BLG 337E- Principles of Computer Communications

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23/10/ 2018

-Medium Access Layer - 2

References:

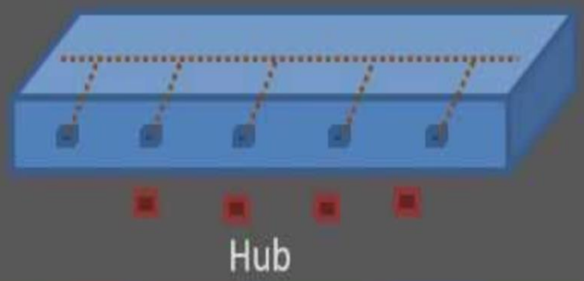
Data and Computer Communications, William Stallings, Pearson-Prentice Hall, 9th Edition, 2010.

-*Computer Networking, A Top-Down Approach Featuring the Internet*, James F.Kurose, Keith W.Ross, Pearson-Addison Wesley, 6th Edition, 2012.

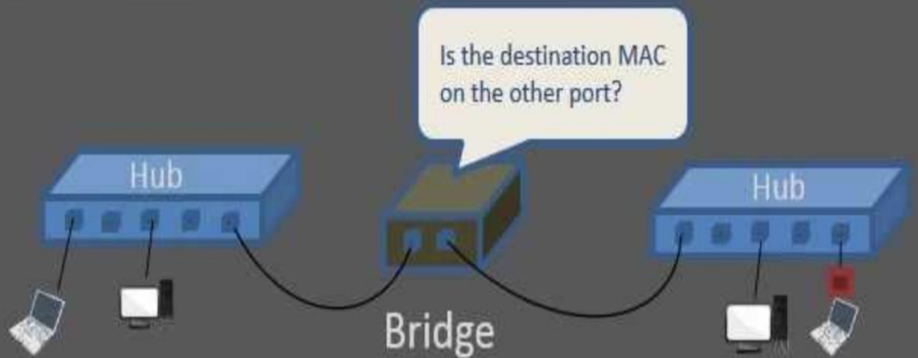
-Google!

Hub vs. Bridge vs. Switch

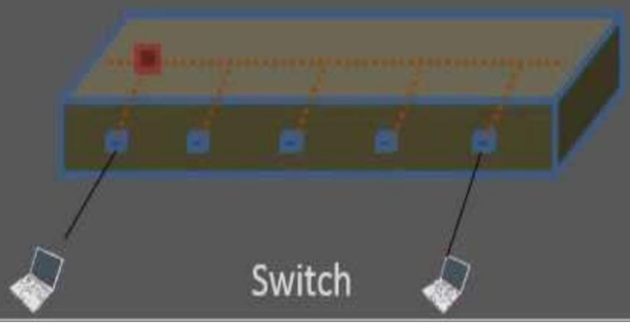
- Hub is really a *repeater*
- A message sent by one host is sent to all other hosts.
- One of the simplest ways to create a network.



- Bridge is a more intelligent form of Hub
- Packets are processed based on MAC address (Hardware Address) inside the incoming packet.



- Switch = Bridge with more than 2 Ports
- More scalable and practical
  - Bridge is not very useful for end-computing devices
  - Hubs cannot handle large data traffic



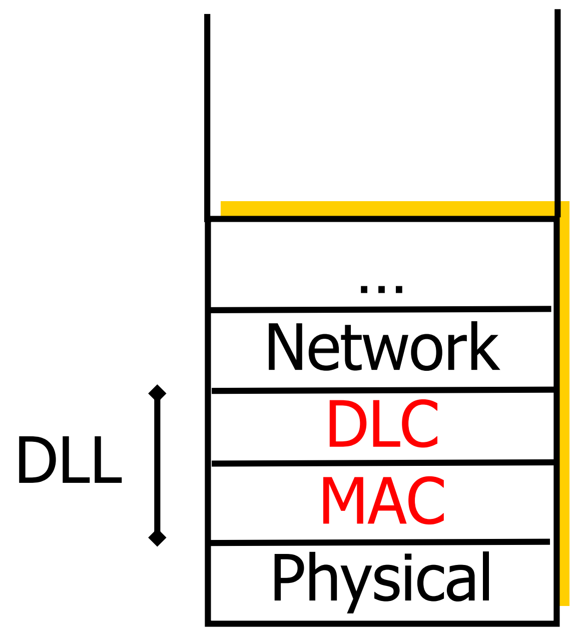
Switch

Hub

Bridge

The Channel Allocation Problem

- Allocate a single broadcast channel among competing users
  - Static Channel Allocation
    - TDM, FDM
  - Dynamic Channel Allocation
    - Multiple Access Protocols: ALOHA, CSMA etc.



DLL: Data Link Layer
DLC: Data Link Control
MAC: Medium Access Control

Dynamic Channel Allocation

- Key assumptions for formulating the allocation problem:
  - *Station Model:*
    - N independent stations (computers, phones, PDAs etc.) each generating frames for transmission with a mean rate of λ frames/sec.
  - *Single Channel Assumption:*
    - A single channel is available for all communication.
  - *Collision Assumption:*
    - If two frames are transmitted simultaneously, they overlap in time and the resulting signal is garbled → COLLISION.
    - All stations can detect collision and collided frame must be retransmitted

Dynamic Channel Allocation

- *Continuous Time:* Frame transmission can begin at any instant, no master clock dividing time into discrete intervals
- *Slotted Time:* Time is divided into discrete slots (intervals), frame transmission always begin at the start of a slot
- *Carrier Sense:*
  - Stations can detect if the channel is busy or not.
  - If busy, no station will attempt until it goes idle.
- *No Carrier Sense:*
  - Stations cannot detect the channel status → They go ahead and transmit
  - Later they determine if the transmission was successful or not

MAC protocols: taxonomy

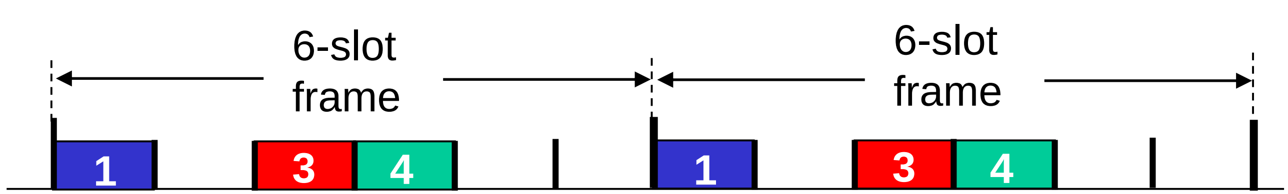
three broad classes:

- *channel partitioning*
  - divide channel into smaller "pieces" (time slots, frequency, code)
  - allocate piece to node for exclusive use
- *random access*
  - channel not divided, allow collisions
  - "recover" from collisions
- *"taking turns"*
  - nodes take turns, but nodes with more to send can take longer turns

Channel partitioning MAC protocols: TDMA

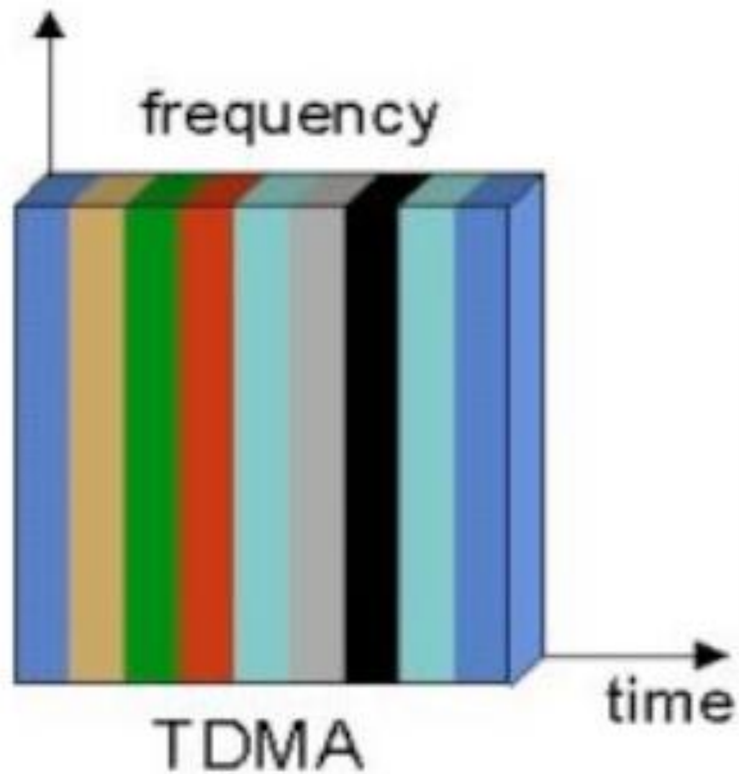
TDMA: time division multiple access

- access to channel in "rounds"
- each station gets fixed length slot (length = pkt trans time) in each round
- unused slots go idle
- example: 6-station LAN, 1,3,4 have pkt, slots 2,5,6 idle



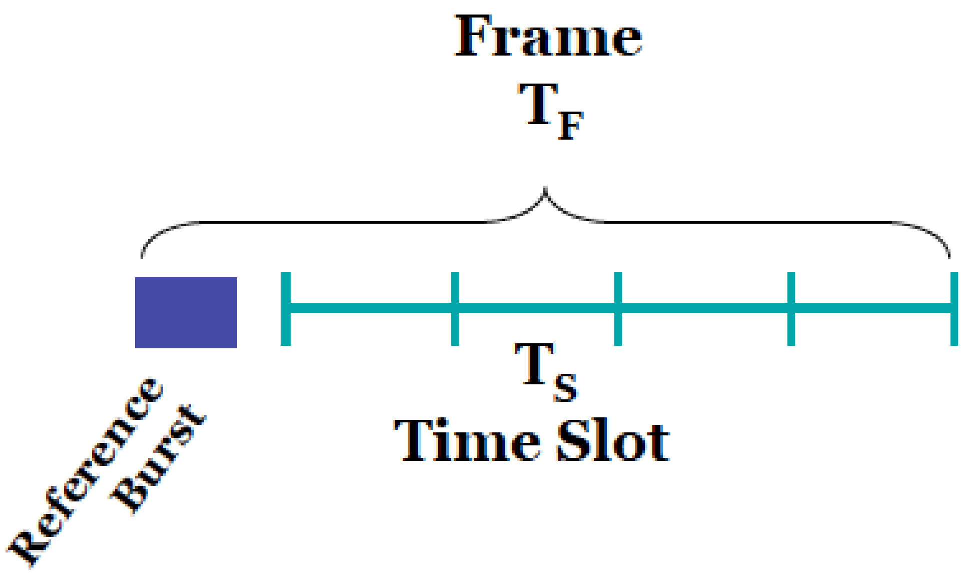
Each user is allowed to transmit only within specified time intervals (Time Slots). Different users transmit in differents Time Slots.

