Local Area Networks (LANs)

Broadcast Networks

Multiple Access Protocols

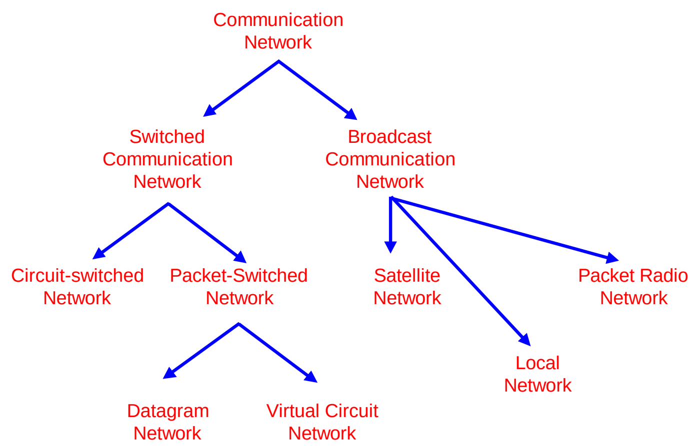
Ethernet (IEEE 802.3)

Token Ring (IEEE 802.5, FDDI)

Introduction

- So far, we have dealt with switched communication networks.
- Recall that switched networks are characterized by point-to-point communications.
- Next we will look at broadcast communication networks

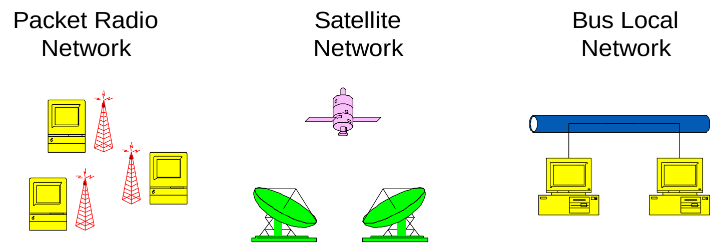
Introduction



Broadcast Networks

- Recall that in broadcast networks:
  - Each station is attached to a transmitter/receiver which communicates over a medium shared by other stations
  - Transmission from any station is received by all other stations
  - There are no intermediate switching nodes

Examples of Broadcast Network



- If more than one station transmits at a time on the broadcast channel, a collision occurs
- Multi-access problem: How to determine which station can transmit?

Multi-access Protocols

- Protocols that solve the resolution problem dynamically are called Multiple Access **(Multi-access)** Protocols
- Different types of multi-access protocols
  - Contention protocols resolve a collision after it occurs. These protocols execute a collision resolution protocol after each collision
  - Collision-free protocols ensure that a collision can never occur

Evolution of Contention Protocols

Aloha

Developed in the 1970s for a packet radio network

Slotted Aloha

Improvement: Start transmission only at fixed times (slots)

CSMA

CSMA = Carrier Sense Multiple Access
Improvement: Start transmission only if no transmission is ongoing

CSMA/CD

CD = Collision Detection
Improvement: Stop ongoing transmission if a collision is detected

Contention Protocols

- **ALOHA Protocols:**
  - (Pure) Aloha
  - Slotted Aloha
- **CSMA (Carrier Sense Multiple Access):**
  - persistent CSMA
  - non-persistent CSMA
  - **CSMA/CD** - Carrier Sense Multiple Access with Collision Detection (= Ethernet)
- There are many more

