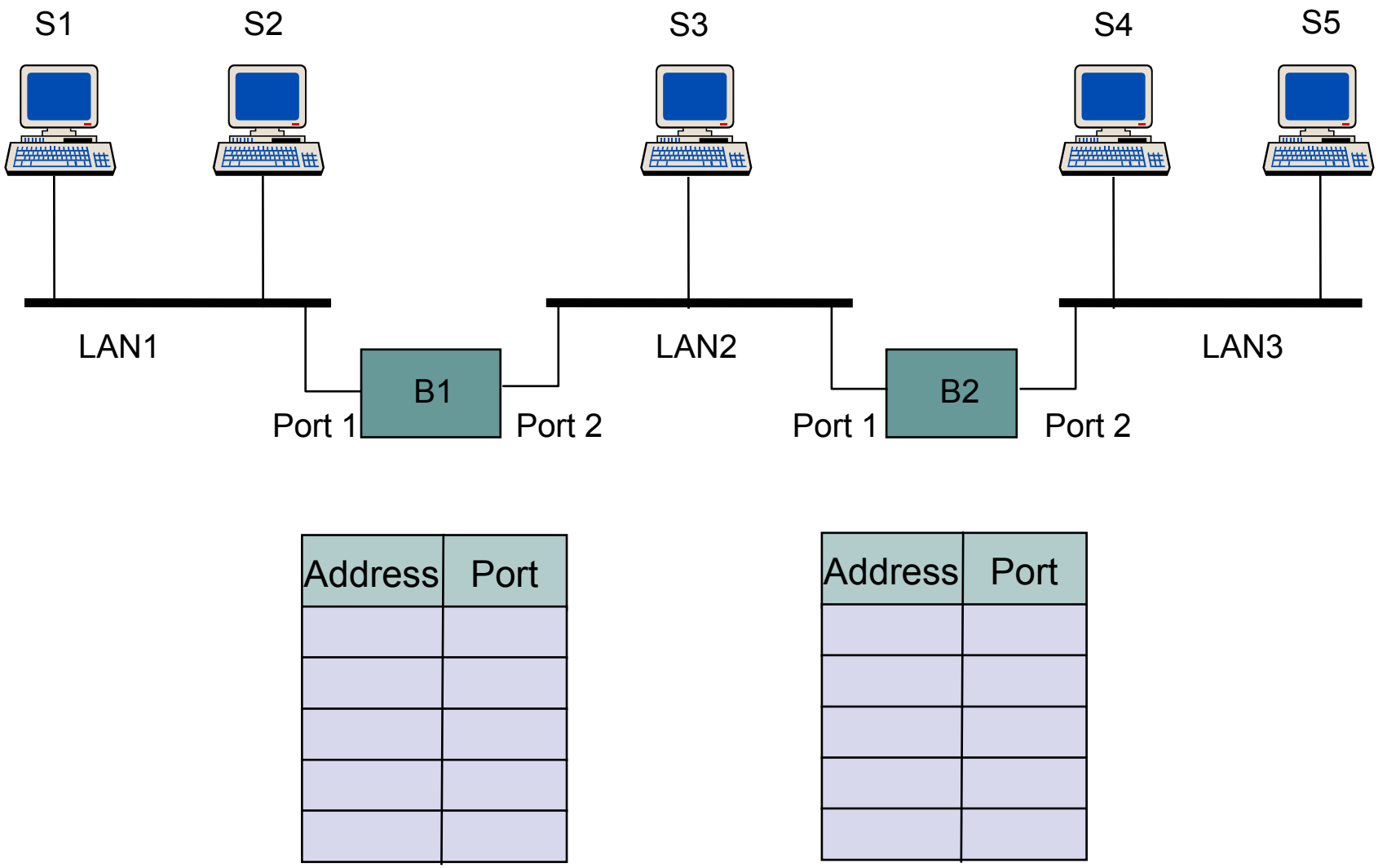


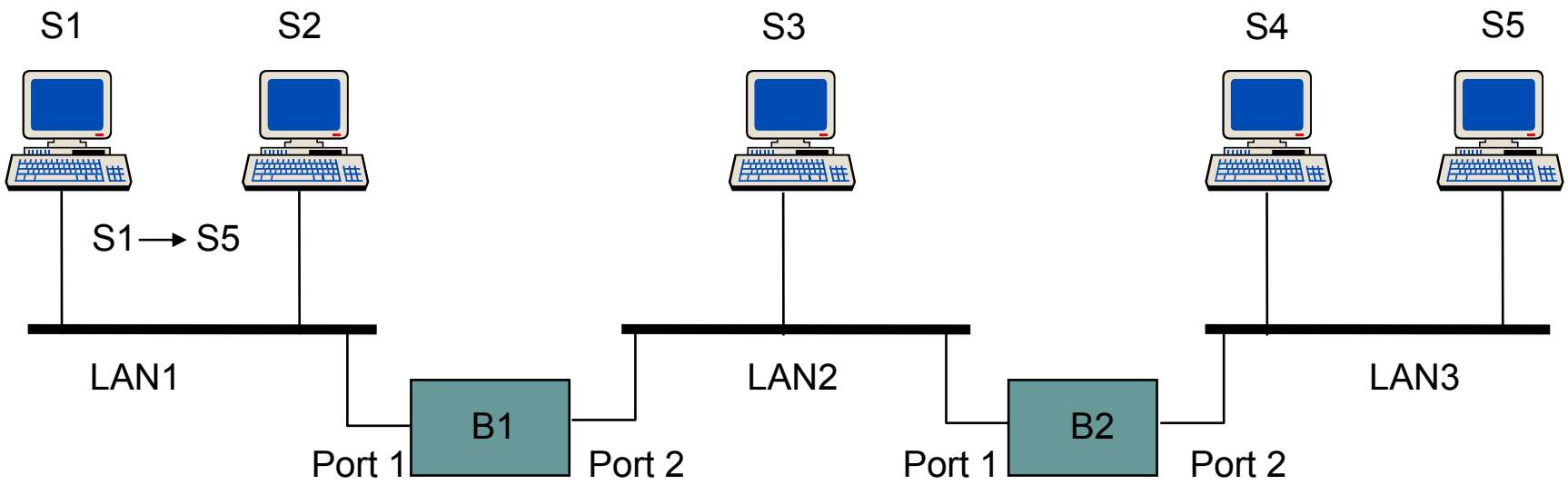

128 bits
16
8
8
16
16
Variable length
Sync
Start frame delimiter
Signal
Service
Length
CRC
Payload data
PLCP Preamble
PLCP Header


57 - 73 slots
4
3
32
16
16
Variable length
Sync
Start frame delimiter
Data rate
DC level adjust
Length
CRC
Payload data
PLCP preamble
PLCP header