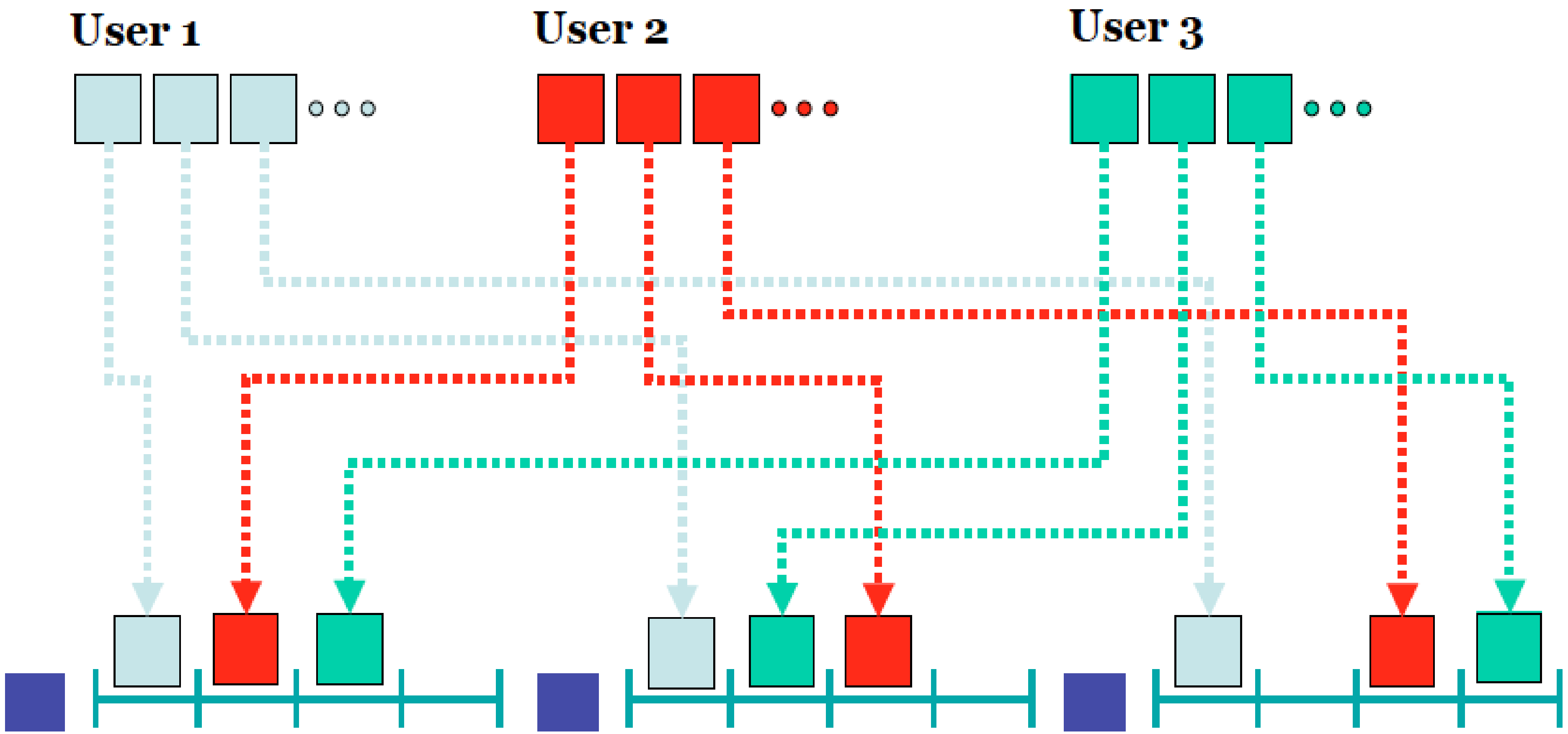
When users transmit, they occupy the whole frequency bandwidth (separation among users is performed in the time domain).



TDMA requires a centralized control node, whose primary function is to transmit a periodic **reference burst** that defines a frame and forces a measure of synchronization of all the users.

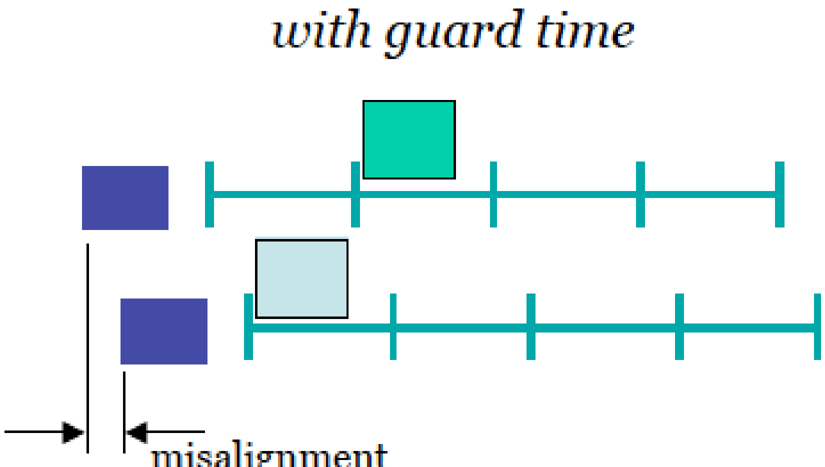
The frame so-defined is divided into time slots, and each user is assigned a Time Slot in which to transmit its information.

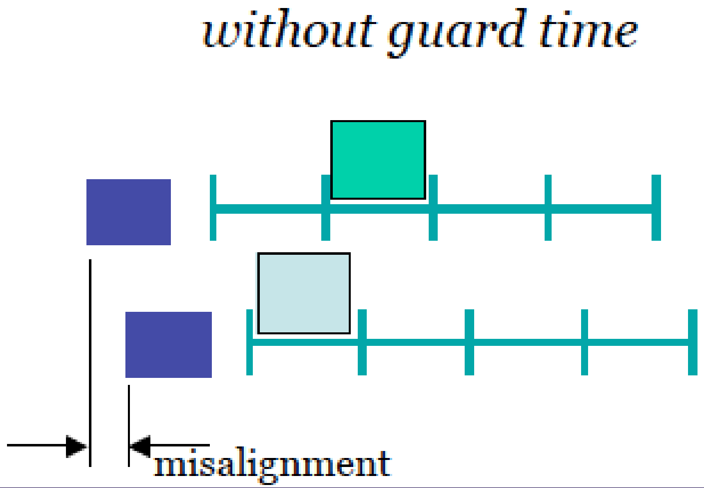



User 1
User 2
User 3

TDMA : guard times

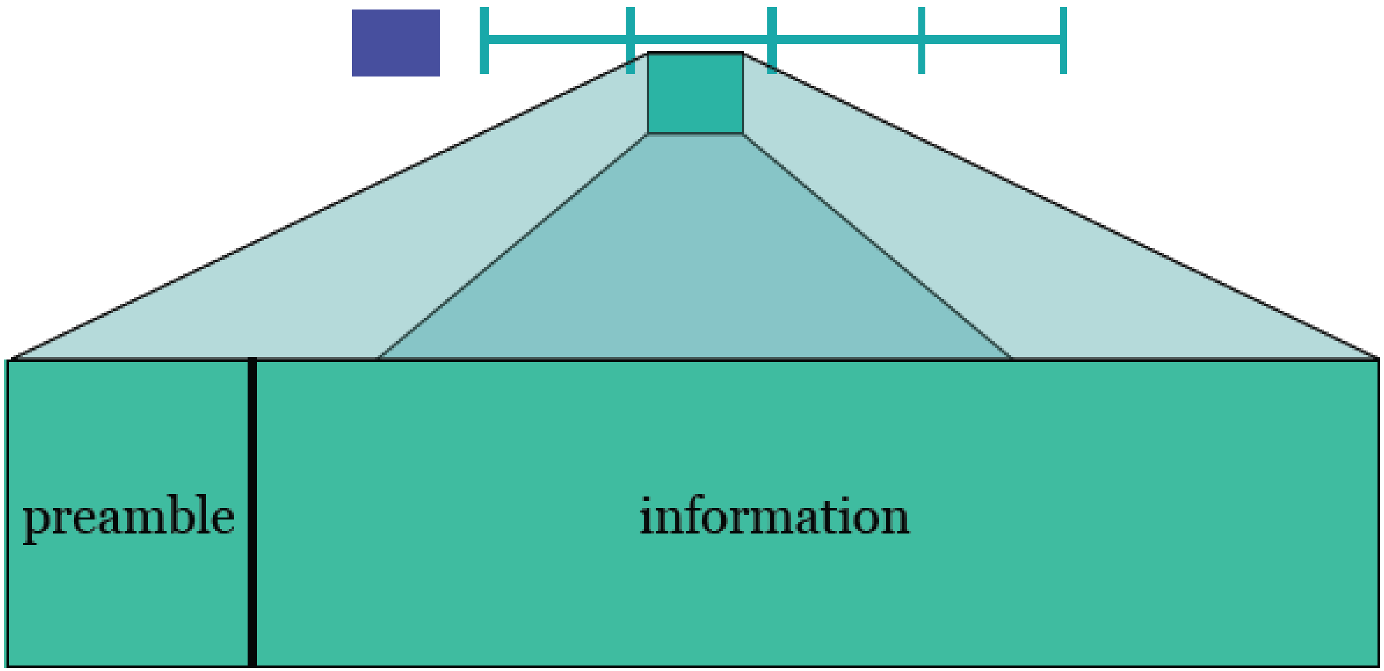
- Since there are significant delays between users, each user receives the reference burst with a different phase, and its traffic burst is transmitted with a correspondingly different phase within the time slot.
- There is therefore a need for **guard times** to take account of this uncertainty.
- Each Time Slot is therefore longer than the period needed for the actual traffic burst, thereby avoiding the overlap of traffic burst even in the presence of these propagation delays.





