CS3640

Link Layer (2): MAC Protocols

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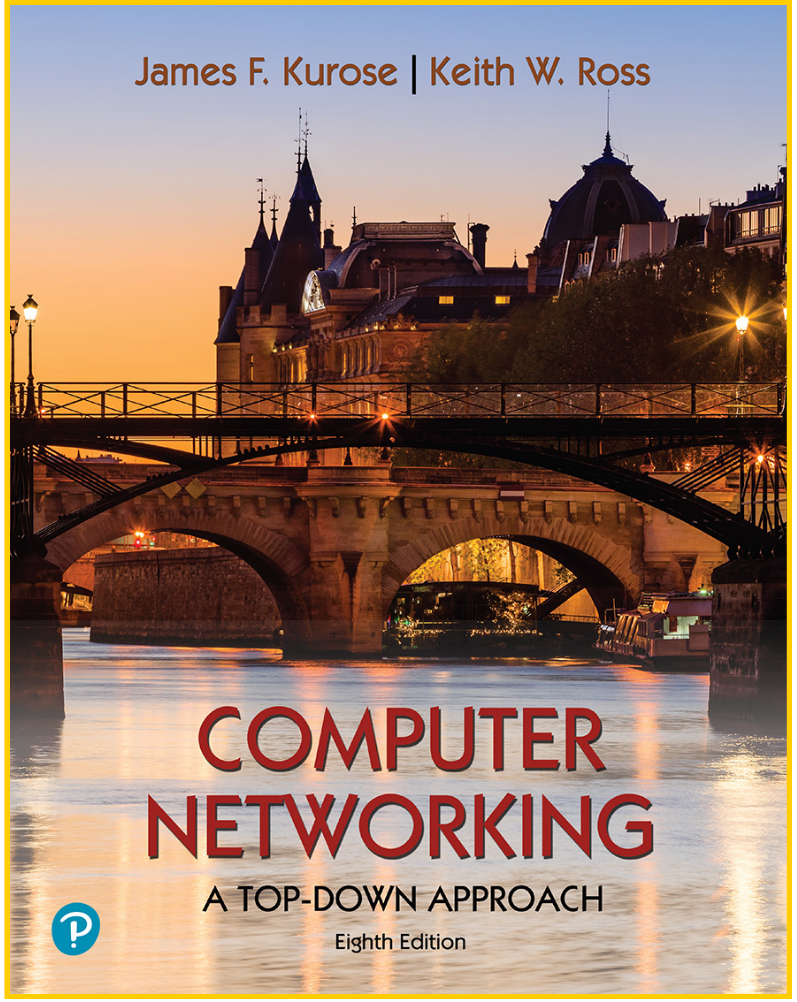
Lecture goals

continued exploration of link layer protocols and technologies

- *Channel Partitioning*
- *Random Access*
- *Taking Turns*
- *Real-world example*



Chapter 6.3

Multiple Access Protocols

sharing a single broadcast channel amongst multiple nodes

1 Channel Partitioning Protocols

divide channel into small pieces (e.g., time slots, frequency), and allocate each piece to one node

2 Random Access Protocols

do not divide the channel, and allow nodes to transmit at any time, but detect/recover from collisions

3 Taking-turns Protocols

nodes take turn to send frames; this dynamism achieves balance between the first two class of protocols

Characterizing MAC Protocols

- MAC protocols are distributed algorithms that determine how nodes share a channel, *i.e., determine when nodes transmit*
- all communications about channel sharing must use channel itself, *i.e, no out-of-band channel for coordination*

An ideal MAC protocol

For a broadcast channel with a rate R bits/sec, it should be/enable the following:

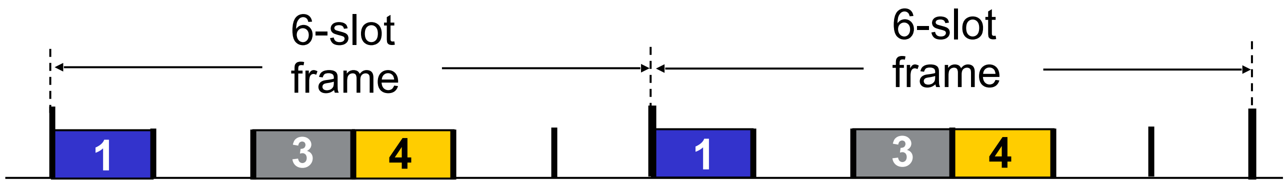
- if only one node wants to transmit, it can send at rate R
- if M nodes want to transmit, each can send at average rate R/M
- be fully decentralized i.e., no centralized controller, no sync of clocks amongst nodes
- be simple