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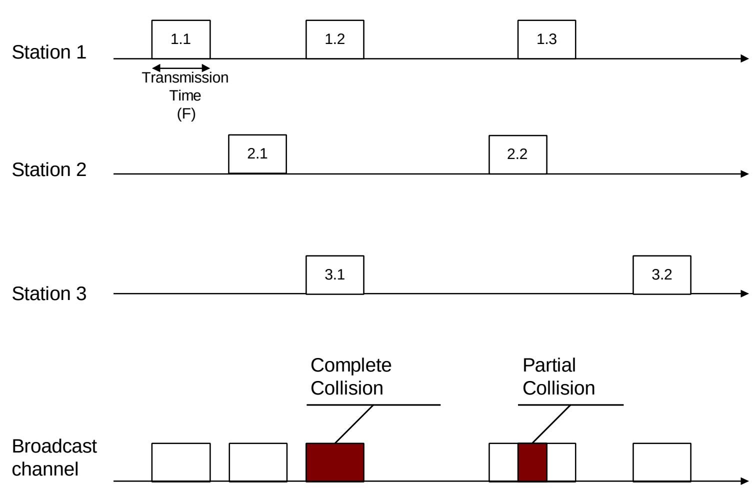
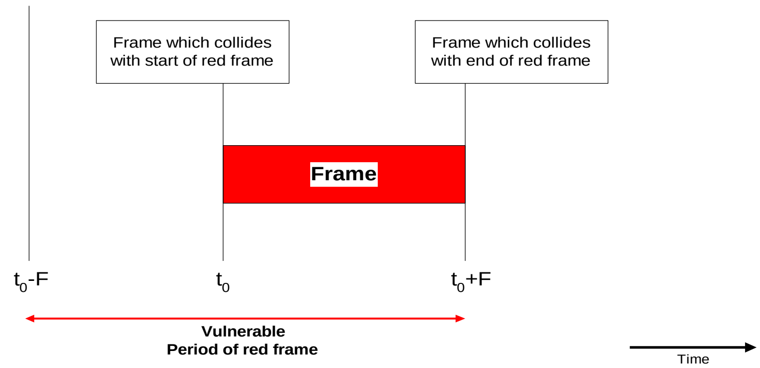
(Pure) ALOHA

- **Topology:** All stations send frames to a central node, which broadcasts the frames to all stations
- **Aloha Protocol:**
  - Whenever a station has data, it transmits
  - Sender finds out whether transmission was successful or experienced a collision by listening to the broadcast from the central node
  - Sender retransmits after some random time if there is a collision

Collisions in (Pure)ALOHA



Collisions and vulnerable period

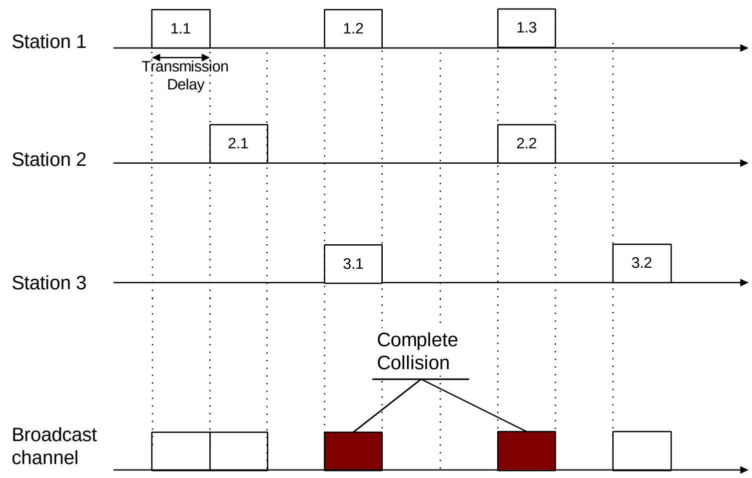


- A frame (red frame) will be in a collision if and only if another transmission begins in the vulnerable period of the frame
- Vulnerable period has the length of 2 frame times

Slotted ALOHA (S-ALOHA)

- **The Slotted Aloha Protocol**
  - Slotted Aloha - Aloha with an additional constraint
  - Time is divided into discrete time intervals **(=slot)**
  - A station can transmit only at the beginning of a frame
- As a consequence:
  - Frames either collide completely or do not collide at all
  - Vulnerable period = 1

Collisions in S-ALOHA



Performance of (Pure)ALOHA

- **Question:** What is the maximum throughput of the ALOHA protocol?
- **Notation:**