TDMA : preamble

- Since each traffic burst is transmitted independently with an uncertain phase relaive to the reference burst, there is the need for a **preamble** at the beginning of each traffic burst.
- The preamble allows the receiver to acquire on top of the coarse synchronization provided by the reference burst a fine estimate of timing and carrier phase.



TDD-TDMA and FDD-TDMA

- time division multiple access

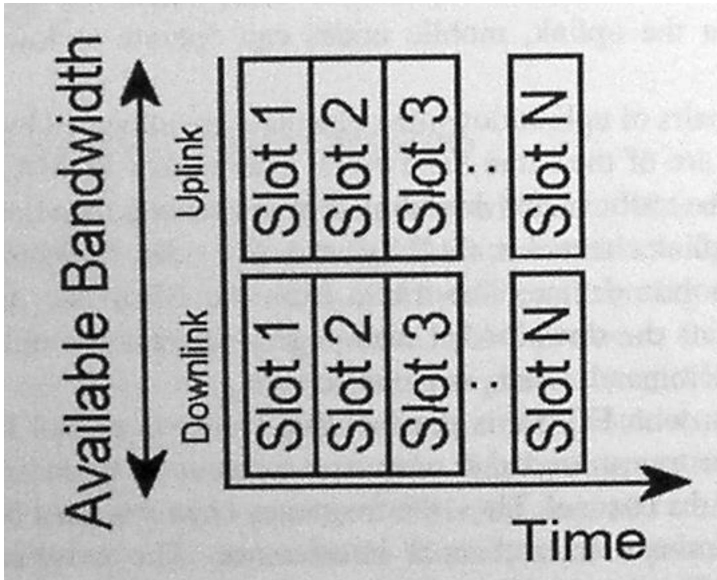


Figure 2.31 Illustration of FDD-TDMA

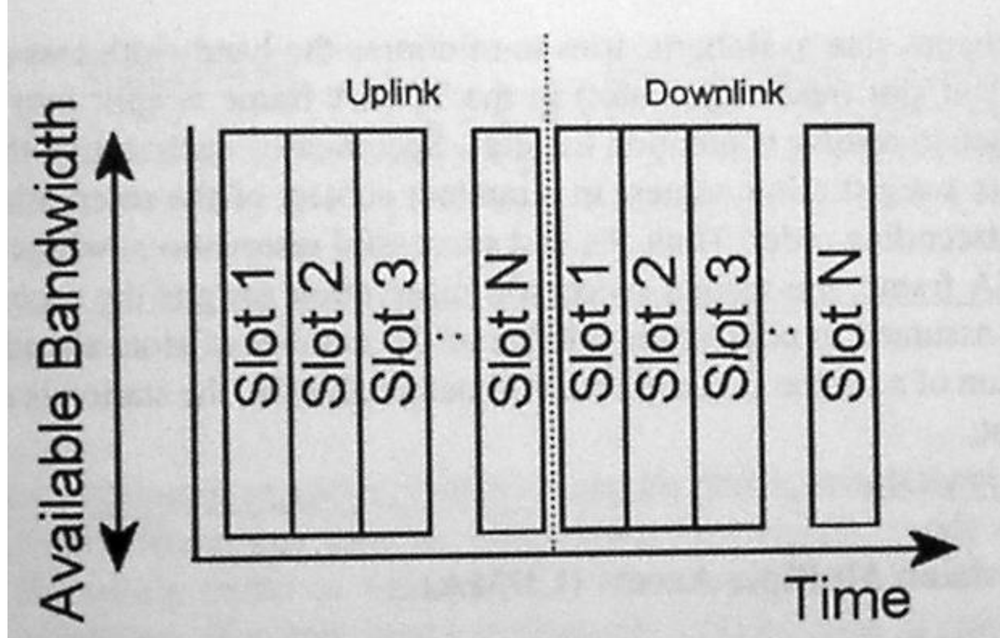
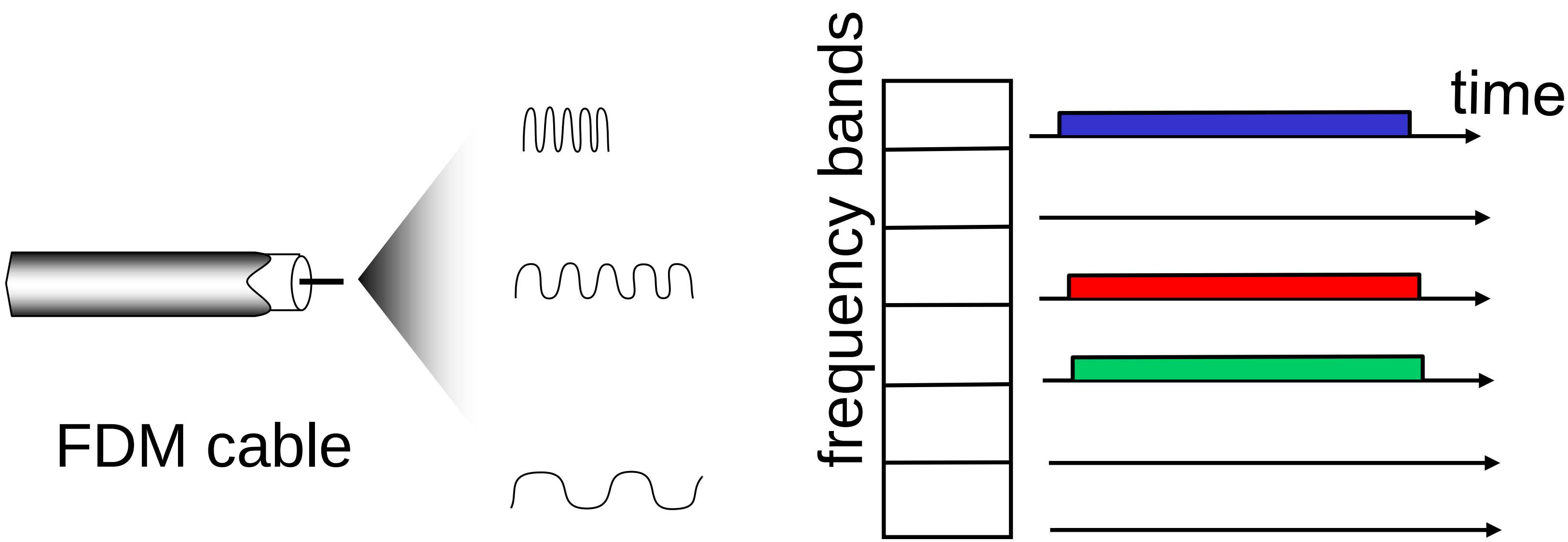


Figure 2.32 Illustration of TDD-TDMA

Channel partitioning MAC protocols: FDMA

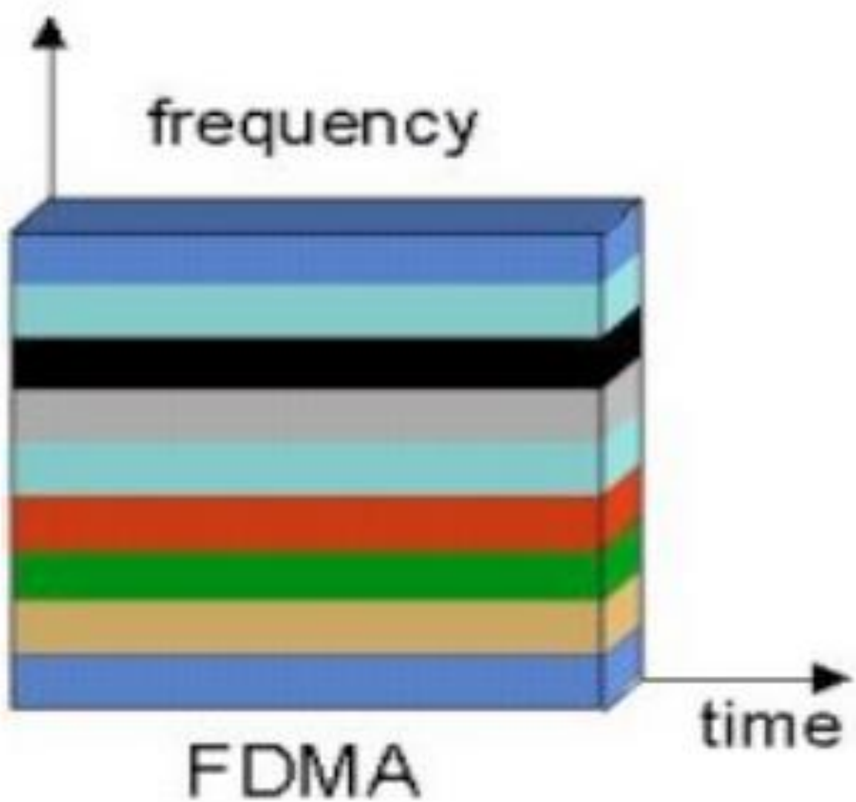
FDMA: frequency division multiple access

- channel spectrum divided into frequency bands
- each station assigned fixed frequency band
- unused transmission time in frequency bands go idle
- example: 6-station LAN, 1,3,4 have pkt, frequency bands 2,5,6 idle



Each user transmits with no limitations in time, but using only a portion of the whole available frequency bandwidth.