S1
S2
S3
LAN1
Bridge
LAN2
S4
S5
S6

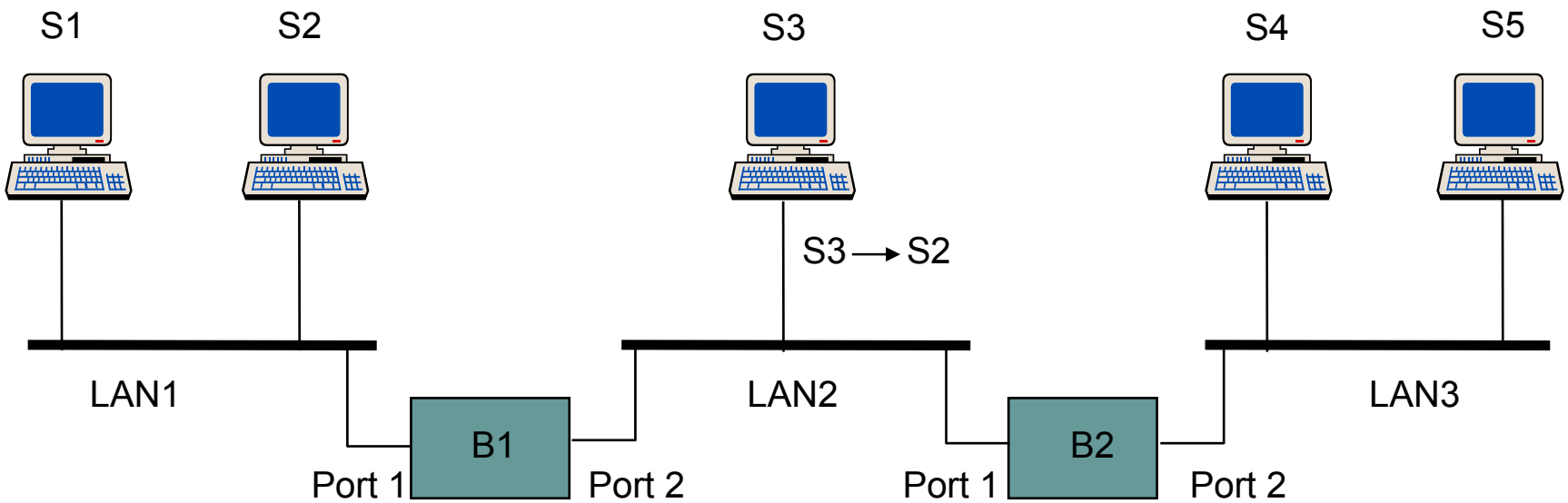

Network
LLC
MAC
Physical
Bridge
MAC
MAC
Physical
Physical
Network
LLC
MAC
Physical


S1
S2
S3
S4
S5
LAN1
LAN2
LAN3
B1
B2
Port 1
Port 2
Port 1
Port 2
Address
Port
Address
Port