Channel Partitioning Protocols

Channel Partitioning Protocols

TDMA: Time Division Multiple Access

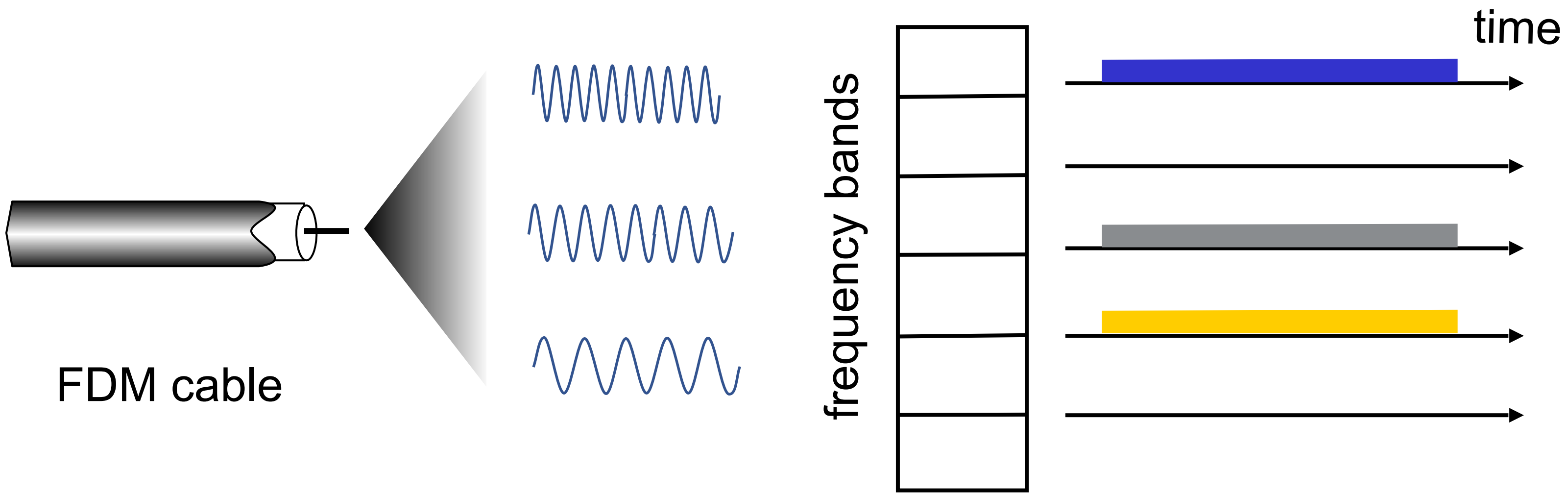
- access to channel in “rounds”
- each station gets fixed length slot (length = packet transmission time) in each round
- unused slots go idle
- example: 6-station LAN, 1,3,4 have packets to send, slots 2,5,6 idle



Channel Partitioning Protocols

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 packet to send, and bands 2,5,6 are idle



Random Access Protocols

Random Access Protocols

- When node has packet to send,
  - ➡ it transmits at full channel data rate R
  - ➡ no *a priori* coordination among nodes
- If two or more nodes transmit simultaneously: collision
- Random Access Protocols specify
  - ➡ how to detect collisions
  - ➡ how to recover from collisions
- Examples of random access protocols
  - ➡ ALOHA, slotted ALOHA
  - ➡ CSMA, CSMA/CD, CSMA/CA