Different users are separated in the frequency domain.



FDMA

- frequency division multiple access

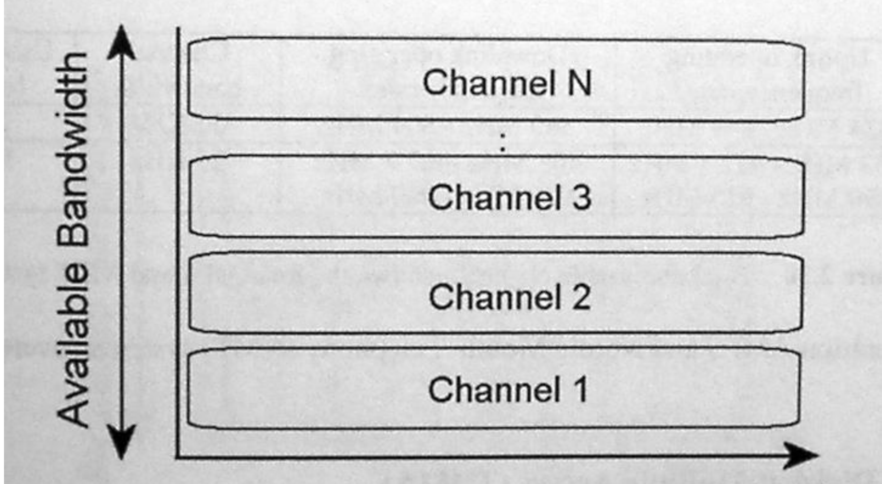


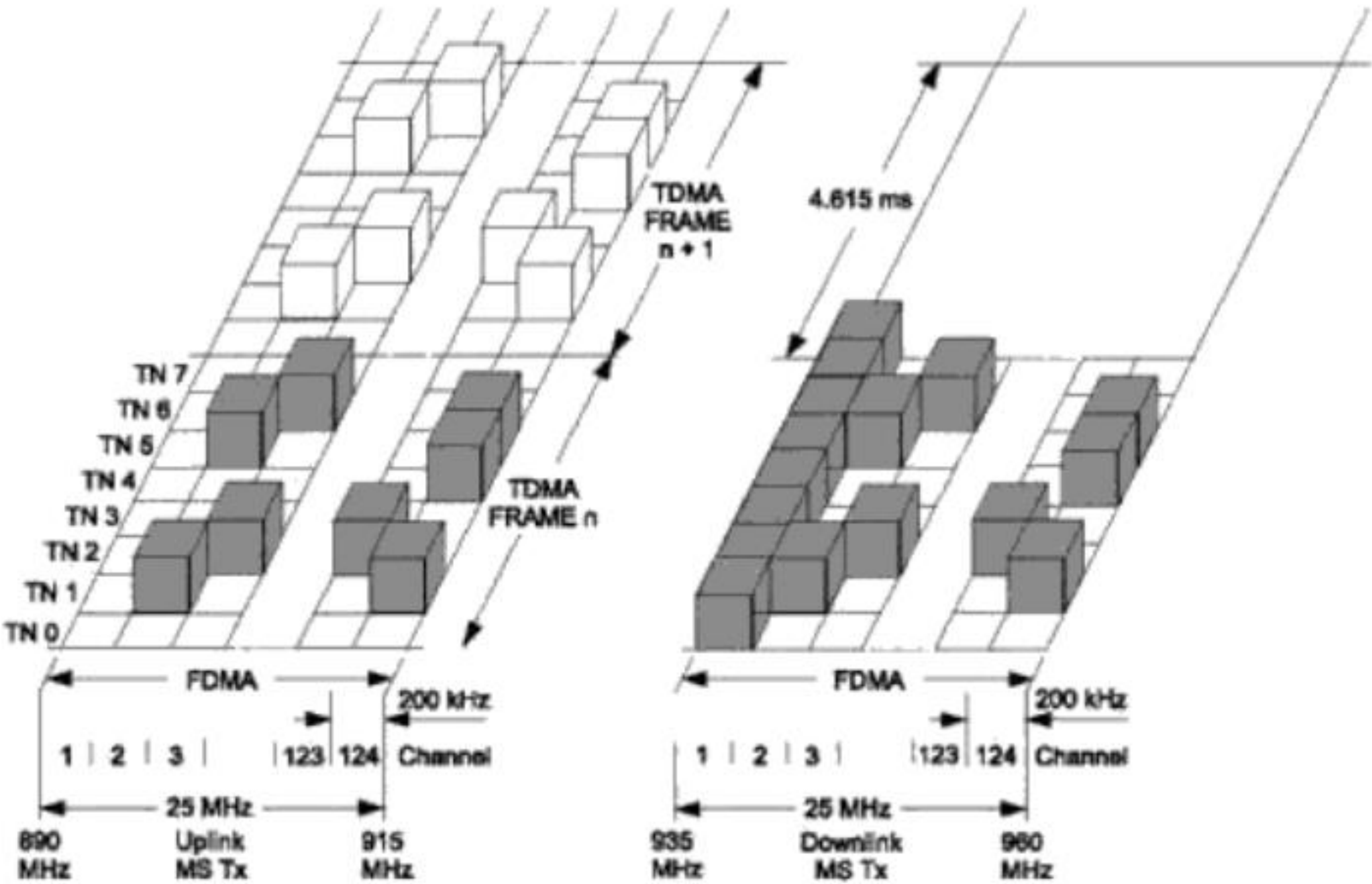
Figure 2.29 Illustration of FDMA

System	Uplink operating frequency range	Downlink operating frequency range	Channel bandwidth	Usable channel bandwidth
AMPS	824 MHz - 849 MHz	869 MHz - 894 MHz	30 KHz	24 KHz
NMT	453 MHz - 457.5 MHz 890 MHz - 915 MHz	463 MHz -467.7 MHz 935 MHz - 960 MHz	25 KHz	9.4 KHz

Figure 2.30 Total and usable channel bandwidths for AMPS and NMT systems

** NMT = nordic Mobile Telephony

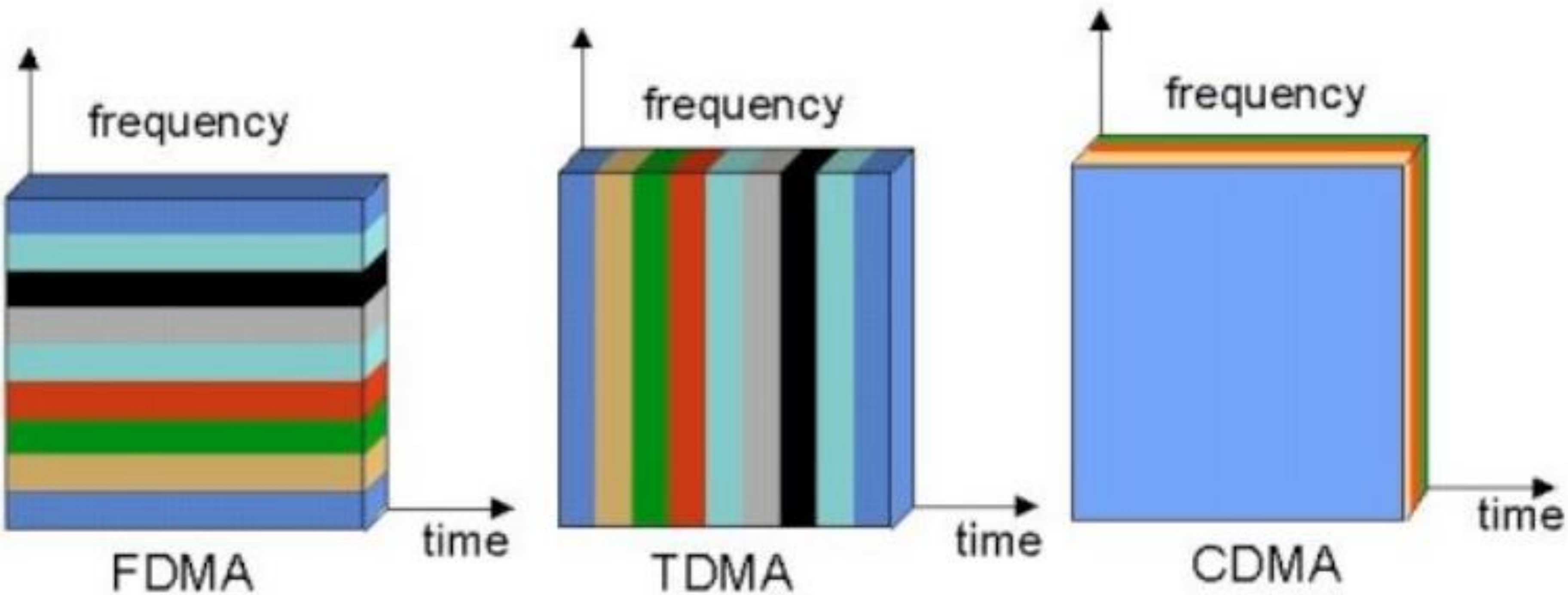
TDMA + FDMA in GSM900 standard



CDMA

- code division multiple access
  - each station has a “station code”
  - each bit is encoded by station code
    - code 1 is mapped to 1
    - code 0 is mapped to -1

