Link Layer Review

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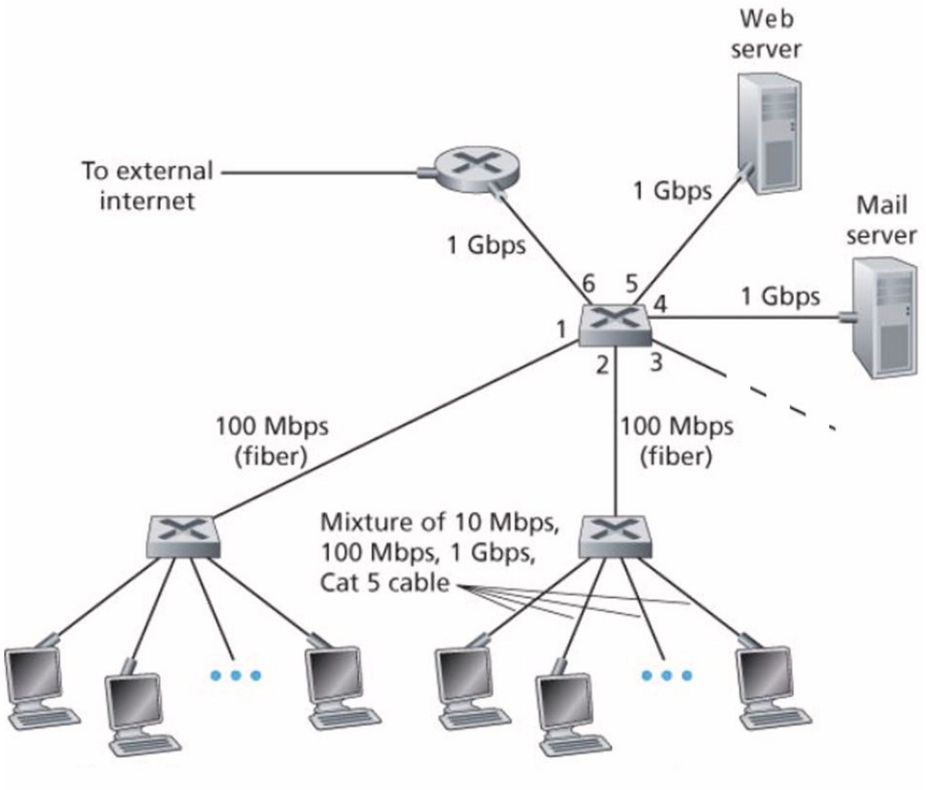
Switched LANs

1. Operate at the Link Layer
2. Switch link-layer **frames**
3. Use link-layer addresses to forward frames



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MAC Addresses

- **Globally unique**
- **Flat structure** (not hierarchical, like IP)!
- **Doesn't change** no matter where the adapter goes.
- **Necessary for communication** on a local area network (LAN).
- Devices use the **Address Resolution Protocol** to acquire the MAC address of another device.

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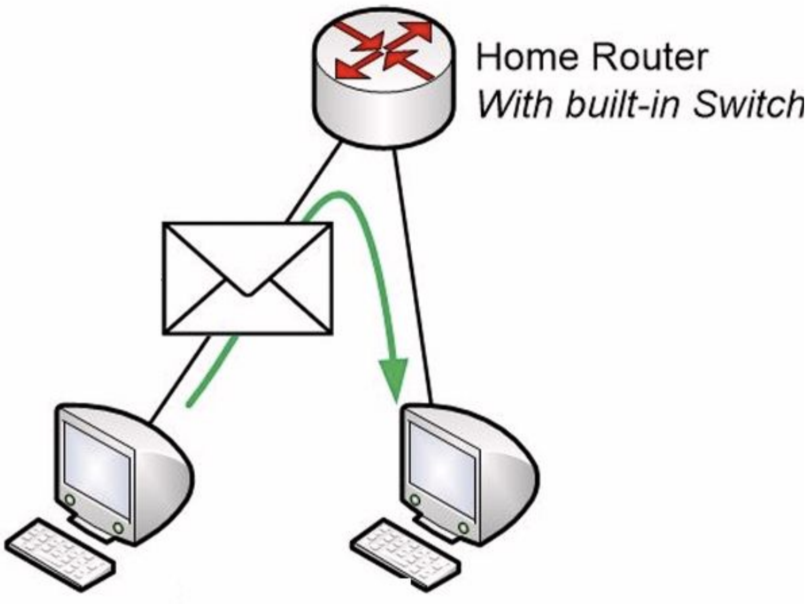
MAC ~ personal ID card
IP ~ postal address

Sending a frame

1. Insert the destination MAC address into the frame
2. Send the frame into the LAN



Receiving a frame

Is the destination address my own MAC address?