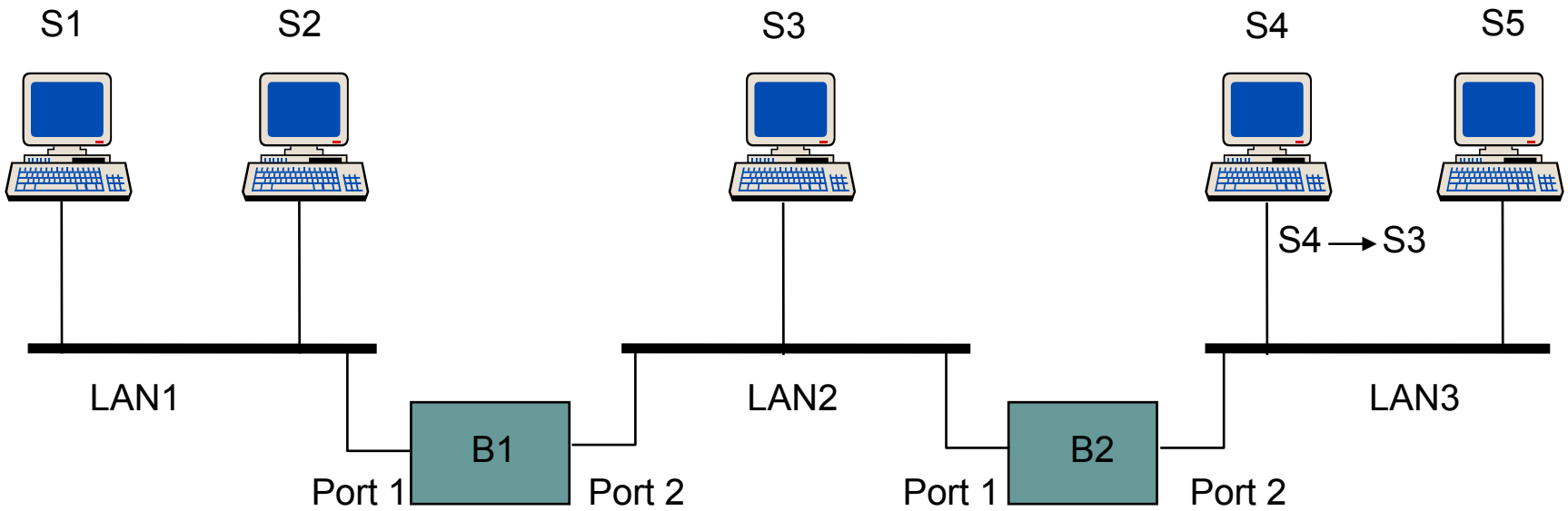

| Address | Port |
|---|---|
| S1 | 1 |
| | |
| | |
| | |
| | |

| Address | Port |
|---|---|
| S1 | 1 |
| | |
| | |
| | |
| | |



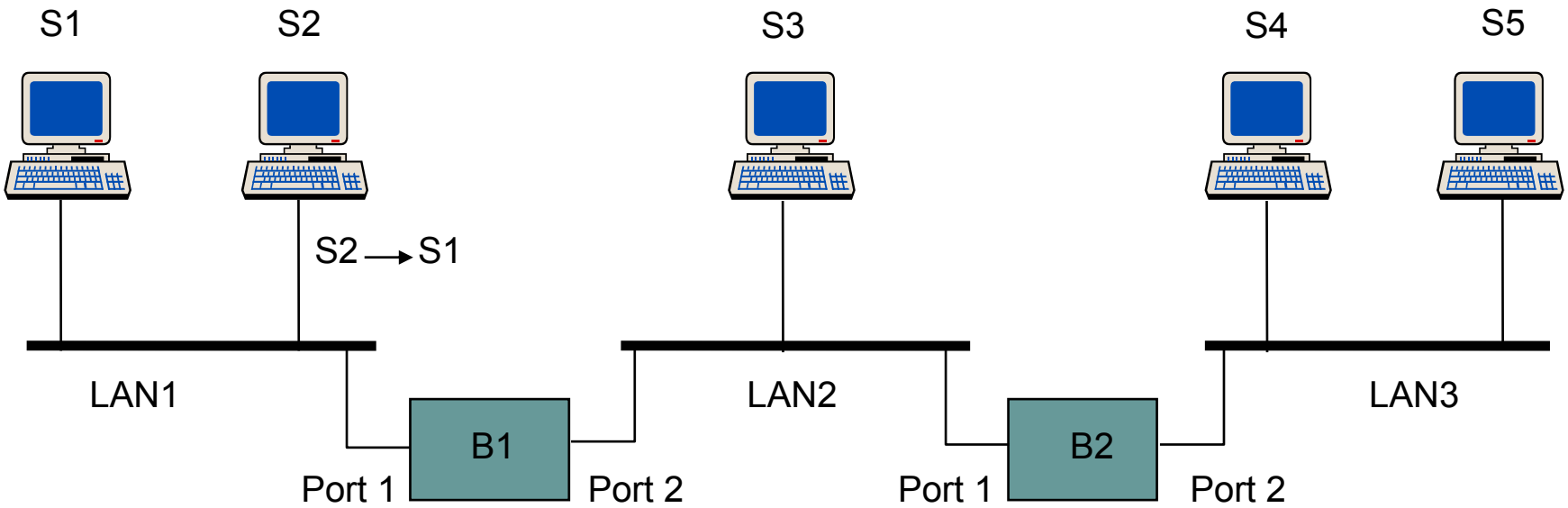

| Address | Port |
|---|---|
| S1 | 1 |
| S3 | 1 |
| | |
| | |
| | |