S — **Throughput**
Expected number of successful transmissions per time unit

Normalization: Frame transmission time is 1
⇨ maximum throughput is 1

G — **Offered Load**
Expected number of transmission and retransmission attempts (from all users) per time unit

Modeling Assumptions

- All frames have a fixed length of one time unit (normalized)
- Infinite user population
- Offered load is modeled as a **Poisson process with rate G**, that is,

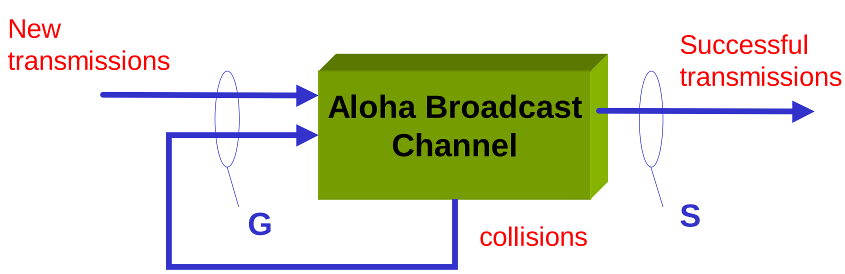
  Prob[k packets are generated in t frame times] =

$$\frac{(Gt)^k}{k!} \times e^{-tG}$$

Throughput of Aloha

- Fundamental relation between throughput and offered load:

  S = G ´ Prob [frame suffers no collision]



Performance of (pure)ALOHA

- Prob [frame suffers no collision] =
  = Prob [no other frame is generated during the vulnerable period for this frame]
  = Prob [no frame is generated during a **2-frame period**]
  = $$\frac{(2G)^0}{0!} \cdot e^{-2G} = e^{-2G}$$

- **Throughput in ALOHA:**
  S = G ´ e^{-2G}

Results

- **Maximum achievable throughput:**
- Take the derivative and set $\frac{\partial S}{\partial G} = 0$
- Maximum is attained at **G = 0.5**
- We obtain: $S_{\max} = 0.5 \times e^{-1} = \frac{1}{2e} = 0.184$
- That is about 18% of the capacity!!!

Performance of S-ALOHA

- Derivation is analogous to Aloha:

  S = G ´ Prob [frame suffers no collision]

- Prob [frame suffers no collision] =

  = Prob [no other frame is generated during a vulnerable period]

  = Prob [no frame is generated during **1 frame period**]

  =

$$= \frac{G^0}{0!} \cdot e^{-G} = e^{-G}$$

Performance of S-ALOHA

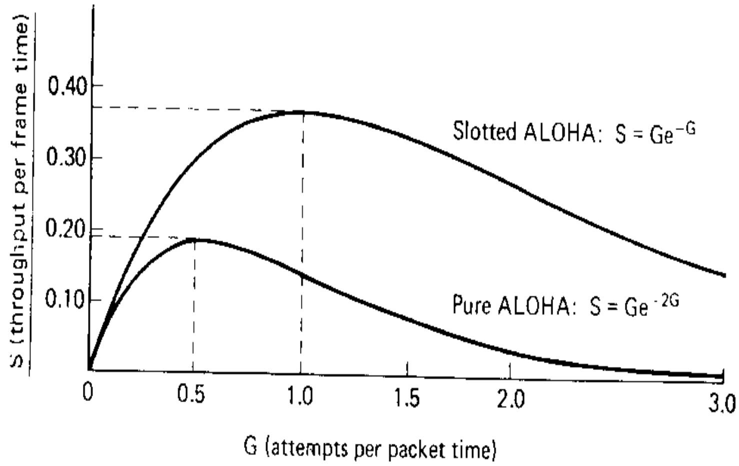
- Total Throughput in ALOHA:

$$S = G \times e^{-G}$$

- Maximum achievable throughput:

$$S_{\max} = e^{-1} = \frac{1}{e} = 0.37$$

Comparison of ALOHA and S-ALOHA



CSMA - Carrier Sense Multiple Access

- ***Improvement to ALOHA protocol:***
  - If stations have **carrier sense capability** (stations can test the broadcast medium for ongoing transmission), and
  - if stations only transmit if the channel is idle,
  - then many collisions can be avoided.
- **Caveat:** This improves ALOHA only if the ratio

$$a = \frac{\text{propagation time}}{\textit{transmission}\ \text{time}}$$

is small. Why?