Slotted ALOHA

Channel assumptions

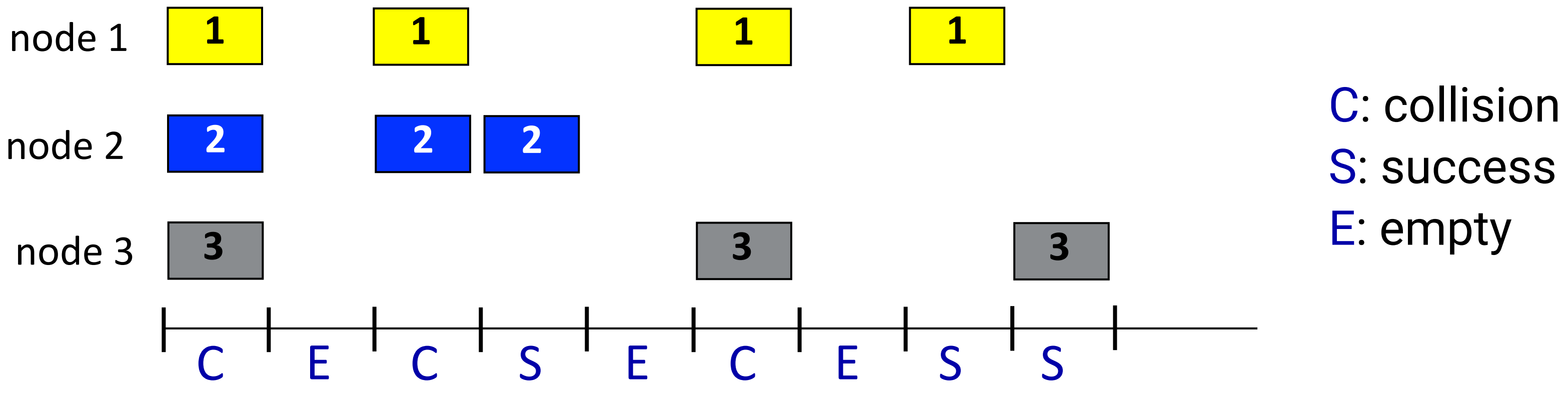
- all frames are of same size
- time is divided into equal length slots *(e.g., time to transmit 1 frame)*
- nodes start to transmit only at the beginning of a slot
- all nodes are implicitly synchronized
- if two or more nodes transmit in slot, all nodes detect collision

Protocol operation

- When a node has a new frame, it transmits it in next slot
- If no collision is detected: node can send new frame in next slot
- If collision is detected: node retransmits the frame in each subsequent slot with probability **p** until success

randomization – *why*?

Slotted ALOHA



Pros

- single active node can continuously transmit at full rate of channel
- highly decentralized
- simple

Cons

- a collision wastes the full slot
- leaves idle slots even when nodes have data to transmit
- clock synchronization

Slotted ALOHA

Efficiency: fraction of slots that transmit data successfully in the long run (assuming many nodes, and all of them have 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
- take limit of Np*(1-p*)N-1 as N goes to infinity, max efficiency = 1/e = .37

At best, only 37% of the slots do useful work!

Carrier Sense Multiple Access (CSMA)

Simple CSMA: listen before transmit

- if channel sensed to be idle: *transmit entire frame*
- if channel sensed to be busy: *defer transmission*

human analogy: don’t interrupt while others are talking!

CSMA/CD: CSMA with collision detection

- collisions detected within short time
- all colliding transmissions are aborted, thus reducing channel wastage
- collision detection easy in wired, difficult with wireless

human analogy: a polite conversationalist

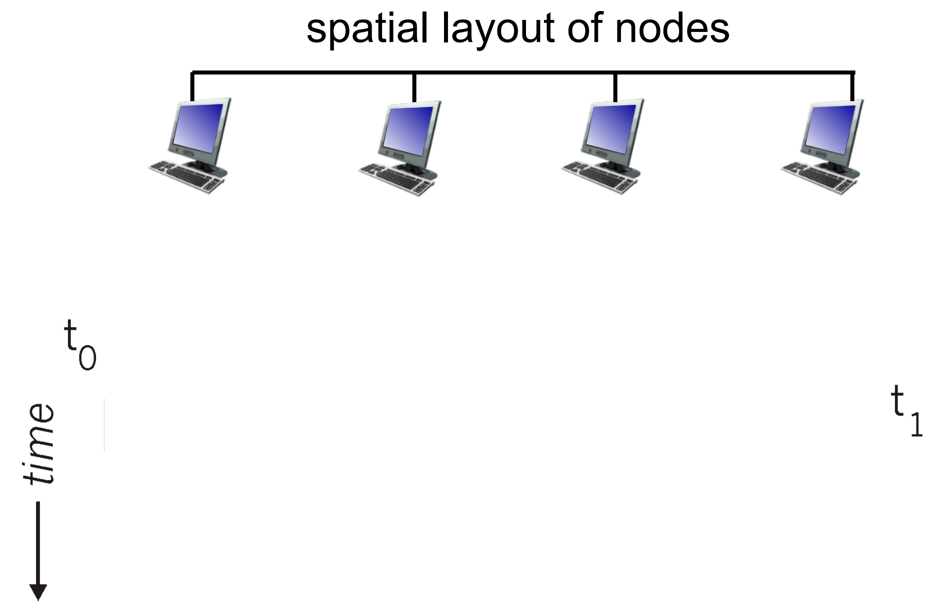
Simple CSMA

Collisions can still occur with carrier sensing:

- propagation delay means two nodes may not hear each other's just-started transmission

When there is a collision: entire packet transmission time is wasted

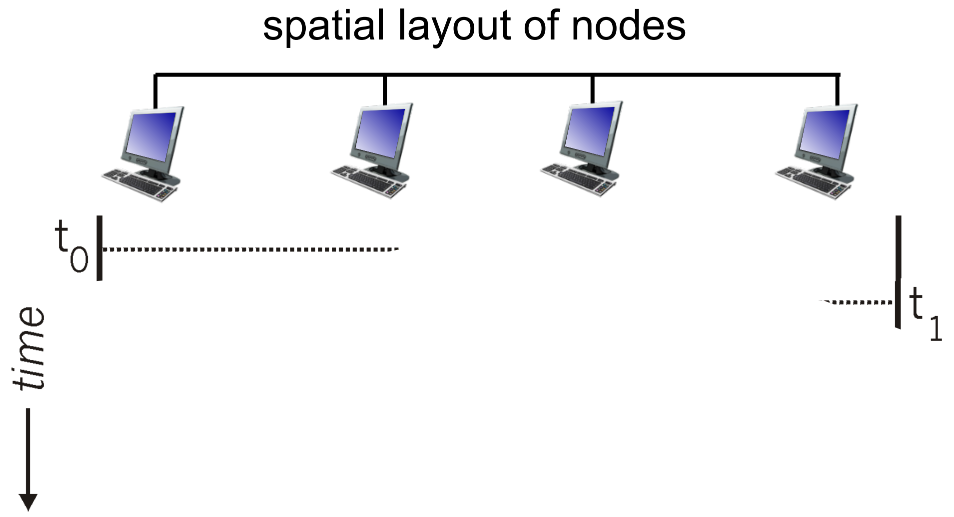
- distance and propagation delay play role in in determining collision probability



CSMA/CD

CSMA/CD reduces the amount of time wasted in collisions

- transmission aborted on collision detection



Ethernet CSMA/CD algorithm

1. Ethernet receives datagram from network layer, creates a frame
2. If Ethernet senses channel:

   if idle: start frame transmission.

   if busy: wait until channel idle, then transmit
3. If entire frame transmitted without collision - done!
4. If another transmission detected while sending: abort, send jam signal
5. After aborting, enter binary exponential backoff
   - after mth collision, chooses K at random from $\{0,1,2, \ldots, 2^m-1\}$. Ethernet waits K·512 bit times, returns to Step 2
   - more collisions: longer backoff interval

Taking-Turns Protocols

Taking Turns MAC Protocols

Channel Partitioning MAC Protocols

- inefficient at low load: if only one node is active, 1/N bandwidth is allocated to it!
- allows sharing the channel *efficiently and fairly* at high load

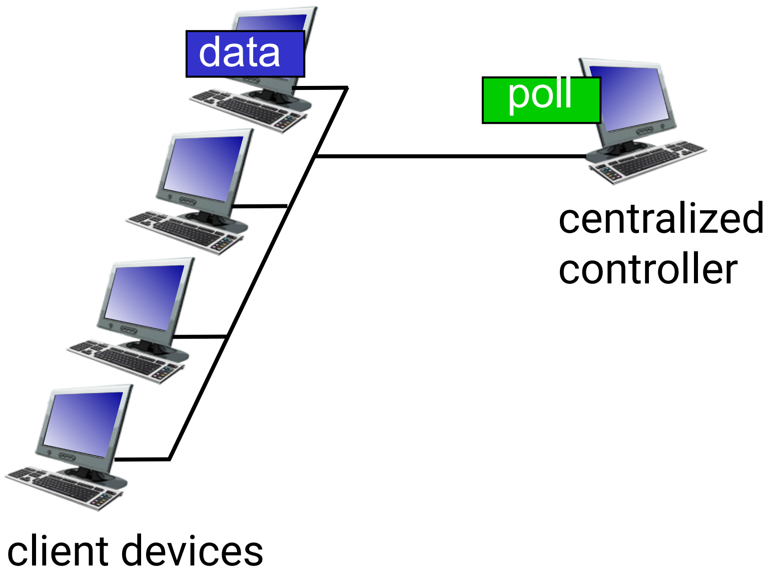
Random Access MAC Protocols

- *efficient at low load*: a single node can fully utilize channel
- experiences overhead at high load due to collisions