Code Division Multiple Access (CDMA)

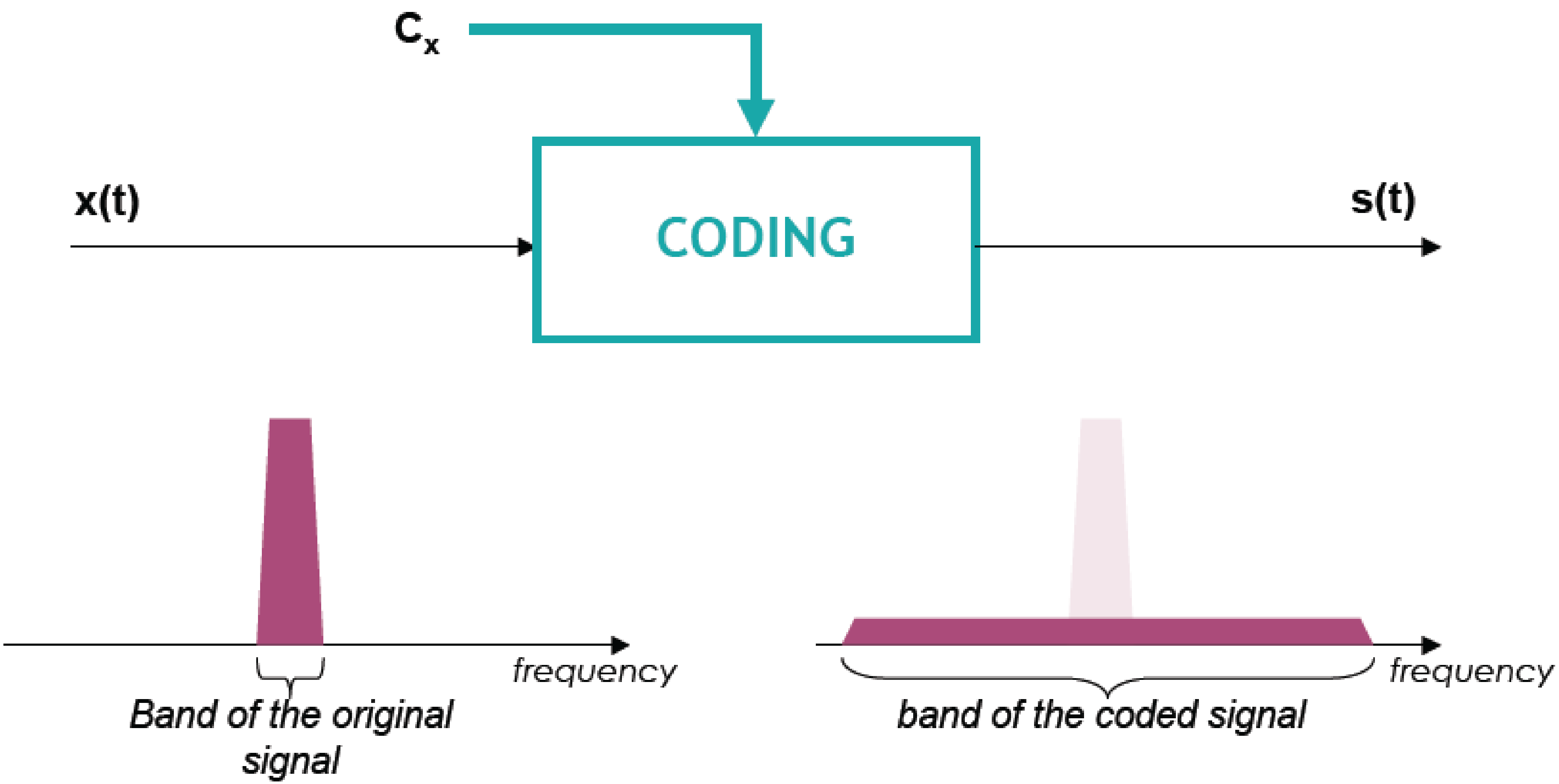


CDMA: basic principles

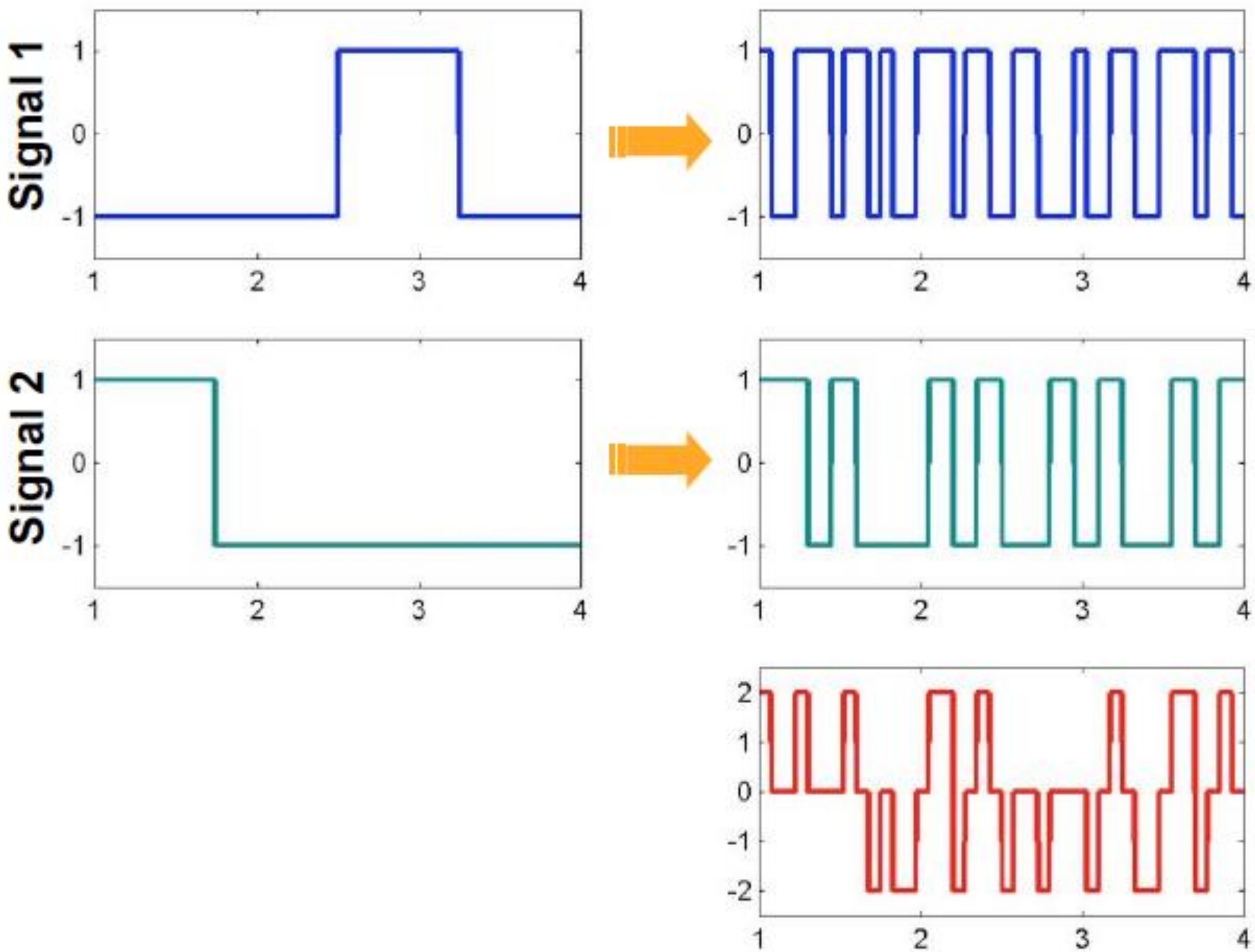
- In CDMA each user is assigned a unique code sequence (spreading code), which it uses to encode its data signal.
- The receiver, knowing the code sequence of the user, decodes the received signal and recovers the original data.
- The bandwidth of the coded data signal is chosen to be much larger than the bandwidth of the original data signal, that is, the encoding process enlarges (spreads) the spectrum of the data signal.
  - CDMA is based on spread-spectrum modulation.
- If multiple users transmit a spread-spectrum signal at the same time, the receiver will still be able to distinguish between users, provided that each user has a unique code that has a sufficiently low cross-correlation with the other codes.

Example of CDMA

Direct Sequence Spread Spectrum



Direct Sequence Spread Spectrum



Coded signal 1

Coded signal 2

Sum of coded signals 1 and 2

Orthogonal Chip Codes, CDMA example

$$\begin{bmatrix} H_n & H_n \\ H_n & -H_n \end{bmatrix}$$

2 codes

1 1

1 -1

4 codes

1 1 1 1

1 1 -1 -1

1 -1 1 -1

1 -1 -1 1

Coding:

M1 10 -> 1 1 1 1 -1-1-1-1

M2 01 -> -1-1 1 1 1 1-1-1

M3 11 -> 1-1 1-1 1-1 1-1

M4 00 -> -1 1 1-1-1 1 1-1

Combined signal:

0 0 4 0 0 0 0 -4

Decoding:

M1 (1,1,1,1)*(0,0,4,0)=4>0 => 1

(1,1,1,1)*(0,0,0,-4)=-4<0 => 0

M2 (1,1,-1,-1)*(0,0,4,0)=-4<0 => 0

(1,1,-1,-1)*(0,0,0,-4)=4>0 => 1

M3 (1,-1,1,-1)*(0,0,4,0)=4>0 => 1

(1,-1,1,-1)*(0,0,0,-4)=4>0 => 1

M4 (1,-1,-1,1)*(0,0,4,0)=-4<0 => 0

(1,-1,-1,1)*(0,0,0,-4)=-4<0 =>0

Random access protocols

- when node has packet to send
  - transmit at full channel data rate R.
  - no *a priori* coordination among nodes
- two or more transmitting nodes ➜ "collision",
- random access MAC protocol specifies:
  - how to detect collisions
  - how to recover from collisions (e.g., via delayed retransmissions)
- examples of random access MAC protocols:
  - slotted ALOHA
  - ALOHA
  - CSMA, CSMA/CD, CSMA/CA

ALOHA

- A type of packet-radio network.
- The first well-known wireless network as well as network system.
- Very simple, but not efficient!