Yes: Extract datagram and pass it up the protocol stack.

No: Discard frame

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How do the hosts know the MAC address to which to send the frame?

The ARP Table!

Each host has an ARP table in its memory

IP Address	Physical Address (MAC)	Type	Expiry (TTL)
192.168.1.1	00:21:29:CC:A7:31	Static	-
192.168.1.24	00:17:31:BA:5C:A4	Dynamic	2m 27s
10.1.2.66	00:1A:70:3C:A6:3D	Dynamic	35s
210.210.3.1	90:6C:AC:2D:DE:9A	Dynamic	1m 14s

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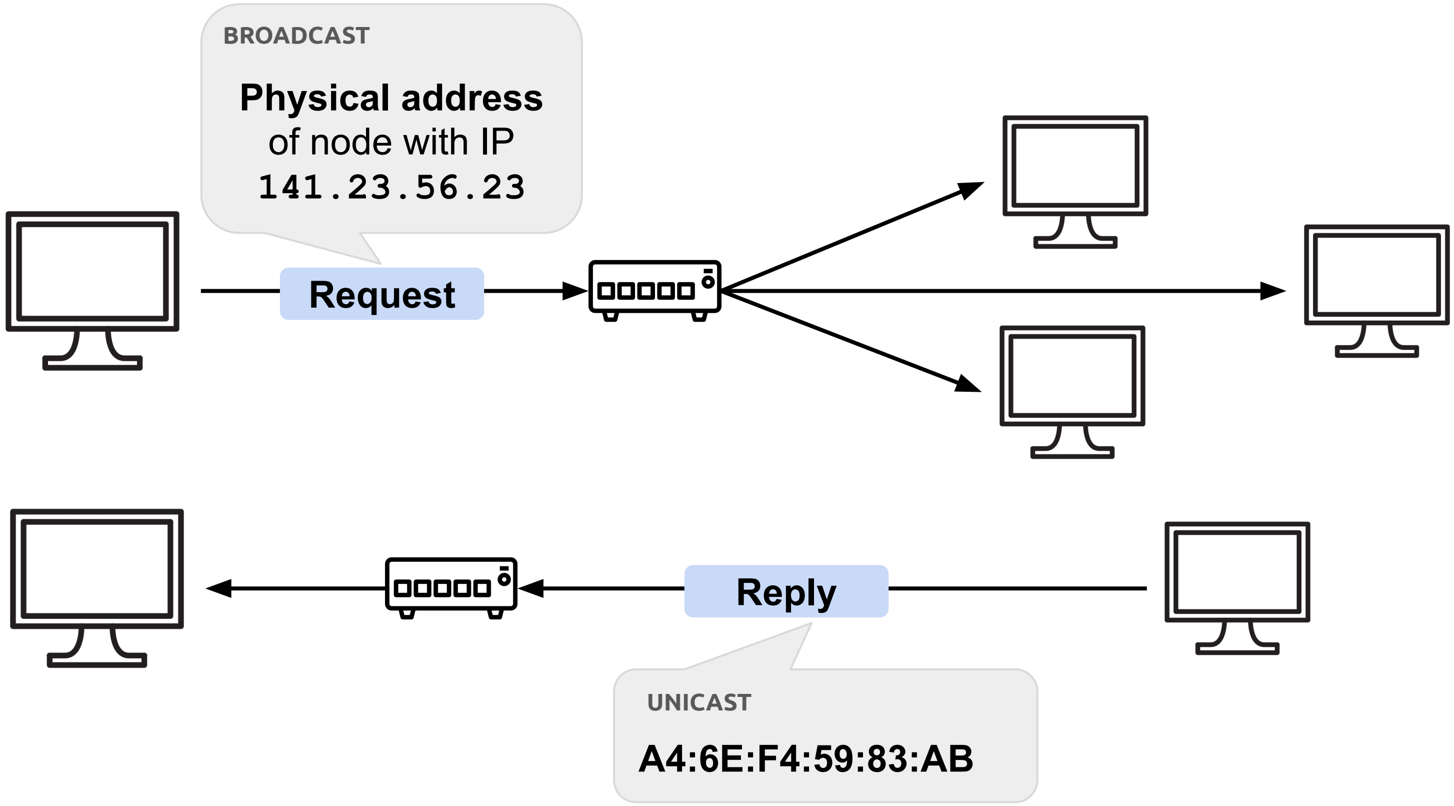
Address Resolution Protocol - Filling the ARP table