CSMA - Carrier Sense Multiple Access

- ***CSMA protocol:***
  - A station that wishes to transmit listens to the medium for an ongoing transmission
  - Is the medium in use?
    - Yes: Station back of for a specified period
      No: Station transmits
  - If a sender does not receive an acknowledgment after some period, it assumes that a collision has occurred
  - After a collision a station backs off for a certain (random) time and retransmits

Variations of CSMA Protocols

- There are a number of variations of CSMA protocols
- Each variant specifies what to do if the medium is found busy:
  - **Non-Persistent CSMA**
  - **1-Persistent CSMA**
  - **p-Persistent CSMA**

Non-Persistent CSMA

- **Non-Persistent CSMA *Protocol:***

  1. If the medium is idle, transmit immediately
  2. If the medium is busy, wait a random amount of time and repeat Step 1

- Random back-off reduces probability of collisions
- Wasted idle time if the back-off time is too long
- May result in long access delays

1-persistent CSMA

- 1-persistent CSMA Protocol:

  1. If the medium is idle, transmit immediately
  2. If the medium is busy, continue to listen until medium becomes idle, and then transmit immediately

- Too selfish: there will always be a collision if two stations want to retransmit

p-Persistent CSMA

- **p-Persistent CSMA *Protocol:***
  1. If the medium is idle, transmit with probability p, and delay for one time unit with probability (1 - p)

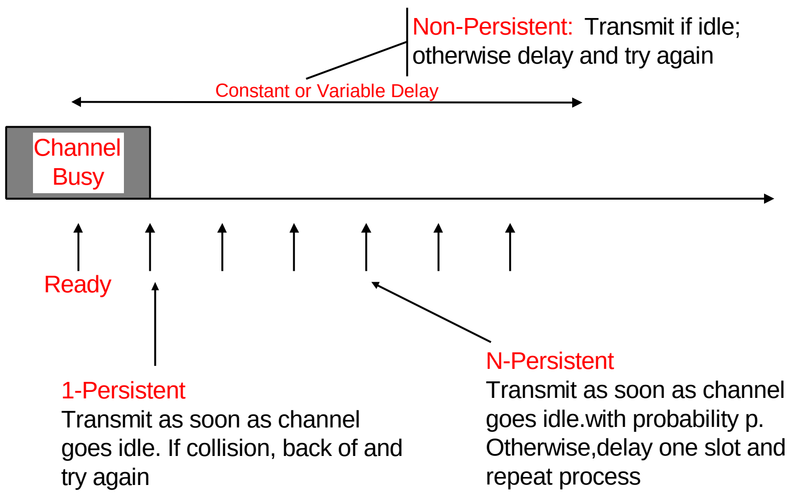
     (time unit = length of propagation delay)
  2. If the medium is busy, continue to listen until medium becomes idle, then go to Step 1
  3. If transmission is delayed by one time unit, continue with Step 1
- Can be a good trade-off between non-persistent and 1-persistent CSMA

How to Select Probability p?

- Assume that N stations have a packet to send and the medium is busy
- Expected number of stations that will attempt to transmit once the medium becomes idle is given by Np
- If Np > 1, then a collision is expected to occur (which results in retransmission, which, in turn, results in more collisions)