| Address | Port |
|---|---|
| S1 | 1 |
| S3 | 1 |
| | |
| | |
| | |



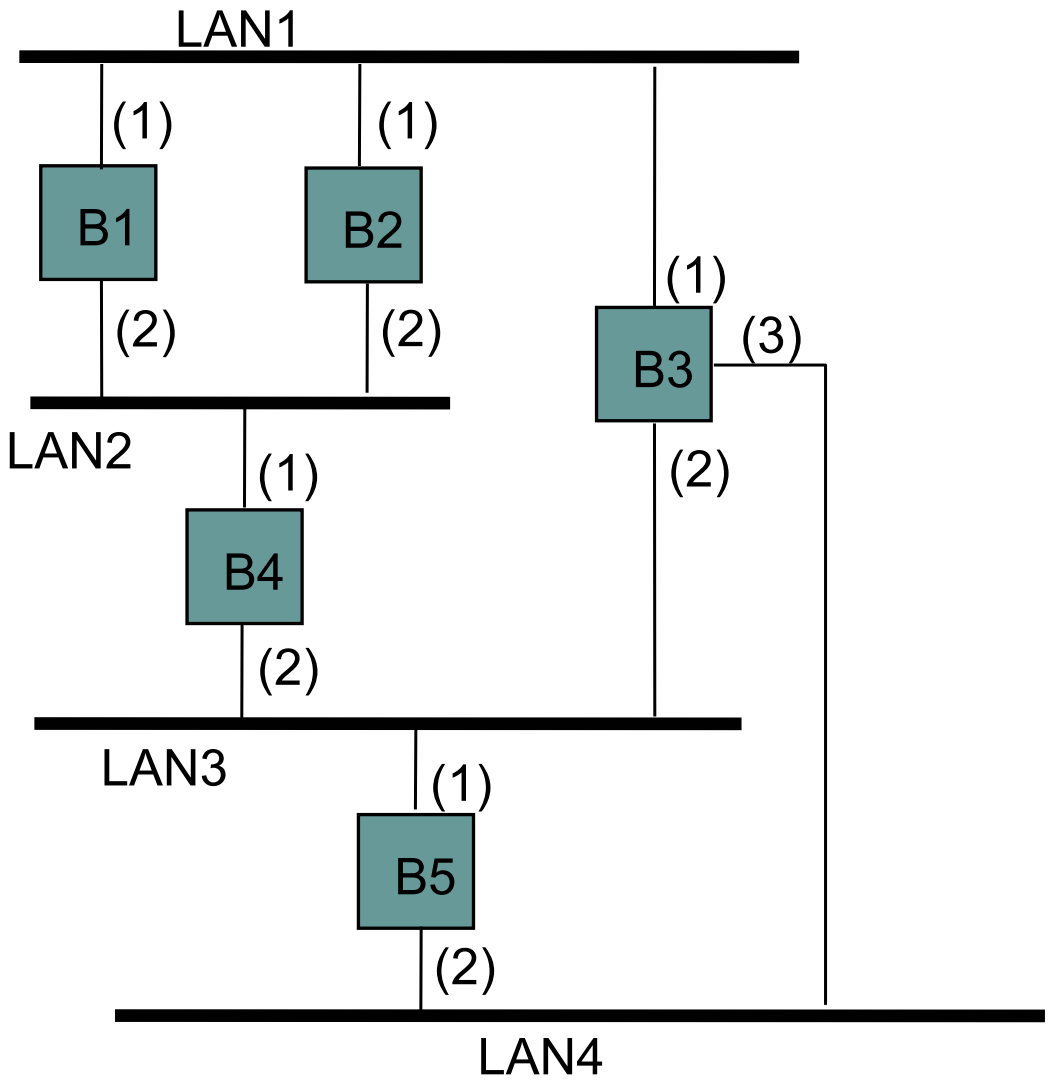

| Address | Port |
|---|---|
| S1 | 1 |
| S3 | 2 |
| S4 | 2 |
| | |
| | |

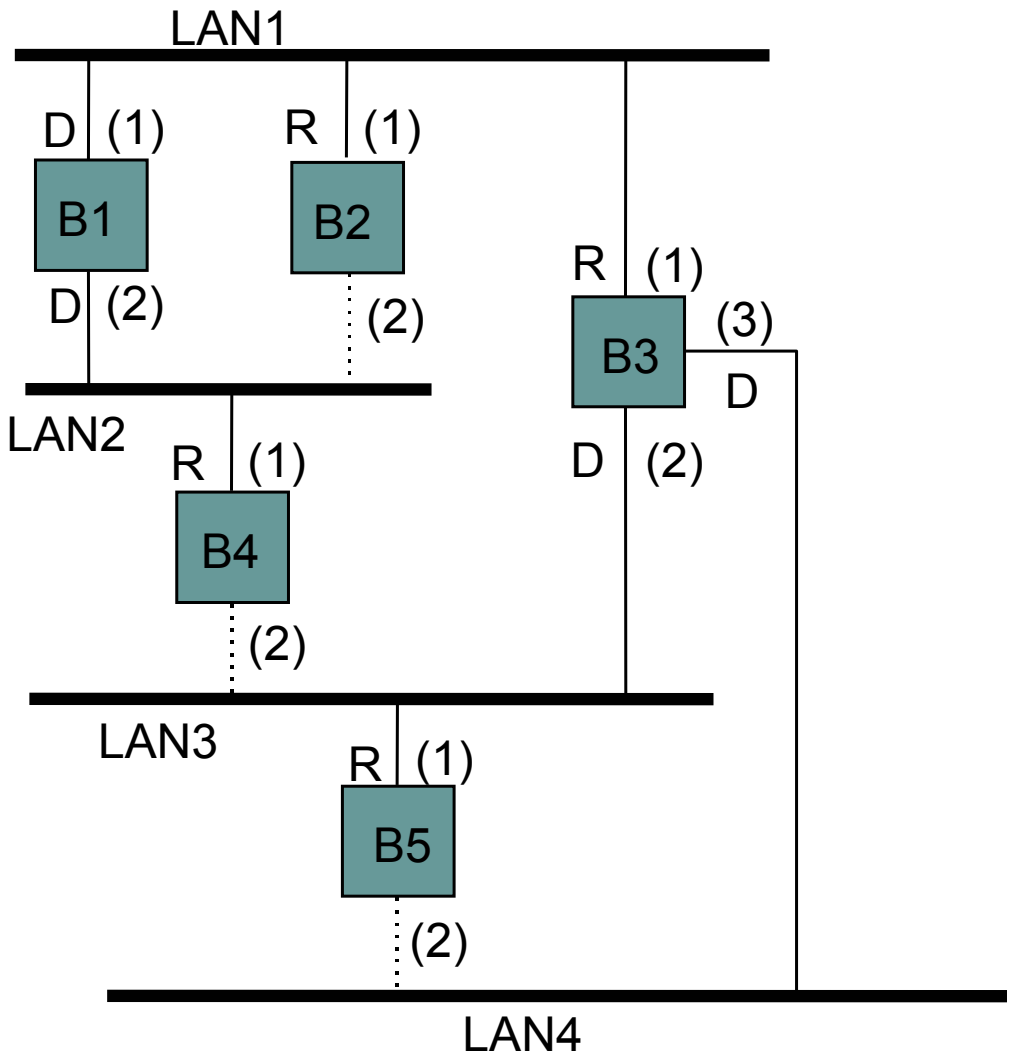
| Address | Port |
|---|---|
| S1 | 1 |
| S3 | 1 |
| S4 | 2 |
| | |
| | |