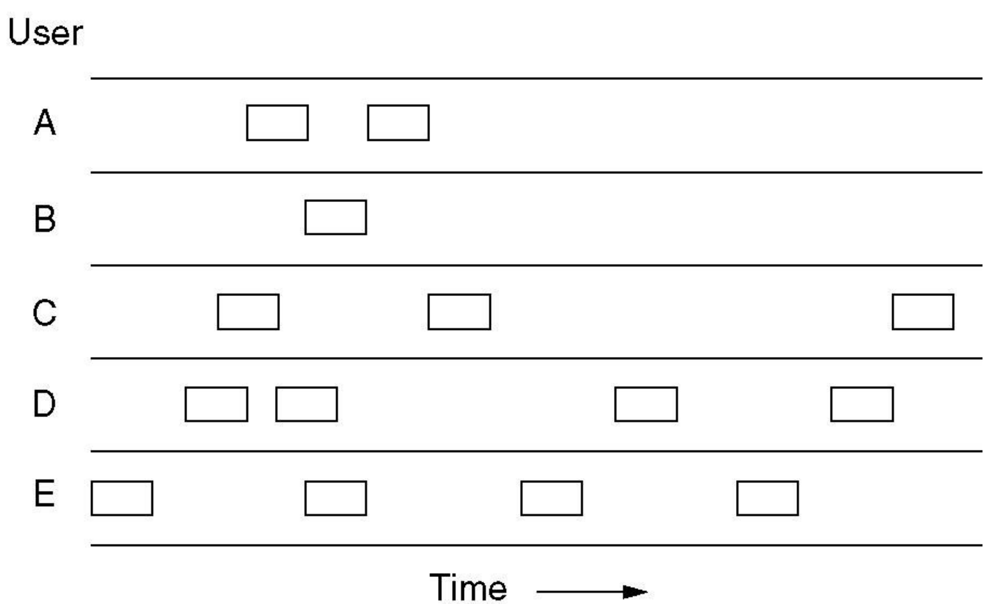
- Variations:
  - pure-ALOHA: whenever desired, send the packet
  - slotted-ALOHA: further divide time axis into slots

ALOHA

- Developed by Norman Abramson in Hawaii and it allowed multiple uncoordinated users access to a shared channel (ground based radio broadcasting)
- Ideas used in the protocol are applicable to any single shared channel with uncoordinated users or computers competing to transmit messages.
- Contention-based channel access (random access), i.e., multiple users share a common channel in a way that they contend for the channel and lead to conflicts.
- Two types were developed:
  - Pure ALOHA
  - Slotted ALOHA

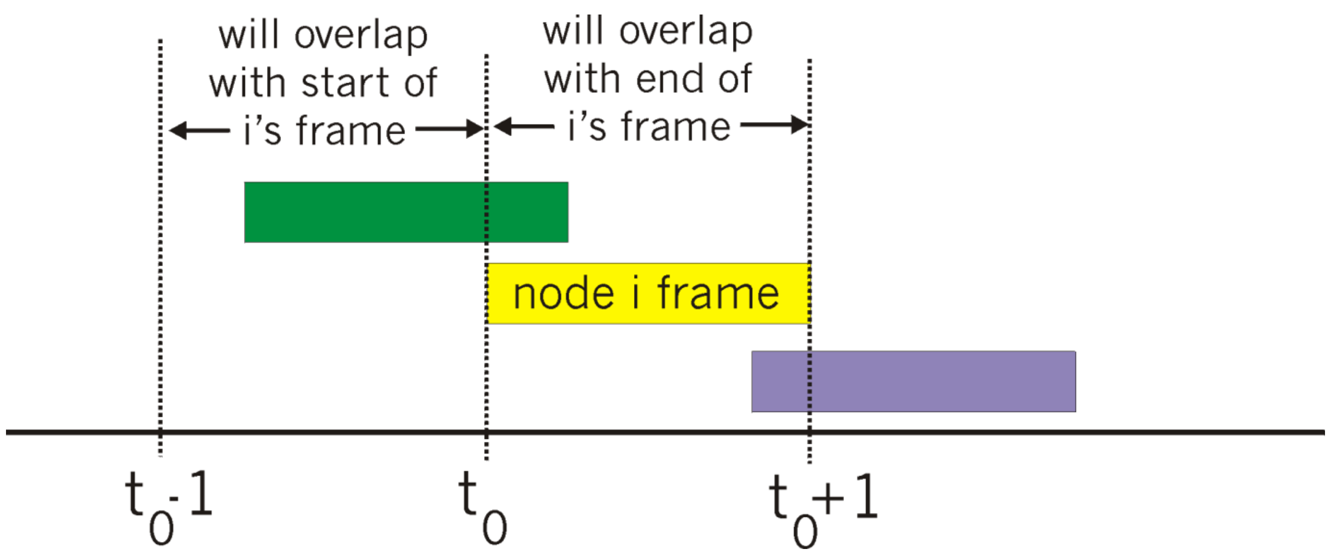
Pure ALOHA

- Each station transmits whenever it wants (i.e., whenever a frame is generated)
- Frames are transmitted at completely arbitrary times
- There will be collisions, and collisions will be detected when they occur
- When collision, sender waits for a random amount of time and sends it again. (Why random??)



Pure (unslotted) ALOHA

- unslotted Aloha: simpler, no synchronization
- when frame first arrives
  - transmit immediately
- collision probability increases:
  - frame sent at t_0 collides with other frames sent in $[t_0-1, t_0+1]$



Pure ALOHA efficiency

P(success by given node) = P(node transmits) $\cdot$

P(no other node transmits in $[t_0\text{-}1, t_0]$ $\cdot$

P(no other node transmits in $[t_0, t_0+1]$

$$= p \cdot (1\text{-}p)^{\mathbf{N-1}} \cdot (1\text{-}p)^{\mathbf{N-1}}$$

$$= p \cdot (1\text{-}p)^{\mathbf{2(N-1)}}$$

… choosing optimum p and then letting n $\longrightarrow \infty$

$$= 1/(2e) = .18$$

even *worse* than slotted Aloha!

Slotted ALOHA

assumptions:

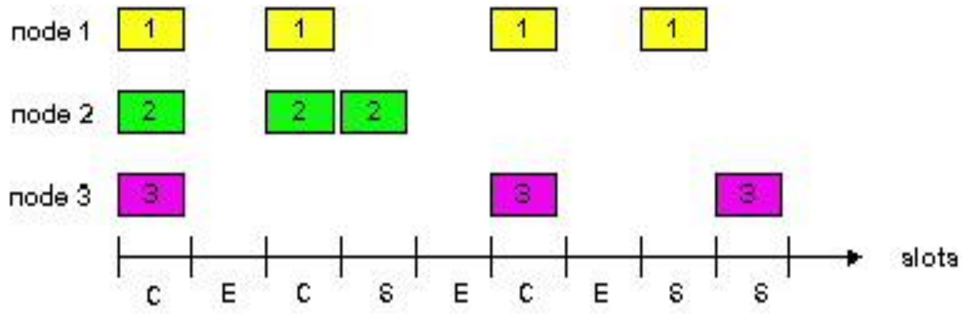
- all frames same size
- time divided into equal size slots (time to transmit 1 frame)
- nodes start to transmit only slot beginning
- nodes are synchronized
- if 2 or more nodes transmit in slot, all nodes detect collision

operation:

- when node obtains fresh frame, transmits in next slot
  - *if no collision:* node can send new frame in next slot
  - *if collision:* node retransmits frame in each subsequent slot with prob. p until success

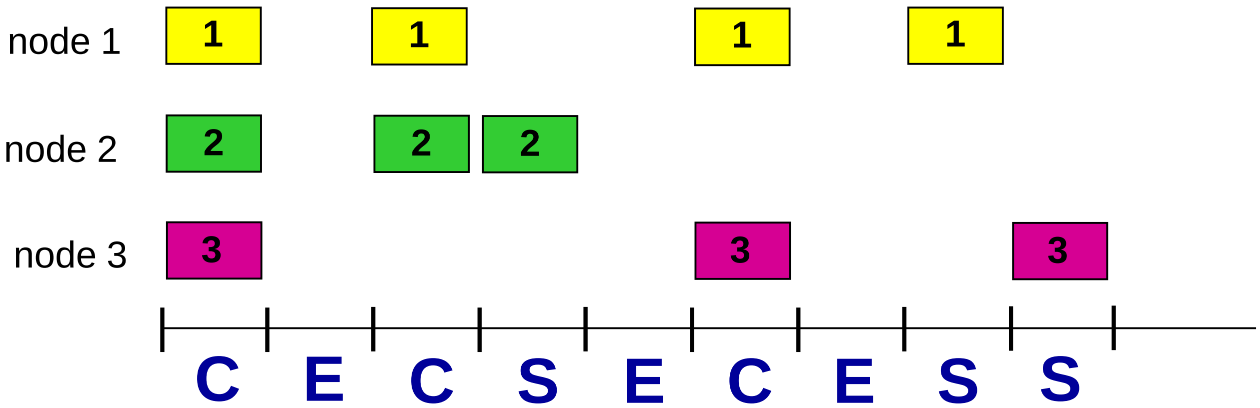
Slotted ALOHA

- A method for doubling the capacity of ALOHA
- Divide up time into intervals, each interval corresponding to one frame
- Senders must agree on the slot boundaries → requires synchronization
  - Can be achieved by a special station emitting a short frame at the start of each slot interval (similar to a clock tick)
- Sender is not allowed to transmit until the start of a slot (after the clock tick)
  - a newly arriving station transmits at the beginning of the next slot
- If collision occurs, sender retransmits the packet in future slot with probability p, until successful