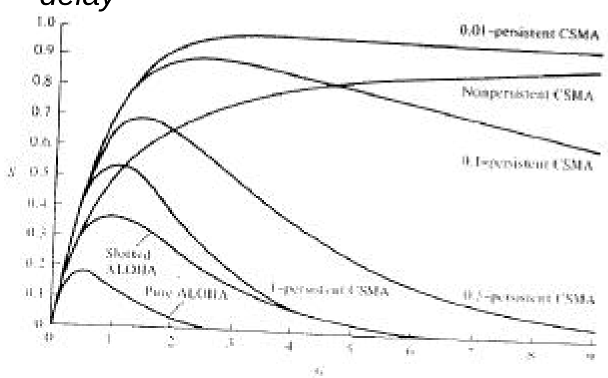
- **Therefore:** Network must make sure that Np < 1, where N is the maximum number of stations that can be active at a time

Comparison of CSMA Strategies



Comparison of ALOHA and CSMA

- ***Load vs. Throughput:***
  - *Assumption: propagation delay << transmission delay*



CSMA / CD

- *Improvement to CSMA protocol:*
  - Carrier Sense Multiple Access with Collision Detection
  - Widely used for bus topology LANs (IEEE 802.3, Ethernet)
  - Only works if propagation delay is small relative to transmission delay (in other words, a must be small)

CSMA/CD

- ***CSMA has an inefficiency:***
  - If a collision has occurred, the channel is unstable until colliding packets have been fully transmitted
- ***CSMA/CD overcomes this as follows:***
  - While transmitting, the sender is listening to medium for collisions. Sender stops if collision has occurred
- Note:
  - ***CSMA:*** Listen Before Talking
  - ***SMA/CD***: Listen While Talking

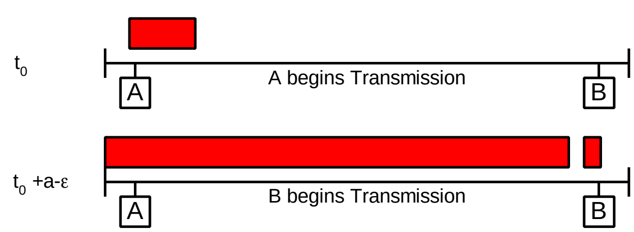
CSMA/CD

- ***Generic CSMA/CD Protocol:***
  - Use one of the CDMA persistence algorithm ***(non-persistent, 1-persistent, p-persistent)*** for transmission
  - If a collision is detected during transmission, cease transmission and transmit a ***jam signal*** to notify other stations of collision
  - After sending the ***jam signal***, back off for a random amount of time, then start to transmit again

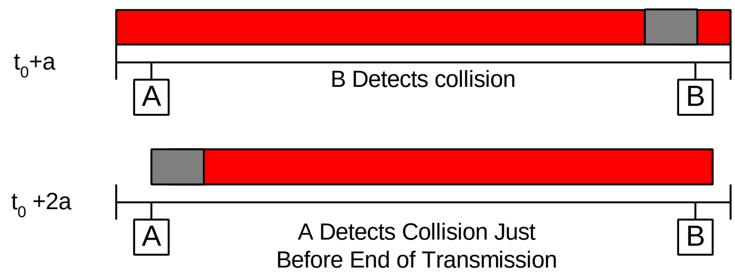
CSMA/CD

- ***Question:*** How long does it take to detect a collision?
- ***Answer:*** In the worst case, twice the maximum

  propagation delay of the medium



Collision Detection in CSMA/CD



CSMA/CD

- Restrictions of CSMA / CD:
  - Packet should be twice as long as the time to detect a collision (2 * maximum propagation delay)
  - Otherwise, CSMA/CD does not have an ad-vantage over CSMA
- Example: Ethernet
  - Ethernet requires a minimum packet size and restricts the maximum length of the medium
  - **Question**: What is the minimum packets size in a 10 Mbit/sec network with a maximum length of 500 meters?