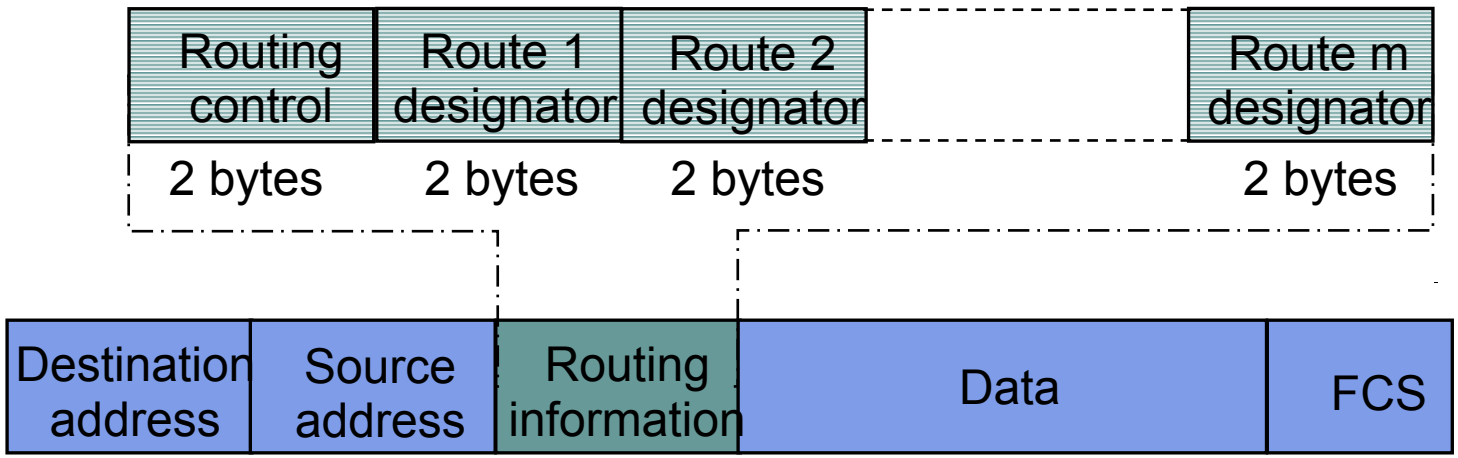


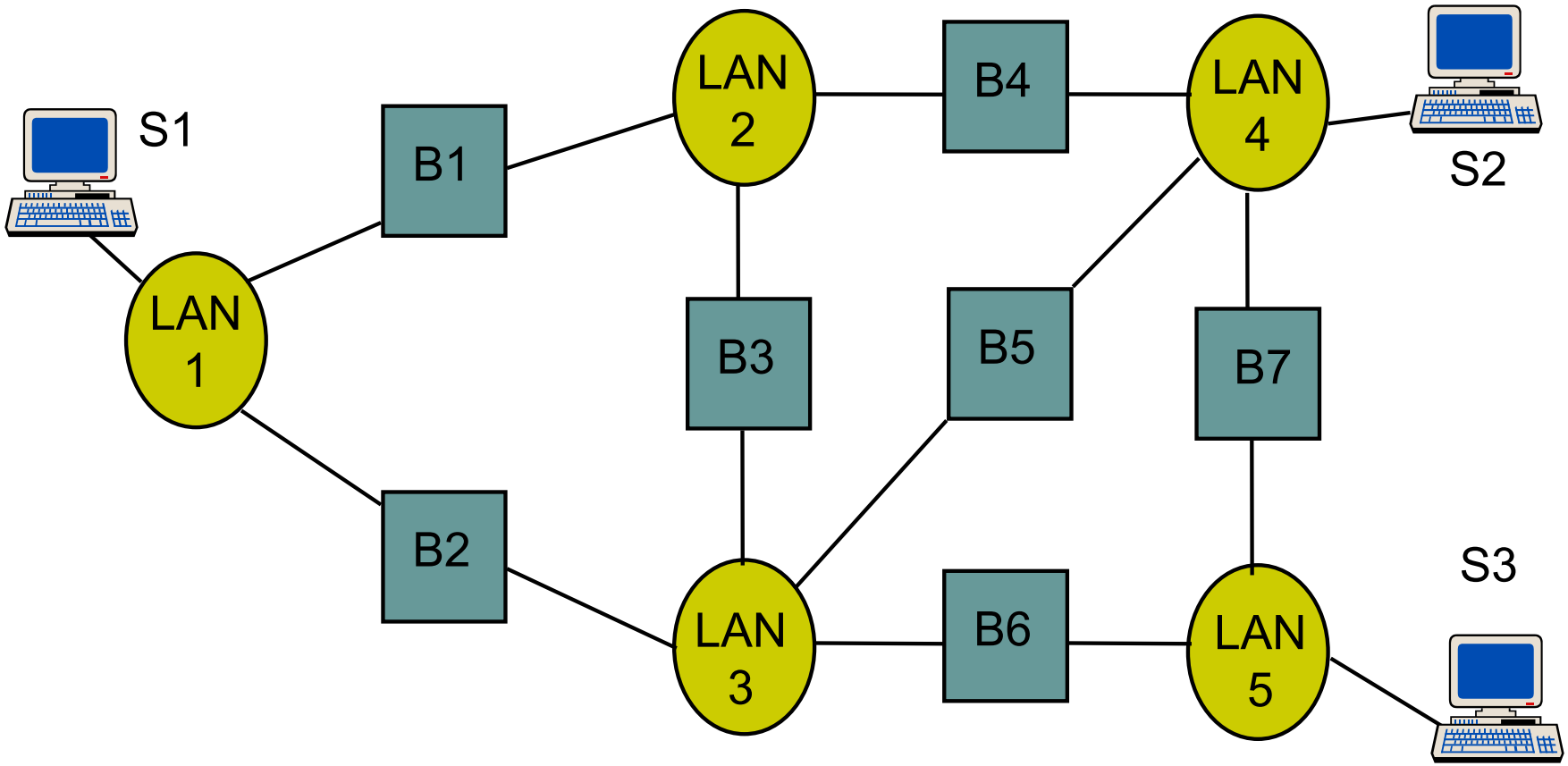

| Address | Port |
|---|---|
| S1 | 1 |
| S3 | 2 |
| S4 | 2 |
| S2 | 1 |
| | |

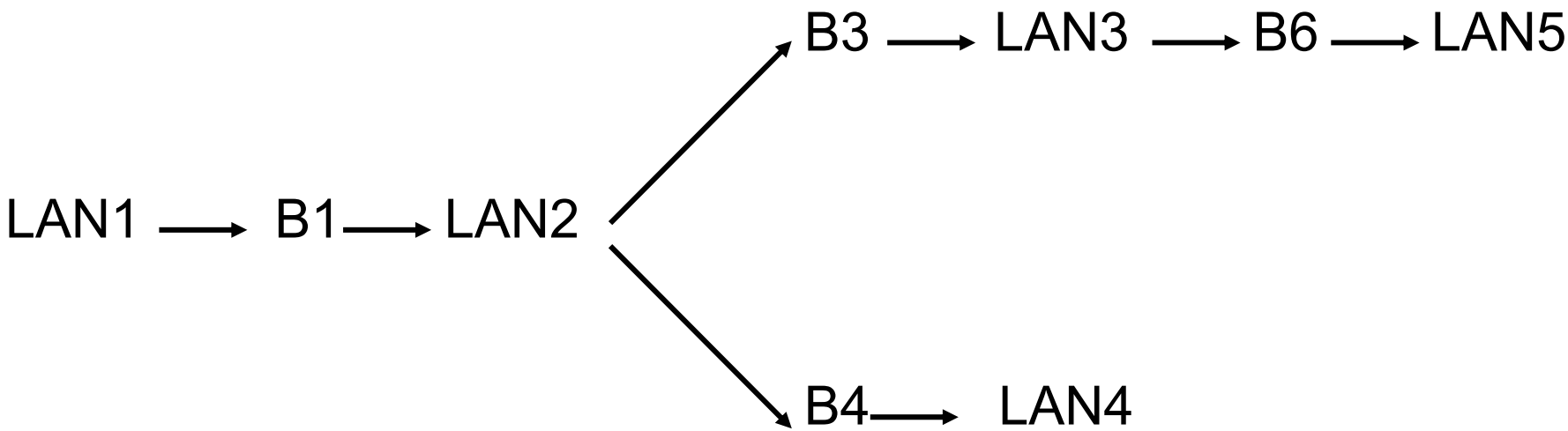
| Address | Port |
|---|---|
| S1 | 1 |
| S3 | 1 |
| S4 | 2 |
| | |
| | |