Link-Layer Switches

They receive incoming link-layer frames and forward them onto outgoing links.

They are transparent to the hosts and routers in the subnet.

For scenarios of very high rate of frames arrival, switch output interfaces have buffers.

Switch Operation

Filtering:
Drop or forward frame?

Forwarding:
Which interface should a frame be directed to?

Address	Interface	Time
62-FE-F7-11-89-A3	1	9:32
7C-BA-B2-B4-91-10	3	9:36
....	....	....

These are achieved with a switch table, which contains:

- MAC address (switches don't use IP!*)
- switch interface → MAC address
- time of entry

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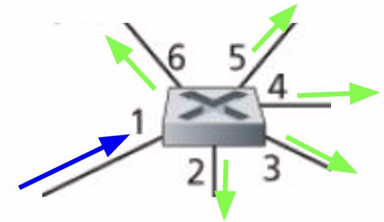
Switch Operation

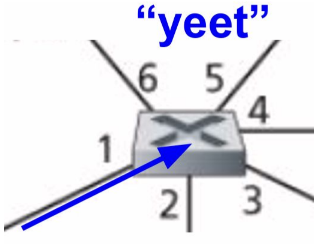
A Frame with destination address DD-DD-DD-DD-DD-DD arrives at the switch on interface 1.

There is **no entry** in the table for DD-DD-DD-DD-DD-DD:



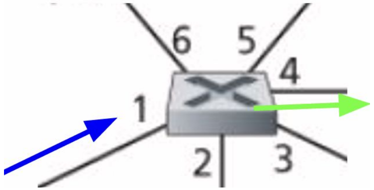
The switch **broadcasts** the frame

There is an entry in the table, associating DD-DD-DD-DD-DD-DD with **interface 1**:



No need to forward.
The switch **discards** the frame.

There is an entry in the table, associating DD-DD-DD-DD-DD-DD with **interface y≠1**:



The switch puts the frame in an output buffer that precedes **interface y**

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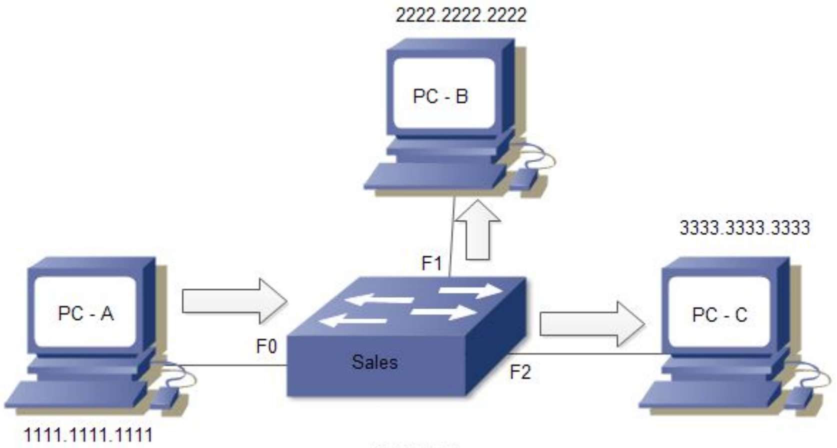
Switch Self-Learning



The switch table is built automatically and dynamically!