Exponential Backoff Algorithm

- Ethernet uses the exponential backoff algorithms to determine when a station can retransmit after a collision

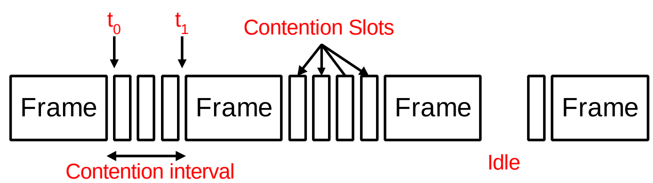
Algorithm:

- Set “slot time” equal to 2a
- After first collision wait 0 or 1 slot times
- After i-th collision, wait a random number between 0 and 2^i-1 time slots
- Do not increase random number range, if i=10
- Give up after 16 collisions

Performance of CSMA/CD

- Parameters and assumptions:
  - End-to-end propagation delay: a
  - Packet transmission time (normalized): 1
  - Number of stations: N
- Time can be thought of as being divided in contention intervals and transmission intervals.
- Contention intervals can be thought of as being slotted with slot length of 2a (roundtrip propagation delay).

Performance of CSMA/CD



- Contention slots end in a collision
- Contention interval is a sequence of contention slots
- Length of a slot in contention interval is 2a
- We assume that the probability that a station attempts to transmit in a slot is P

Performance of CSMA/CD

- Derivation of maximum throughput of CSMA/CD:
- Let A be the probability that some station can successfully transmit in a slot. We get:

$$A = \binom{N}{1} \cdot P^1 \cdot (1-P)^{N-1} = N \cdot P \cdot (1-P)^{N-1}$$

- In the above formula, A is maximized when P=1/ N. Thus:

$$A = (1 - \frac{1}{N})^{N-1}$$

Performance of CSMA/CD

- Prob [contention interval has a length of j slots] =

  Prob [1 successful attempt] x Prob [j-1 unsuccessful attempts] =

$$A \cdot (1-A)^{j-1}$$

- The expected number of slots in a contention interval is then calculated as:

$$\sum_{j=0}^{\infty} j \cdot A \cdot (1-A)^{j-1} = \frac{1}{A}$$

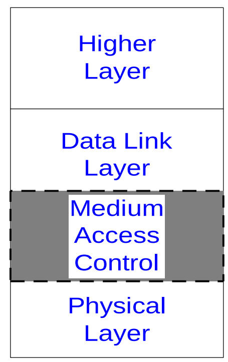
Performance of CSMA/CD

- Now we can calculate the maximum efficiency of CSMA/CD with our usual formula:

$$\frac{\text{Frame Time}}{\text{Frame Time} + \text{Overhead}}$$
$$= \frac{\text{Frame Time}}{\text{Frame Time} + \text{Average contention interval}}$$
$$= \frac{1}{1 + \frac{2a}{A}}$$

LAN - Overview

- Almost all local area networks use a multiple access channel
- The interesting part of LANs is the protocol that control the access to the channel (Medium Access Control or MAC)
- MAC protocols are implemented as a sublayer of the Data Link Layer (MAC Layer)



Standards of MAC Protocols

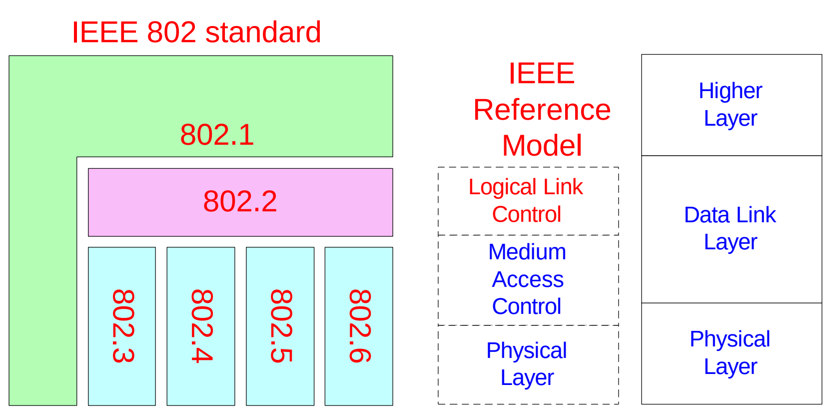
- Bus Networks:
  - IEEE 802.3 CSMA/CD (= Ethernet)
  - IEEE 802.4 Token Bus
- Ring Networks:
  - IEEE 802.5 Token Ring
  - ANSI FDDI
- Dual Bus Networks:
  - IEEE 802.6 DQDB
- Tree Networks
  - IEEE 802.14 HFC (Cable Modems