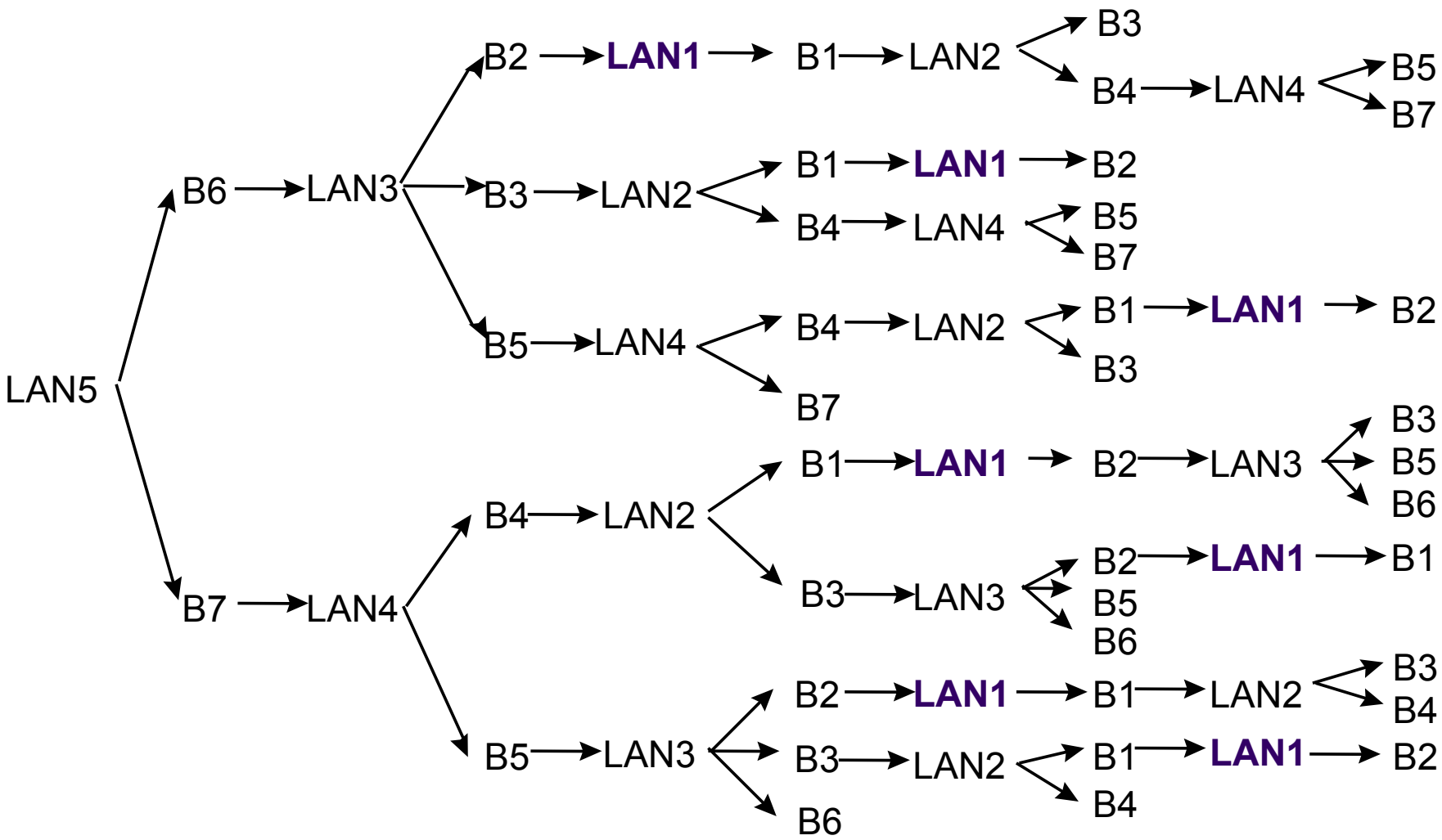

LAN1
(1)
(1)
B1
B2
(1)
(2)
(2)
B3
(3)
LAN2
(1)
(2)
B4
(2)
LAN3
(1)
B5
(2)
LAN4

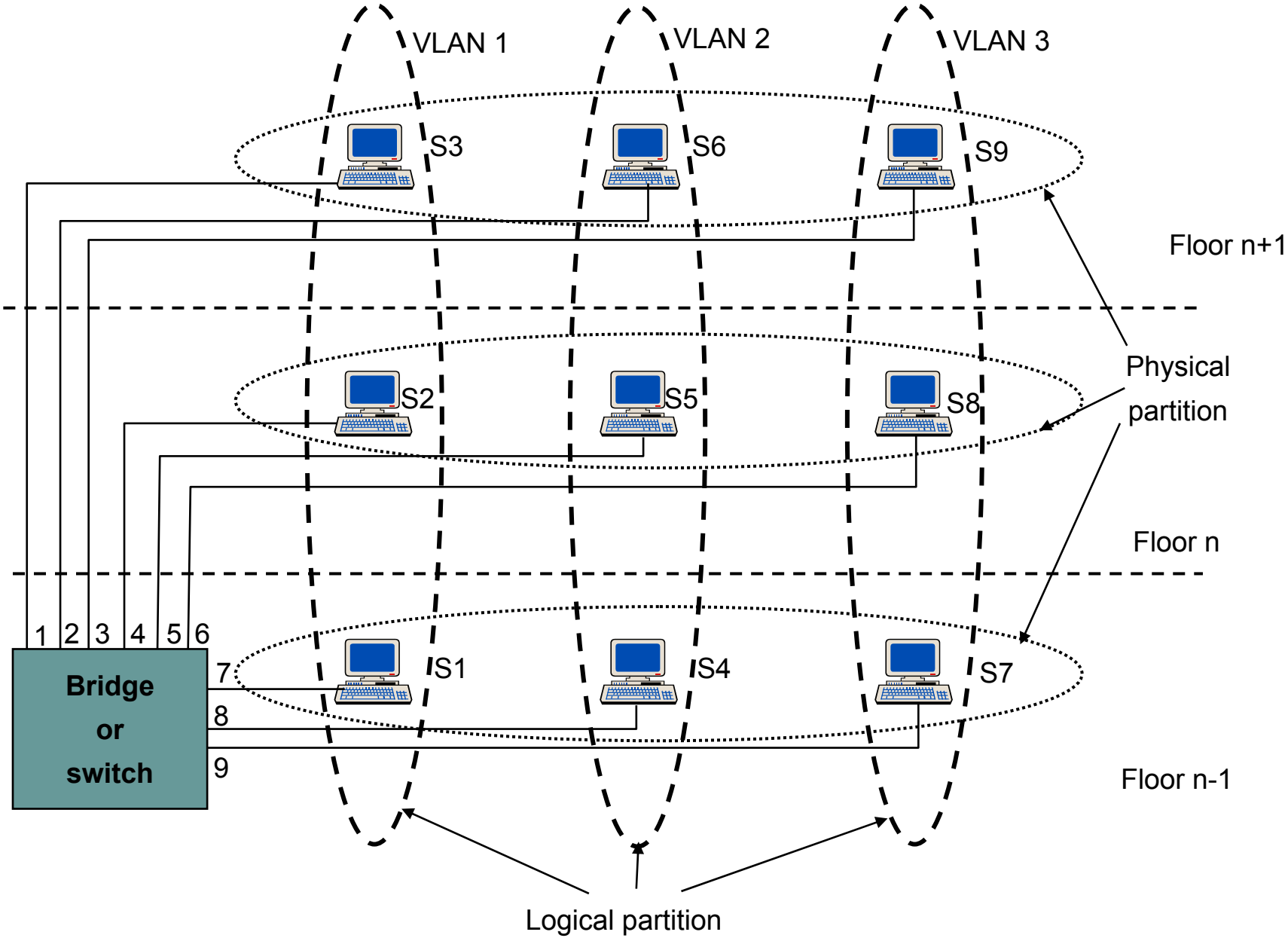

LAN1
D
(1)
R
(1)
B1
B2
D
(2)
(2)
R
(1)
B3
(3)
D
LAN2
R
(1)
D
(2)
B4
(2)
LAN3
R
(1)
B5
(2)
LAN4

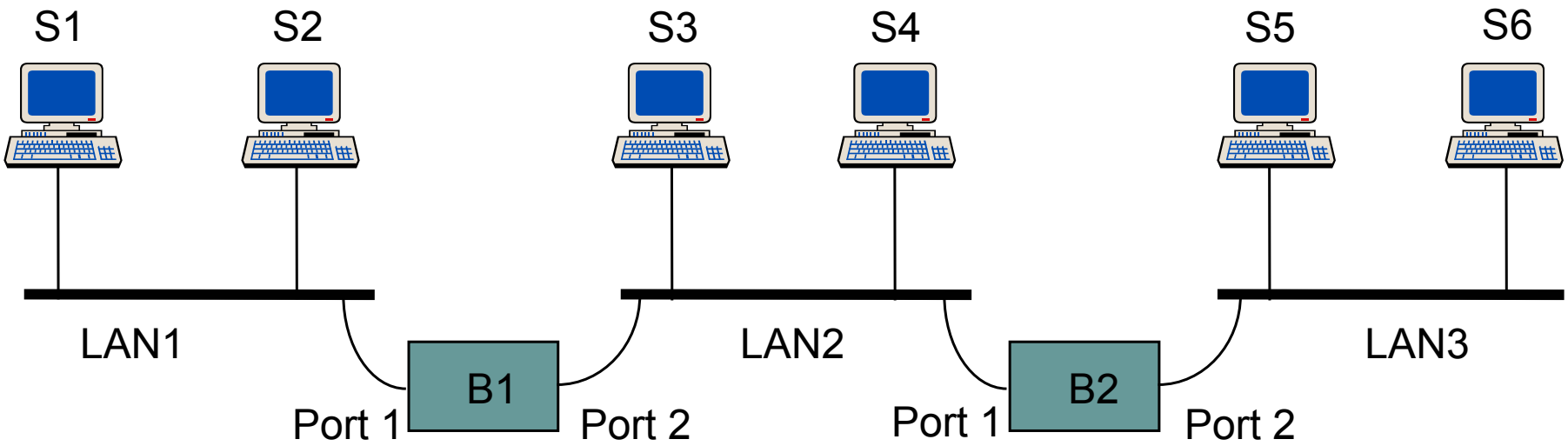

Routing control
Route 1 designator
Route 2 designator
Route m designator
2 bytes
2 bytes
2 bytes
2 bytes
Destination address
Source address
Routing information
Data
FCS