1. The switch table is initially empty.
2. For each incoming frame received on an interface, the switch stores in its table:
   a. the MAC address in the frame's source address field
   b. the interface from which the frame arrived
   c. the current time.
3. The switch deletes an address in the table if no frames are received with that address as the source address after some period of time (the aging time)

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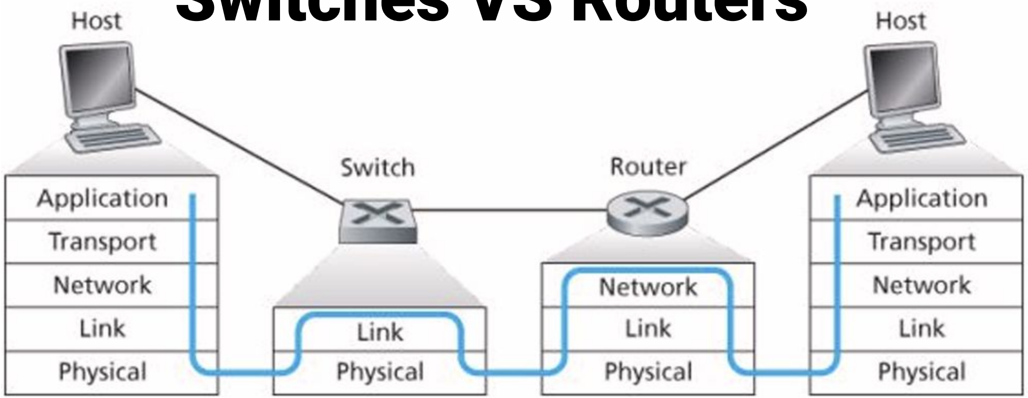
https://www.computernetworkingnotes.com/ccna-study-guide/how-switch-learns-the-mac-addresses-explained.html

Switches VS Routers



	Hubs	Routers	Switches
Traffic isolation	No	Yes	Yes
Plug and play	Yes	No	Yes
Optimal routing	No	Yes	No

Switches → small networks:
localize traffic, increase aggregate throughput without requiring any configuration of IP addresses

Routers → larger networks (in addition to switches):
Routers provide a more robust isolation of traffic, control broadcast storms, and use more "intelligent" routes among the hosts in the network.

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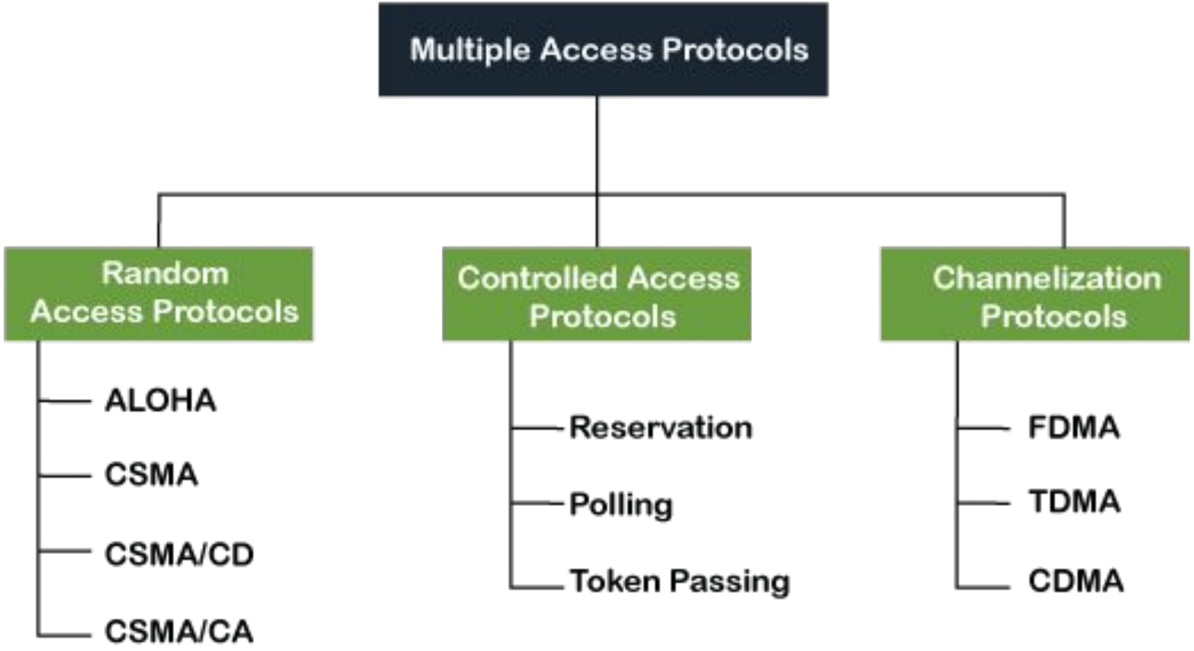
Multiple Access Links

If there is no dedicated link between sender and receiver, multiple stations can access the channel simultaneously.