Success (S),
Collision (C),
Empty (E) slots

Slotted ALOHA



Pros:

- single active node can continuously transmit at full rate of channel
- highly decentralized: only slots in nodes need to be in sync
- simple

Cons:

- collisions, wasting slots
- idle slots
- nodes may be able to detect collision in less than time to transmit packet
- clock synchronization

Slotted ALOHA: efficiency

efficiency: long-run fraction of successful slots (many nodes, all with many frames to send)

- *suppose: N* nodes with many frames to send, each transmits in slot with probability *p*
- prob that given node has success in a slot = $p(1-p)^{N-1}$
- prob that *any* node has a success = $Np(1-p)^{N-1}$

- max efficiency: find p* that maximizes $Np(1-p)^{N-1}$
- for many nodes, take limit of $Np^*(1-p^*)^{N-1}$ as N goes to infinity, gives:

  max efficiency = 1/e = .37

at best: channel used for useful transmissions 37% of time!

!

Problems with Pure/Slotted ALOHA

- Pure ALOHA
  - Transmit whenever a message is ready
  - Retransmit when there is a collision
- Slotted ALOHA
  - Time is divided into equal time slots
  - Transmit only at the beginning of a time slot
  - Avoid partial collisions
  - Increase delay, and require synchronization

They do not listen to the channel !!!

Carrier Sense Multiple Access (CSMA) Protocols

- In Local Area Networks, it is possible for computers to detect whether other computers are transmitting or not
- Unlike ALOHA, stations listen for a carrier (i.e., transmission) and act accordingly
- These protocols have a much better throughput rate (% of successfully transmitted frames) compared to ALOHA.
- Protocols in which computers listen for a carrier (signal on the medium) and act accordingly are called **carrier sense** protocols.
  - **1-persistent** CSMA
  - **nonpersistent** CSMA
  - **p-persistent** CSMA

CSMA (carrier sense multiple access)

CSMA: listen before transmit:

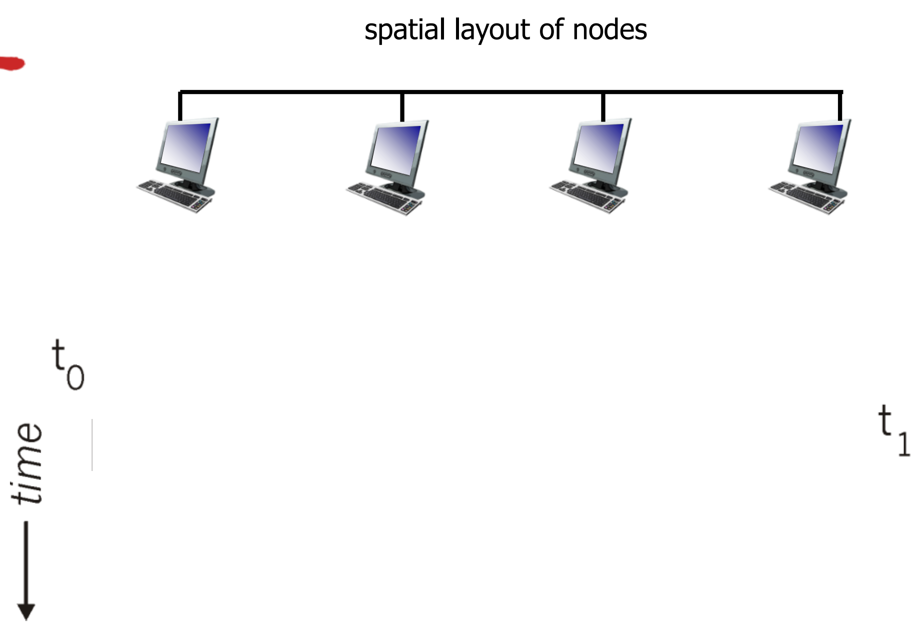
if channel sensed idle: transmit entire frame

- if channel sensed busy, defer transmission

- human analogy: don't interrupt others!

CSMA collisions

- collisions *can* still occur: propagation delay means two nodes may not hear each other's transmission
- collision: entire packet transmission time wasted
  - distance & propagation delay play role in in determining collision probability



1-persistent CSMA

1. When a station has data to send, it first listens to the channel to see if it is busy
2. If channel busy

   → *the station waits until it becomes idle*
3. When the station detects an idle channel

   → *it transmits a frame*
4. While transmitting the frame, station listens to channel to see if collision
5. If collision

   → *station waits a random amount of time and attempts to transmit again (starts all over again)*

The protocol is called 1-persistent because the station transmits with a probability of 1 whenever it finds the channel idle.

1-persistent CSMA

```
while (frame exists) do
begin
    listen to channel (idle);
    if idle then
        repeat
            xmit (frame);
            check (collision);
            if collision then wait (random);
        until (not collision);
end
```

1-persistent CSMA

- Collision still possible e.g., due to propagation delay
  - The time it takes for the electrical signal to propagate over the medium is known as the **propagation delay**.
  - Possible (slightly) that after a station begins sending, another one becomes ready to send and senses the channel
  - If the first station's signal has not reached the second one, then the second will sense an idle channel, begin sending→ COLLISION
  - *The longer the propagation delay, the worse this effect is*

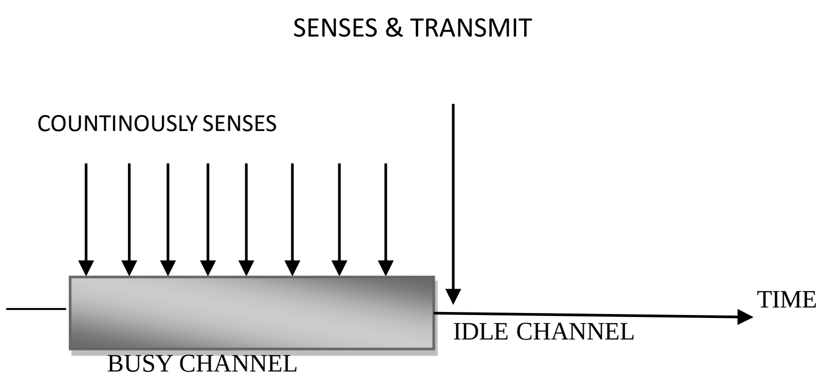
- Even if propagation delay is zero, there will still be collisions
  - Two stations become ready to transmit during another computers transmission
  - Both will wait until channel idle and then begin sending → COLLISION

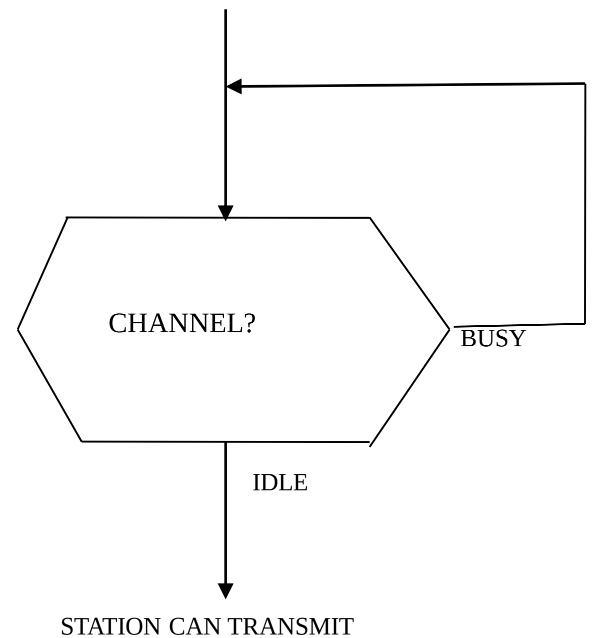
1-persistent CSMA is much better than Pure ALOHA because at least stations wait until there are no transmissions before attempting to transmit !

Drawback of 1-persistent

- The propagation delay time greatly affects this protocol. Let us suppose, just after the station 1 begins its transmission, station 2 also become ready to send its data and sense the channel. If the station 1 signal has not yet reached station 2, station 2 will sense the channel to be idle and will begin its transmission. This will result in collision.

- Even if propagation delay time is zero, collision will still occur. If two stations become ready in the middle of third station's transmission both stations will wait until the transmission of first station ends and both will begin their transmission exactly simultaneously. This will also result in collision.





nonpersistent CSMA

- In this protocol, an attempt is made to be less greedy than 1-persistent CSMA
- Before sending, a station senses the channel
  - If channel idle → begins sending
  - If busy → wait a random time before listening again
  - If idle → it transmits its frame.
- *Advantage:* Instead of waiting for the channel to become idle as in the 1-persistent case, on detecting that the channel is busy, a station waits a random time before listening again.