S1
LAN 1
B1
B2
LAN 2
B3
LAN 3
B4
B5
B6
LAN 4
B7
LAN 5
S2
S3


LAN1
B1
LAN2
B3
LAN3
B6
LAN5
B4
LAN4

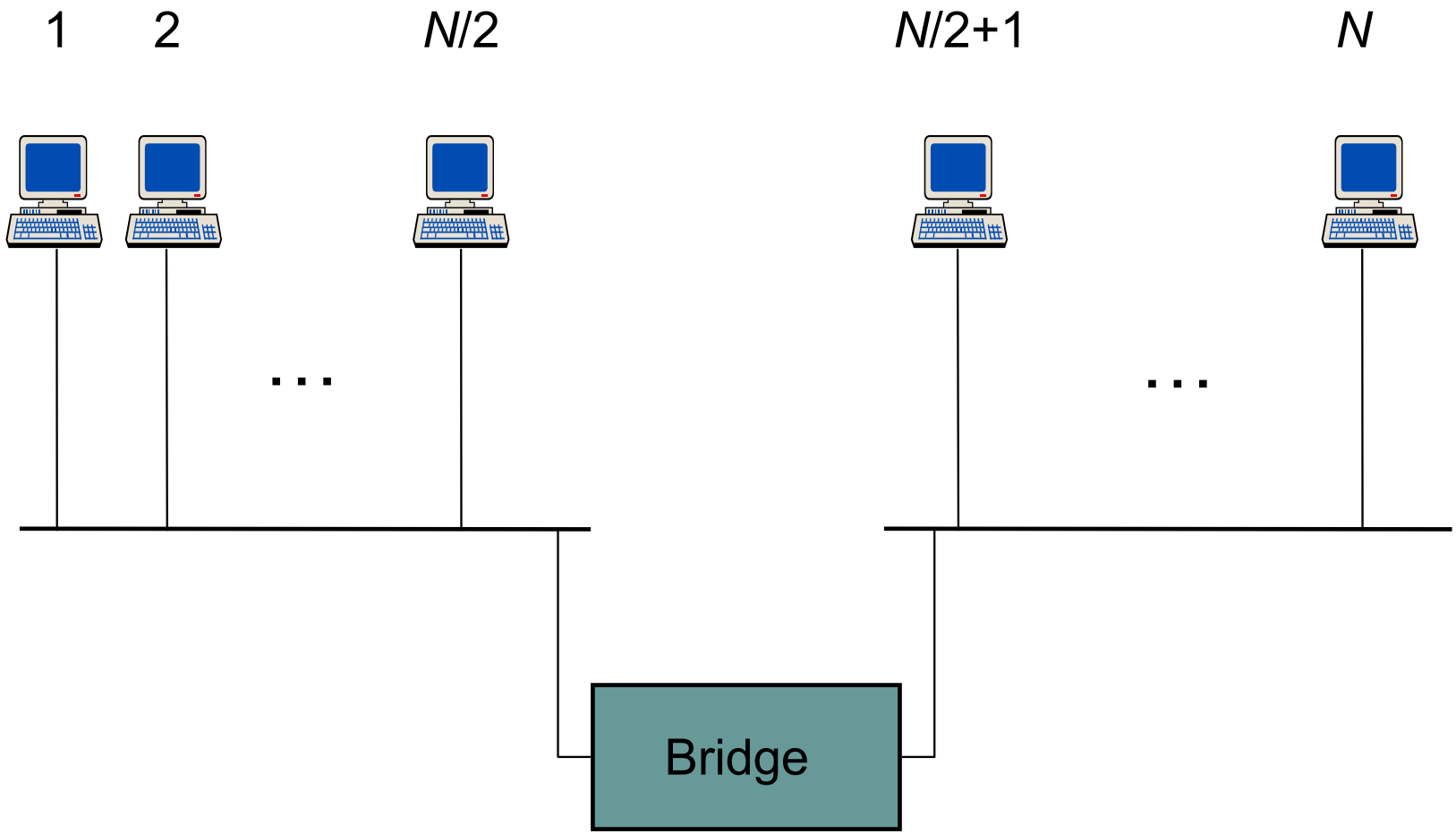

LAN5
B6
LAN3
B2
LAN1
B1
LAN2
B3
B4
LAN4
B5
B7
B3
LAN2
B1
LAN1
B2
B4
LAN4
B5
B7
B5
LAN4
B4
LAN2
B1
LAN1
B2
B3
B7
B7
LAN4
B4
LAN2
B1
LAN1
B2
LAN3
B3
B5
B6
B3
LAN3
B2
LAN1
B1
B5
B6
B5
LAN3
B2
LAN1
B1
LAN2
B3
B4
B3
LAN2
B1
LAN1
B2
B4
B6