Multiple Access Control is required to decrease collision and avoid crosstalk
-> Multiple Access Protocols



https://www.javatpoint.com/multiple-access-protocols

Random Access Protocols

They allow multiple devices to access a shared communication channel or medium in random or arbitrary order.

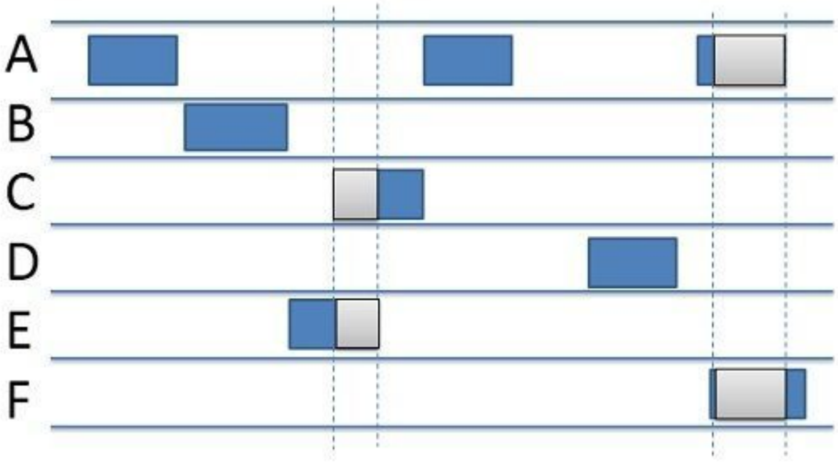
- No fixed time for sending data
- No fixed sequence of devices sending data

Pure ALOHA

- Each node sends a frame whenever one is available
- Receivers send acknowledgements to the senders when they receive a frame The senders wait for a time-out period before retransmission

Only one channel and many nodes -> chance of collision

- If there is a collision, each node has to **back off** before it tries to retransmit
- The backoff is a random amount of time (to avoid further collisions)

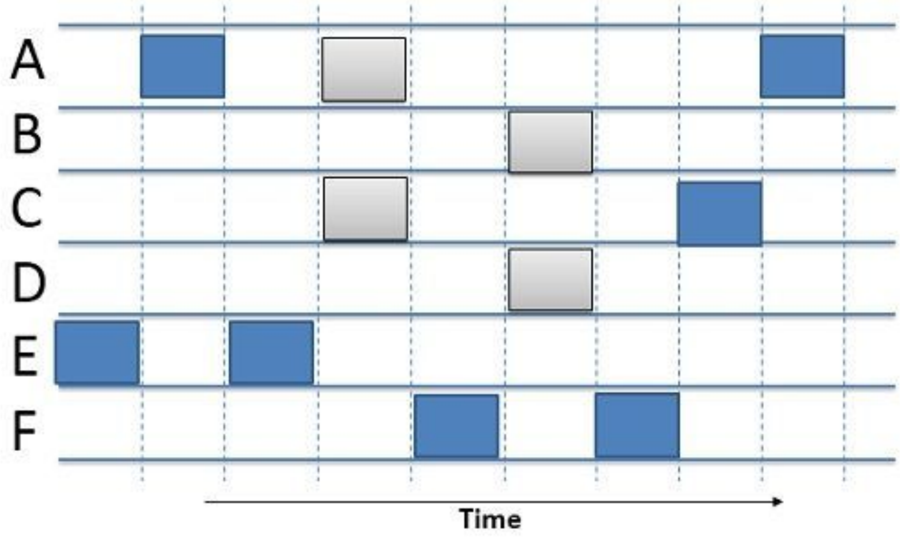


Slotted ALOHA

Improvement on pure ALOHA

- The channel is divided into small, fixed-length time slots
- Users are only allowed to transmit data at the beginning of each time slot
- The data transmitted must fit in the time slot

Synchronizing the transmissions reduces the chances of collisions



Pure ALOHA

- Suppose four active nodes—nodes A, B, C and D—are competing for access to a channel using slotted ALOHA.
- Assume each node has an infinite number of packets to send.
- Each node attempts to transmit in each slot with probability p.
- The first slot is numbered slot 1, the second slot is numbered slot 2, and so on.

a. What is the probability that node A succeeds for the first time in slot 5?

b. What is the probability that some node (either A, B, C or D) succeeds in slot 4?