Intuitively, it has better channel utilization and longer delays than 1-persistent CSMA.

nonpersistent CSMA

```
while (frame exists) do
begin
      collision=true;
      repeat
         listen to channel (idle);
         if idle then begin
                  collision=false;
                  xmit (frame);
                  check (collision);
         end;
         wait (random);
      until (not collision);
end
```

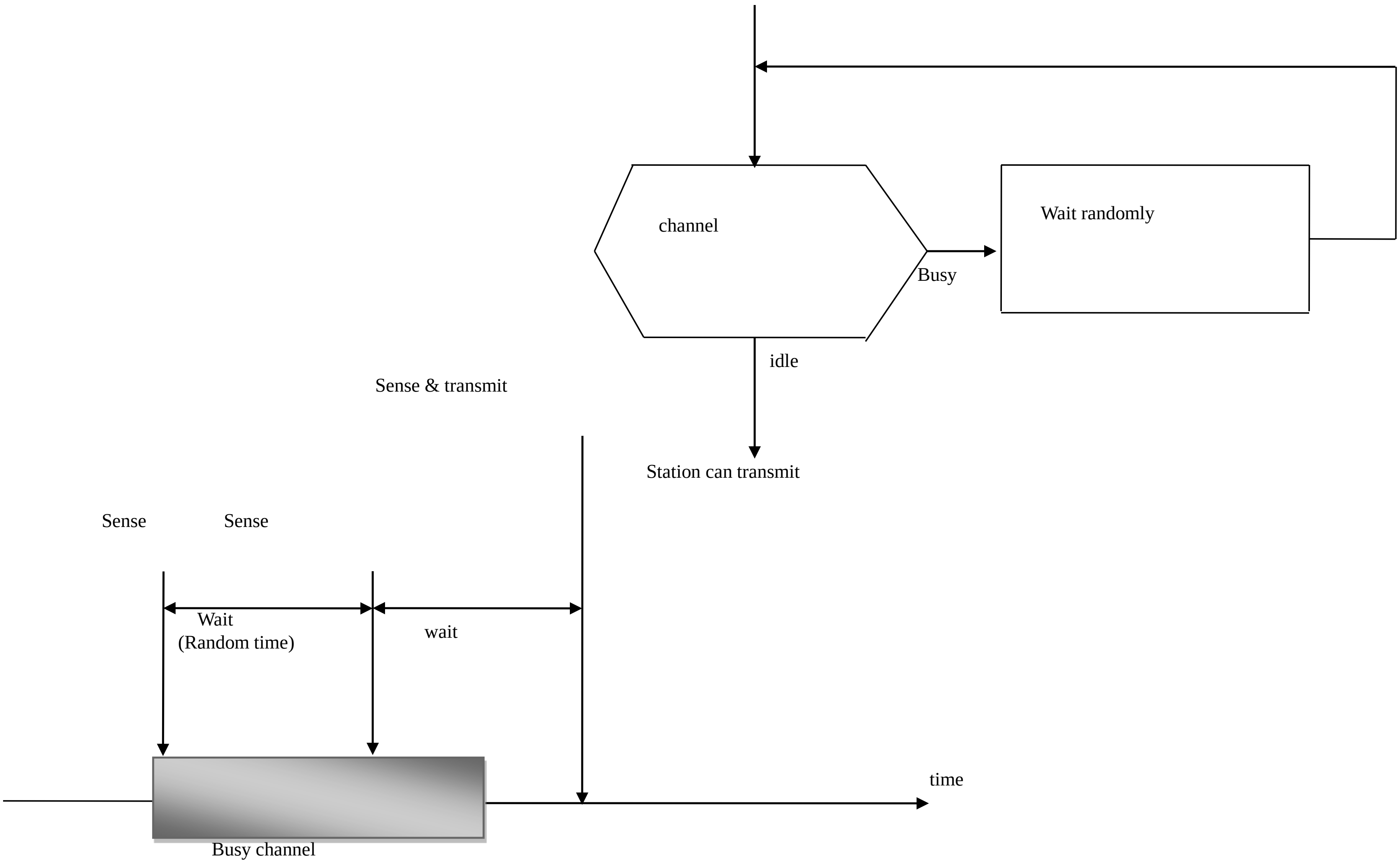
If collision occurs, collision=true

Advantages of non-persistent

- It reduces the chances of collision because the stations wait a random amount of time. It is unlikely that two or more stations Will wait for same amount of time and will retransmit at the same time.

Disadvantages of non-persistent

- It reduces the efficiency of network because the channel remains idle when there may be station with frames to send. This is due to the fact that the stations wait a random amount of time after the collision.


channel
Busy
Wait randomly
idle
Station can transmit
Sense & transmit
Sense
Sense
Wait
(Random time)
wait
time
Busy channel

p-persistent CSMA

- This protocol applies to slotted channels
- When a station is ready to transmit, it senses the channel
  - If the channel is idle

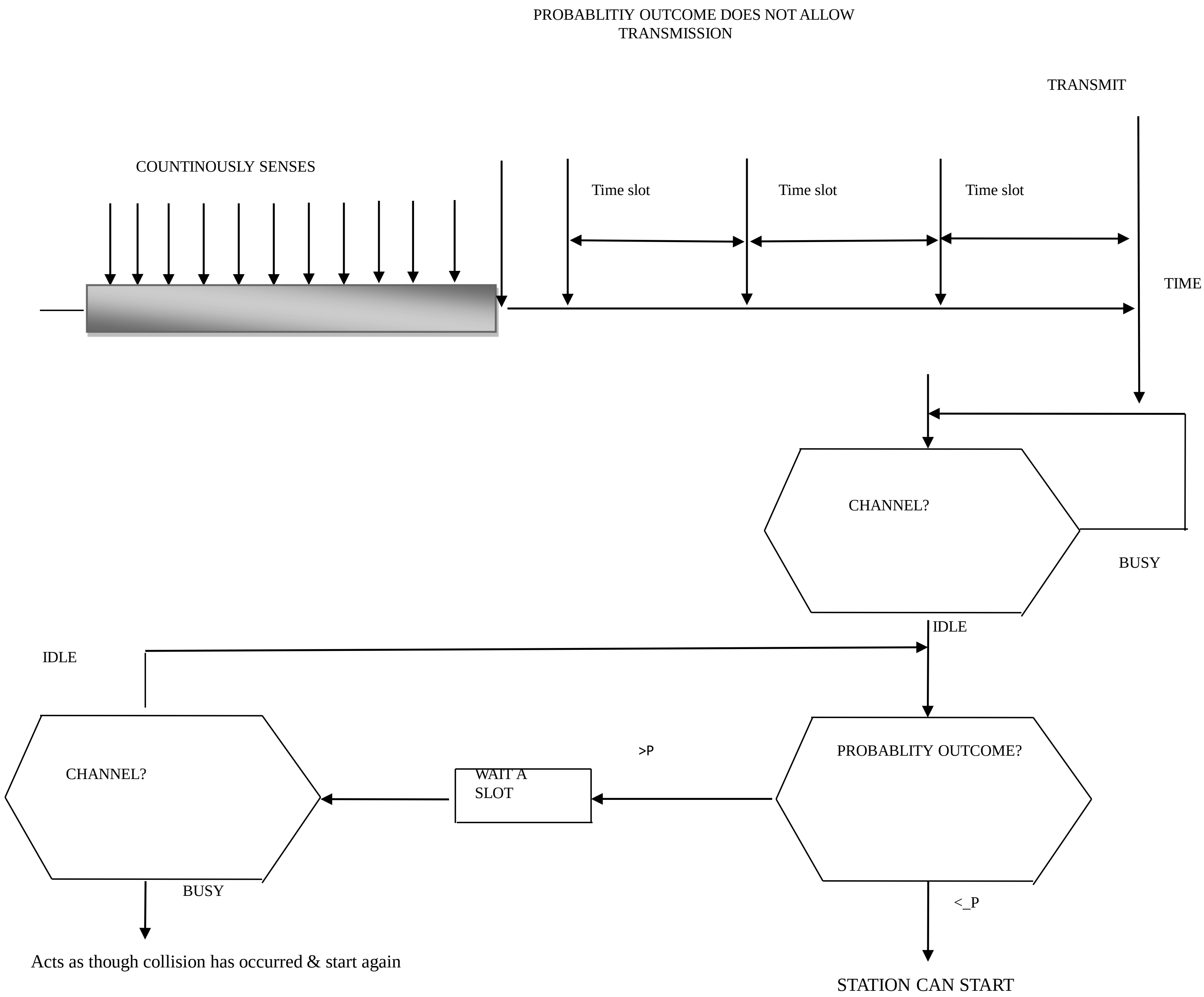
    → the station either transmits with a probability p or waits a further slot with probability q=1 - p
  - If the channel still idle during this slot

    → then again it either transmits or defers with probabilities p or q
  - This is repeated until either the frame is transmitted or another station has begun transmitting
    - If the channel is busy (another station transmitting), station acts as if collision → waits a random time and starts again
  - If the channel is initially busy

    → it waits until the next slot and applies above algorithm

p-persistent CSMA

```
while (frame exists) do
begin
        collision=true;
        repeat
            listen to channel (idle);
            if idle then
                        if (rand <p) then begin
                                    collision=false;
                                    xmit (frame);
                                    check (collision);
                                    if collision then wait (random)
                        end;
            until (not collision);
end
```


PROBABLITIY OUTCOME DOES NOT ALLOW TRANSMISSION
TRANSMIT
COUNTINOUSLY SENSES
Time slot
Time slot
Time slot
TIME
CHANNEL?
BUSY
IDLE
IDLE
CHANNEL?
>P
WAIT A SLOT
PROBABLITY OUTCOME?
BUSY
<_P
Acts as though collision has occurred & start again
STATION CAN START

Persistent and Nonpersistent CSMA

- Comparison of the channel utilization versus load for various random access protocols.
- CSMA has better channel utilization (and longer delays than ALOHA)