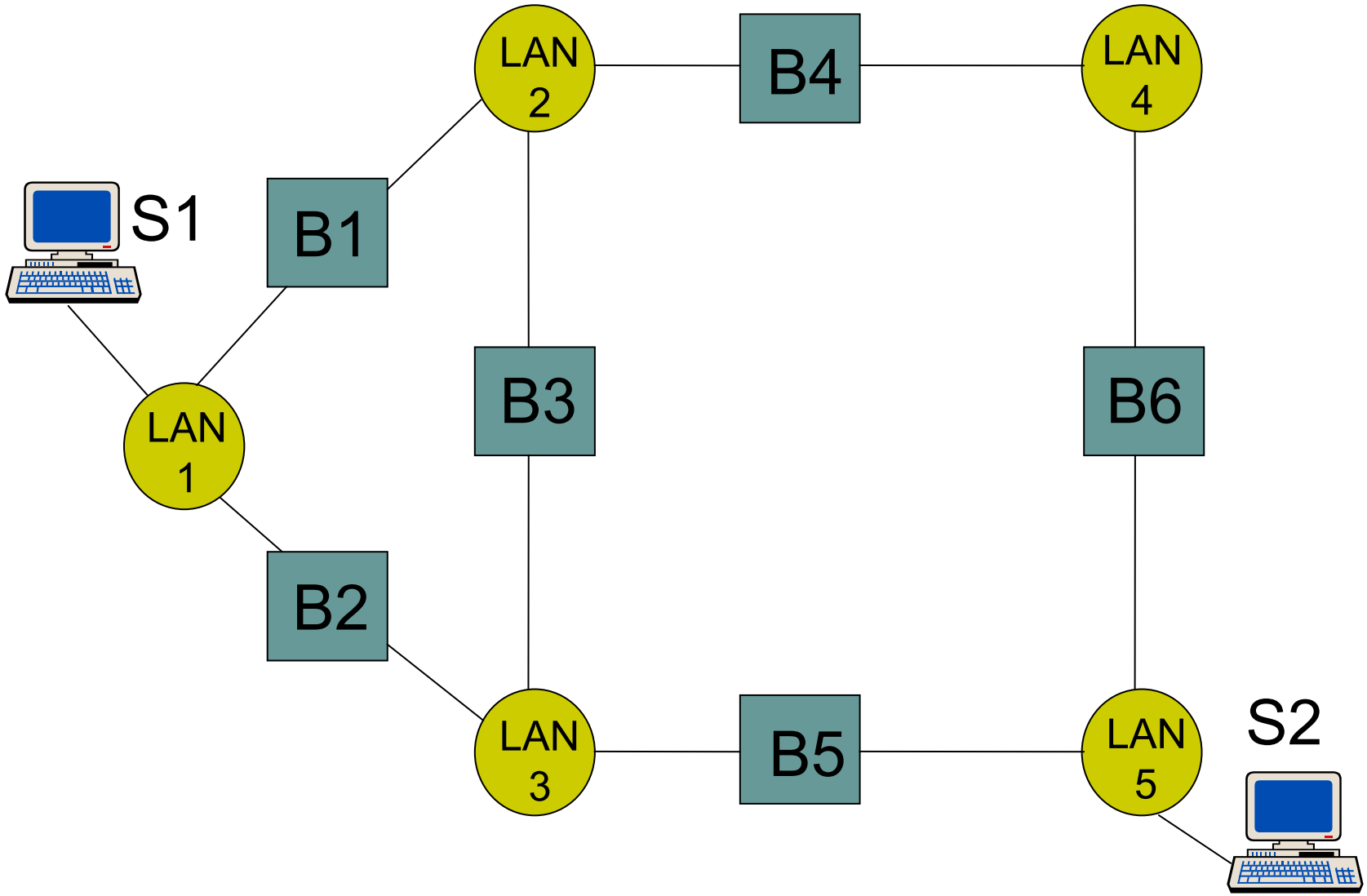

VLAN 1
VLAN 2
VLAN 3
S3
S6
S9
Floor n+1
S2
S5
S8
Physical
partition
Floor n
1 2 3 4 5 6
Bridge
or
switch
7
8
9
S1
S4
S7
Floor n-1
Logical partition

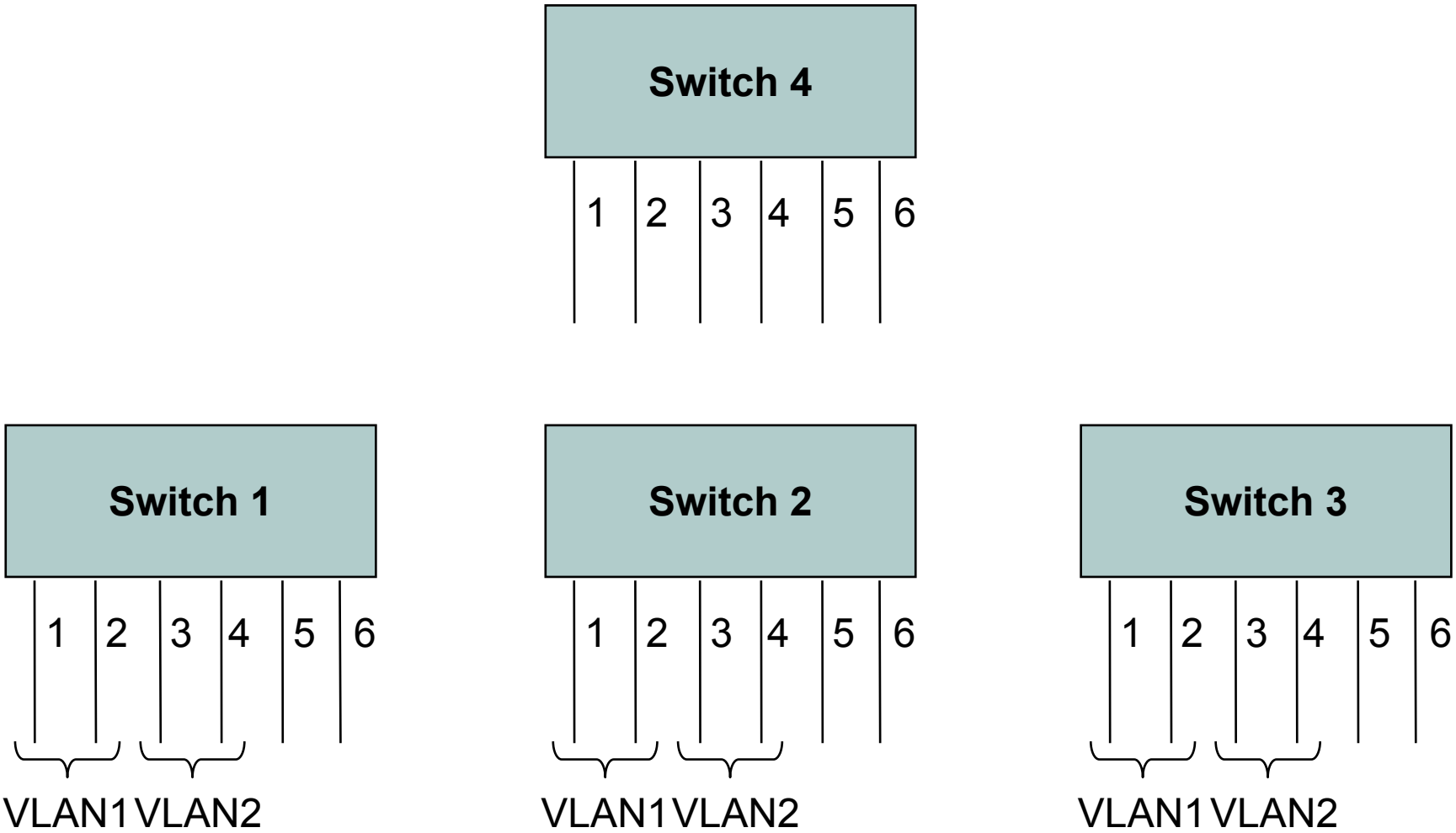



| Station | Port |
|---|---|
| | |
| | |
| | |
| | |
| | |

| Station | Port |
|---|---|
| | |
| | |
| | |
| | |
| | |


1
2
N/2
N/2+1
N
Bridge


LAN 2
B4
LAN 4
S1
B1
B3
B6
LAN 1
B2
LAN 3
B5
LAN 5
S2


Switch 4
1 2 3 4 5 6
Switch 1
1 2 3 4 5 6
VLAN1 VLAN2
Switch 2
1 2 3 4 5 6
VLAN1 VLAN2
Switch 3
1 2 3 4 5 6
VLAN1 VLAN2