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Pure ALOHA

a. What is the probability that node A succeeds for the **first time** in slot 5?

P(A transmits in a slot) = $p^*(1-p)^3$,
so P(A does not transmit in a slot) = $1-p^*(1-p)^3$

P(A transmits in slot 5) = $\underbrace{(1-p(1-p)^3)^4}_{\text{No transmission before slot 5}} \; \underbrace{p(1-p)^3}_{\text{Transmission at slot 5}}$

No transmission before slot 5 **Transmission at slot 5**

b. What is the probability that some node (either A, B, C or D) succeeds in slot 4?

Similarly, P(**any** transmits in slot 4) = $\mathbf{4}\,p(1-p)^3$

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Pure ALOHA efficiency

"Efficiency" - the probability of a node transmitting successfully

In our case: $4\,p\,(1-p)^3$

So, the efficiency in general is: $N\,p(1-p)^N$

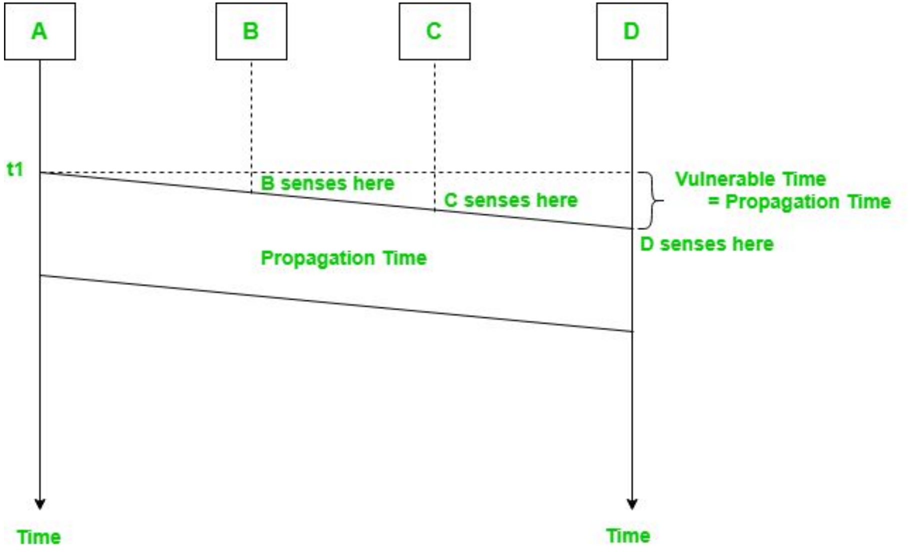
where N is the number of nodes in the network

CSMA

The node is required to first sense the medium before transmitting data

- Channel is idle: begin transmission
- Channel is busy: wait until channel is idle

Still a chance of collision
due to propagation delay!



https://www.geeksforgeeks.org/multiple-access-protocols-in-computer-network/

CSMA/CD

CSMA variant, “Collision Detection”

Stations can terminate transmission of data if collision is detected.

While transmitting, if the adapter senses other transmissions in the channel other than its own, it sends a jam signal and aborts the transmission.

It backs off for a random amount of time and then senses the channel again.

CSMA/CD - Exponential Backoff

The backoff period is selected at random (uniformly), from the set {0, 1, …, 2^K-1}, where K is the number of failed attempts to send a particular frame.