Taking Turns Protocols *look for best of both worlds!*

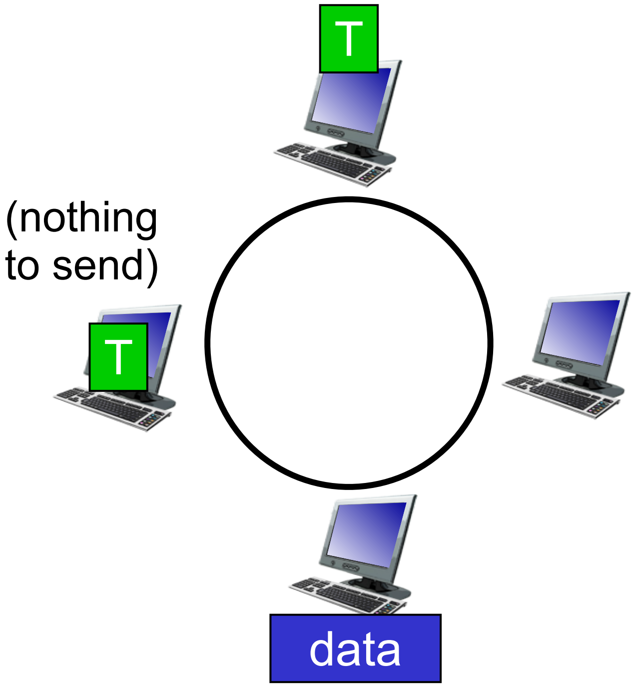
Polling Protocols

- a controller "invites" other nodes to transmit in turn
- typically used with "dumb" devices
- suffers from polling overhead, latency, and single point of failure (controller)



Token Passing Protocols

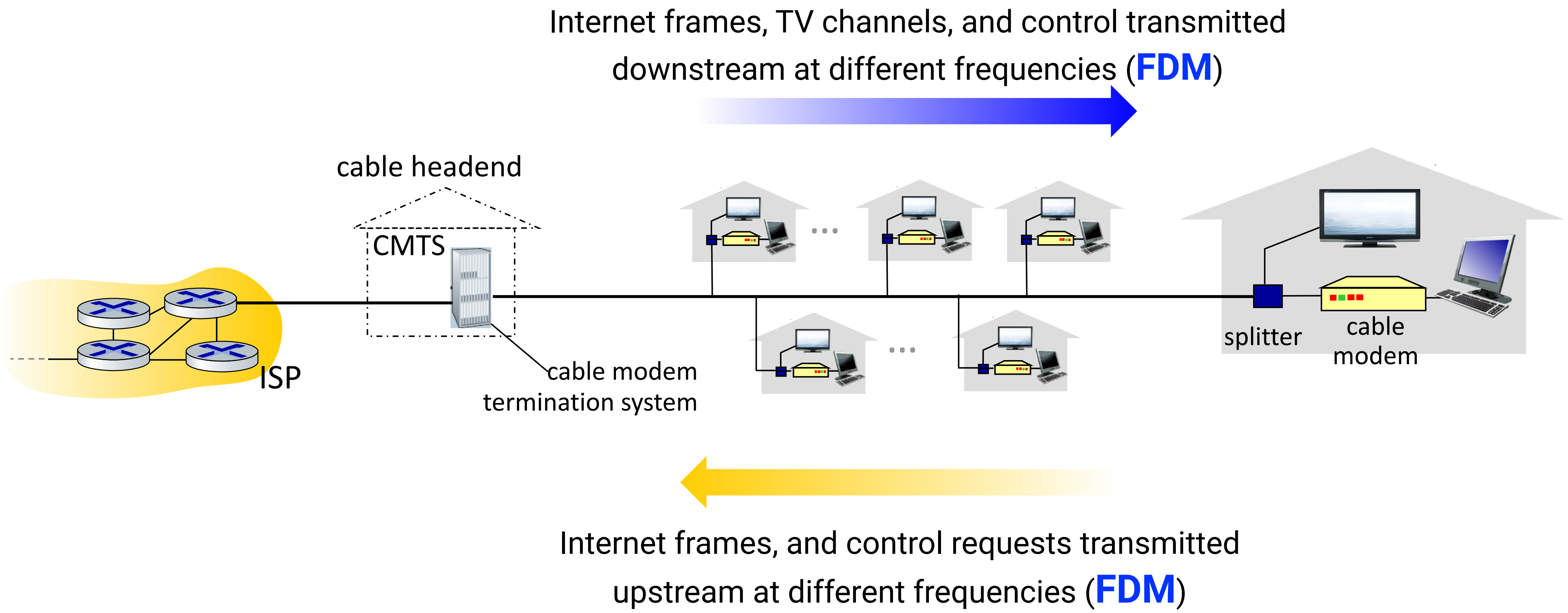
- control token message explicitly passed from one node to next, sequentially
- transmit while holding token
- suffers from token overhead, latency, and single point of failure (token)