IEEE 802 Architecture

- The IEEE 802 Architecture is a family of standards for LANs (local area networks) and MANs (metropolitan area networks)

- Organization of IEEE 802 Protocol Architecture:
  - Higher Layers: 802.1 Higher Layer Interfaces
  - Logical Link Control: 802.2 Logical Link Control (LLC)
  - MAC Layers:
    - 802.3 CSMA/CD
    - 802.4 Token Bus
    - 802.5 Token Ring
    - etc.

IEEE 802 LAN Standard



IEEE 802 LAN Standard

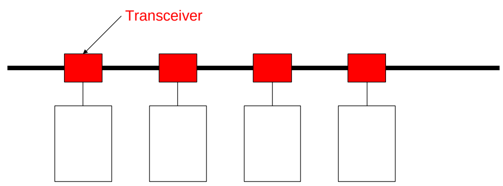
	IEEE 802.3	IEEE 802.4	IEEE 802.5	FDDI	IEEE 802.6
LLC	IEEE 802.2 Unacknowledged connectionless service Connection-oriented service Acknowledged connectionless service				
MAC	CSMA/CD	Token Bus	Token Ring	FDDI	DQDB
Physical	Broadband coaxial: 10Mbps Unshielded twisted pair: 1-100Mbps Optical Fiber 10-1000Mbps	Broadband coaxial: 1,5,10Mbps Carrierband 1,5,10Mbps Optical fiber 5,10,20 Mbps	Shielded twisted pair: 4,16Mbps Unshielded twisted pair: 4Mbps	Optical fiber: 100Mbps	Optical fiber or coaxial 44.736 MBps

IEEE 802 LAN Architecture

- Functions of the LLC:
    - Similar to HDLC
    - Provides SAPs to higher layers
    - Provides different services:
        - acknowledged connectionless service
        - unacknowledged connectionless service
        - connection-oriented service
    - Framing
    - Error control
    - Addressing

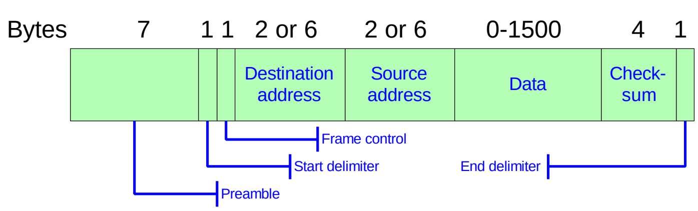
IEEE 802.3 (CSMA/CD)

- Bus topology:



- Generally referred to as “Ethernet”
- Based on CSMA/CD
- Applies exponential back-off after collisions
- Data Rate: 2 - 1,000 Mbps
- Maximum cable length is dependent on the data rate
- Uses Manchester encoding

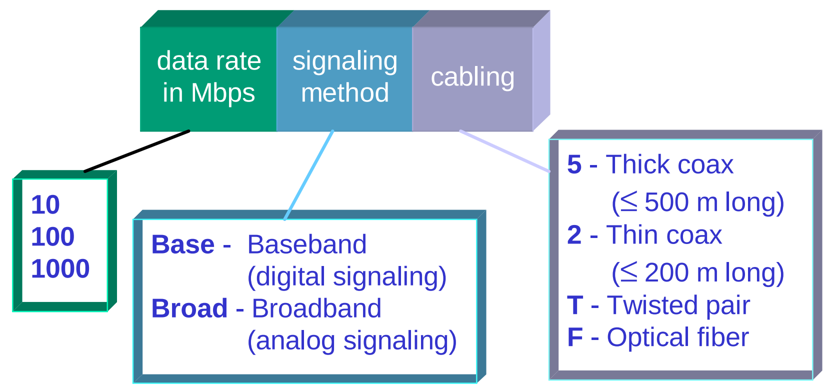
IEEE 802.3 Frame Format



- Preamble is a sequence of 7 bytes, set to “10101010” for each byte. Preamble helps receiver to synchronize with bit pattern before actual frame is received
- At 10 Mbps, a frame must be at least 46 bytes long. Otherwise, a station may not detect a collision of its own transmission
- Maximum frame size is set to 1500 bytes of data, minimum frame size is set to 512 bits.