Example:

Attempt 1: Collision -> K=1
Backoff selected from {0, 1}

Attempt 2: Collision -> K=2
Backoff selected from {0, 1, 2, 3}

Attempt 3: Collision -> K=3
Backoff selected from {0, 1, 2, 3, 4, 5, 6, 7}
…

Error Detection and Correction

Parity check: When checking vector / row / column:

1 0 1 1 0 1 0 … 1

- if even number of 1s → 0 : 1 0 1 1 0 1 0 … 1 | 0
- if odd number of 1s → 1 : 1 0 1 1 0 1 0 … 1 | 1

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Parity check: When checking vector / row / column:

1 0 1 1 0 1 0 … 1

- if even number of 1s → 0 : 1 0 1 1 0 1 0 … 1 | 0
- if odd number of 1s → 1 : 1 0 1 1 0 1 0 … 1 | 1

Let's remember the
2D parity check:

Row parity →

Column parity ↓

$d_{1,1}$	…	$d_{1,j}$	$d_{1,j+1}$
$d_{2,1}$	…	$d_{2,j}$	$d_{2,j+1}$
…	…	…	…
$d_{i,1}$	…	$d_{i,j}$	$d_{i,j+1}$
$d_{i+1,1}$	…	$d_{i+1,j}$	$d_{i+1,j+1}$

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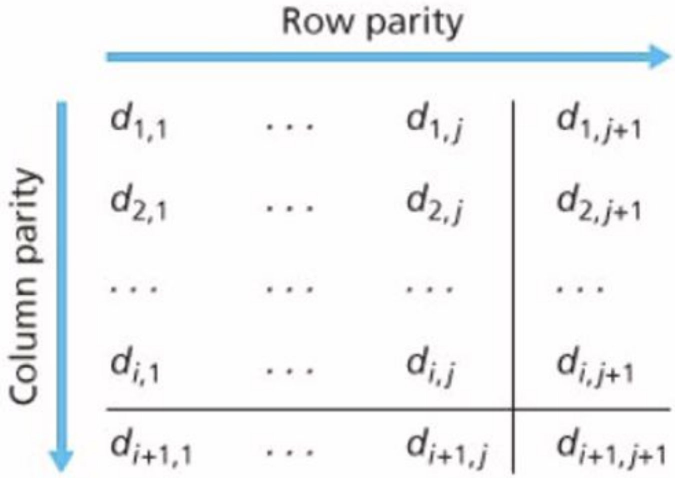
Parity check: When checking vector / row / column:

1 0 1 1 0 1 0 … 1 → if even number of 1s → 0 : 1 0 1 1 0 1 0 … 1 | 0

1 0 1 1 0 1 0 … 1 → if odd number of 1s → 1 : 1 0 1 1 0 1 0 … 1 | 1

Let's remember the **2D parity check**:



1	0	1	0	1	1
1	1	1	1	0	0
0	1	1	1	0	1
0	0	1	0	1	0

Which one has the error?
Can we identify it?

1	0	1	0	1	1
1	0	1	1	0	0
0	1	1	1	0	1
0	0	1	0	1	0

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Which one has the error?
Can we identify it?

1	0	1	0	1	1
1	1	1	1	0	0
0	1	1	1	0	1
0	0	1	0	1	0

1	0	1	0	1	1
1	0	1	1	0	0
0	1	1	1	0	1
0	0	1	0	1	0

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Which one has the error?
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1	0	1	0	1	1
1	1	1	1	0	0
0	1	1	1	0	1
0	0	1	0	1	0

1	0	1	0	1	1
1	0	1	1	0	0
0	1	1	1	0	1
0	0	1	0	1	0

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Which one has the error?
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1	0	1	0	1	1
1	1	1	1	0	0
0	1	1	1	0	1
0	0	1	0	1	0

1	0	1	0	1	1
1	0	1	1	0	0
0	1	1	1	0	1
0	0	1	0	1	0

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CRC (Cyclic Redundancy Check)

Let's say our data sequence D is 1101 and we are using a 3-bit generator G of 101.

```
  110100    (Original data with padding)
/ 101       (Generator)
----------
  0111      (First XOR operation, align G with the first '1' in D)
    101     (Generator aligned with the first '1' after the XOR)
   ------
    0100    (Result of XOR, now align G with the first '1' again)
     101    (Generator)
    ------
      010   (Result of XOR, and this is less than the length of G)
```

So R=10

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Let’s see if that worked:

Receiver gets D+R and already knows G (it was already agreed upon).

In out case, D=1101 and we calculated R to be R=10, so D+R = 110110

Let's do the derivation.

```
110110
101
---
 111
 101
 ---
  101
  101
  ---
   000  The transmission is error-free!
```