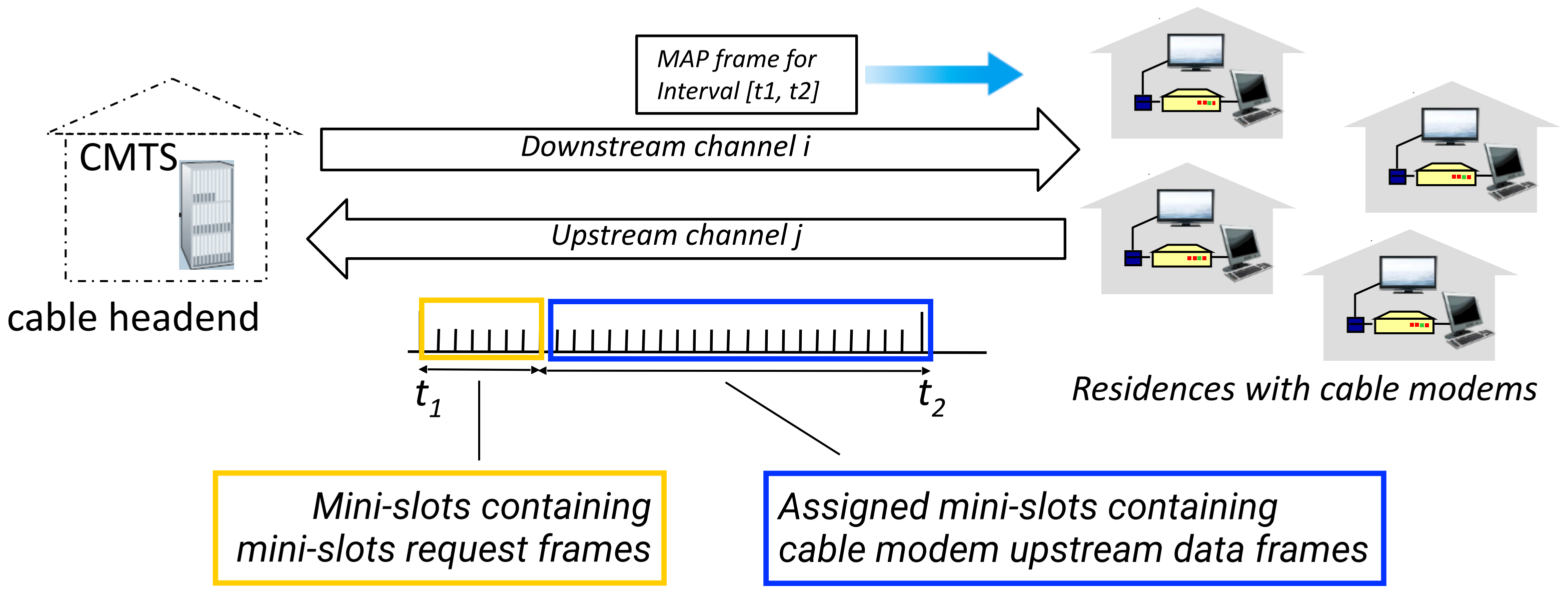


Protocols in Practice

Example: Cable Access Network

DOCSIS: Data Over Cable Service Interface Specification





Upstream frequency channels are further divided into mini-slots using **TDM**

- Mini-slot-data frames: to send data upstream; could only be used after CMTS grants permission
- Mini-slot-request frames: modems send request for a desired mini-slot in the next interval
- However, mini-slot-request frames are not preassigned; so modems employ **random access** to select one or more slots, and use **binary backoff** upon inferring collision
- CMTS sends a MAP frame in downstream to assigns upstream mini-slots for the next iteration

Spot Quiz (ICON)