Ethernet

- There are many different physical layer configurations for 802.3 LANs
- The following notation is used to denote the configuration

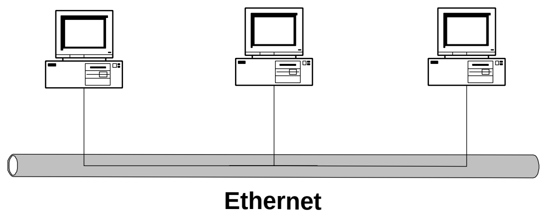


Ethernet

- Speed: 10 Mbps
- Standard: 802.3
- Physical Layers:
  - Used today:
    - 10Base-T 10 Mbps Twisted Pair
    - 10Base2 **(Thin Ethernet)** 10 Mbps thin coax cable
  - Used in the past:
    - 10Base5 **(Thick Ethernet)** 10 Mbps thick coax cable
  - There is even an analog version:
    - 10Broad36 10 Mbps on coax cable using analog signaling

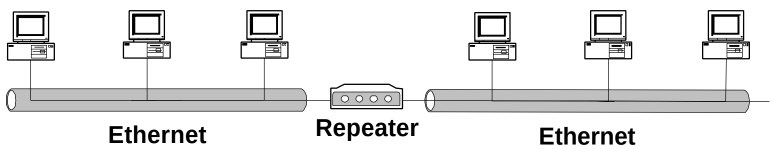
Bus Topology

- 10Base5 and 10Base2 Ethernets have a bus topology



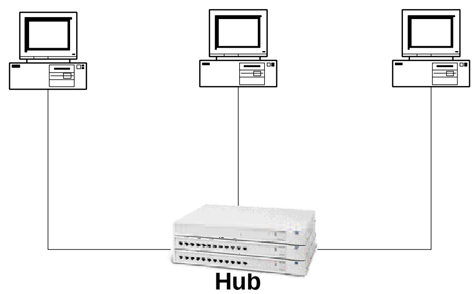
Repeaters

- Maximum length of a segment is 500m (10Base5) and 200m (10Base2)
- The maximum span can be extended by connecting segments via repeaters
- Repeaters do not isolate collisions



Star Topology

- With 10Base-T, stations are connected to a hub in a star configuration



- The distance of a node to the hub must be ≤ 100 m

Fast Ethernet

- Fast Ethernet is synomymous with Ethernet at 100 Mbps rates
- Standard: IEEE 802.3u
  - 100BASE-T4 (100 Mbps over telephone-grade twisted pair)
  - 100Base-TX (100 Mbps over Category 5 twisted pair)
  - 100Base-FX (100 Mbps over Fiber Optic)

- The 100Base-X schemes have two physical links, one for receiving and one for transmitting, each at 100 Mbps. A station can send and transmit at the same time (full-duplex)
- 100 Base-T4 operates in half-duplex mode

Gigabit Ethernet

- Data rate is 1 Gbps = 1000 Mbps
- Standard: IEEE 802.3z
- Physical Layers:
  - 1000Base-SX short-wave laser over multimode fiber
  - 1000Base-LX long-wave laser over single mode fiber and multimode fiber
  - Twisted pair version coming soon
- Used for backbone of a campus area network

Ethernet Switches

- Ethernet switches allow to completely avoid collisions
- An Ethernet switch is basically a packet switch for Ethernet frames with CSMA/CD as data link protocol
- Each port is isolated and builds its own collision domain