Ethernet

Chapter 2

- Most successful local area networking technology of last 20 years.
- Developed in the mid-1970s by researchers at the Xerox Palo Alto Research Centers (PARC).
- Uses CSMA/CD technology
  - Carrier Sense Multiple Access with Collision Detection.
  - A set of nodes send and receive frames over a shared link.
  - Carrier sense means that all nodes can distinguish between an idle and a busy link.
  - Collision detection means that a node listens as it transmits and can therefore detect when a frame it is transmitting has collided with a frame transmitted by another node.

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Ethernet

Chapter 2

- Uses ALOHA (packet radio network) as the root protocol
  - Developed at the University of Hawaii to support communication across the Hawaiian Islands.
  - For ALOHA the medium was atmosphere, for Ethernet the medium is a coax cable.
  - If link is idle, transmit the packet
- DEC and Intel joined Xerox to define a 10-Mbps Ethernet standard in 1978.
- This standard formed the basis for IEEE standard 802.3
- More recently 802.3 has been extended to include a 100-Mbps version called Fast Ethernet, a 1000-Mbps version called Gigabit Ethernet, 10 Gbps and 100Gbps versions

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Ethernet

Chapter 2

- A classical Ethernet segment is implemented on a coaxial cable of up to 500 m.
  - This cable is similar to the type used for cable TV except that it typically has an impedance of 50 ohms instead of cable TV's 75 ohms.
- Hosts connect to an Ethernet segment by tapping into it.
- A transceiver (a small device directly attached to the tap) detects when the line is idle and drives signal when the host is transmitting.
- The transceiver also receives incoming signal.
- The transceiver is connected to an Ethernet adaptor which is plugged into the host.
- The protocol is implemented on the adaptor.

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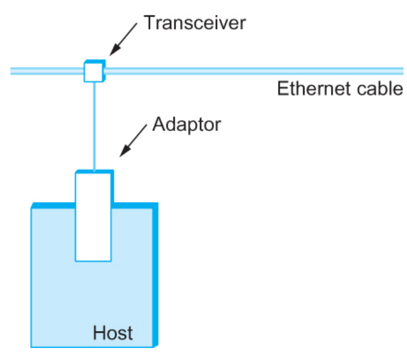
Ethernet

Chapter 2



Ethernet transceiver and adaptor

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Ethernet

Chapter 2

- Multiple Ethernet segments can be joined together by *repeaters.*
- A *repeater* is a device that forwards digital signals.
- No more than four repeaters may be positioned between any pair of hosts.
  - A classical Ethernet has a total reach of only 2500 m.
  - Maximum of 1024 hosts
- Modern Ethernets
  - use category 5 twisted copper pair (cat 6 or cat 7 for 10Gbps)
  - Use optical fibers
  - Can be longer than 500 meters between repeaters

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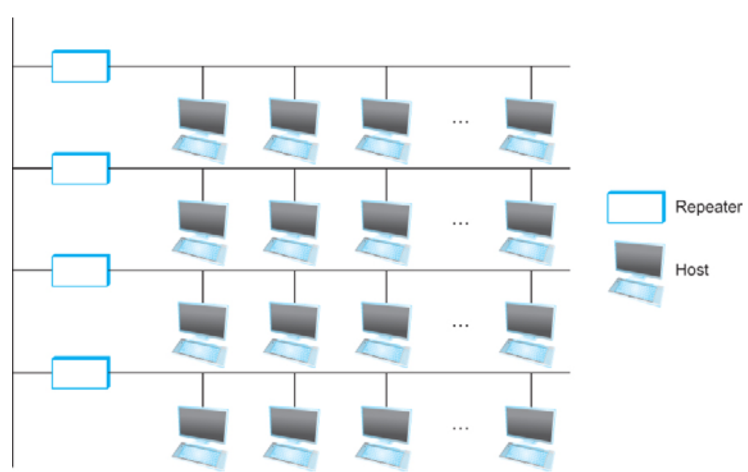
Ethernet

Chapter 2



Ethernet repeater

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Ethernet

Chapter 2

- Any signal placed on the Ethernet by a host is broadcast over the entire network
  - Signal is propagated in both directions.
  - Repeaters forward the signal on all outgoing segments.
  - Terminators attached to the end of each segment absorb the signal.
- Classical Ethernet uses Manchester encoding scheme.
- Higher speed Ethernets use 4B/5B or 8B/10B encoding

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Ethernet

Chapter 2

- New Technologies in Ethernet
  - Instead of using coax cable, an Ethernet can be constructed from a thinner cable known as 10Base2 (the original was 10Base5)
    - 10 means the network operates at 10 Mbps
    - Base means the cable is used in a baseband system
    - 2 means that a given segment can be no longer than 200 m
    - 5 means that a given segment can be no longer than 500 m

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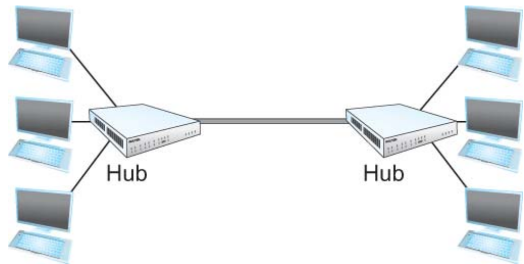
Ethernet

- New Technologies in Ethernet
  - Another cable technology is 10BaseT
    - T stands for twisted pair
    - Limited to 100 m in length
  - With 10BaseT, the common configuration is to have several point to point segments coming out of a multiway repeater, called *Hub*

Ethernet



Ethernet Hub

Access Protocol for Ethernet

Chapter 2

- The algorithm is commonly called Ethernet's Media Access Control (MAC).
  - It is implemented in Hardware on the network adaptor (link layer).
- Frame format
  - Preamble (64bit or 8 Bytes): allows the receiver to synchronize with the signal (sequence of alternating 0s and 1s).
  - Host and Destination Address (48bit or 6 Bytes each).
  - Packet type (16bit or 2 Bytes): acts as demux key to identify the higher level protocol.
  - Data (up to 1500 bytes)
    - Minimally a frame must contain at least 46 bytes of data.
    - Frame must be long enough to detect collision.
  - CRC (32bit or 4 Bytes)
  - Minimal length is 64 Bytes (not including the preamble)

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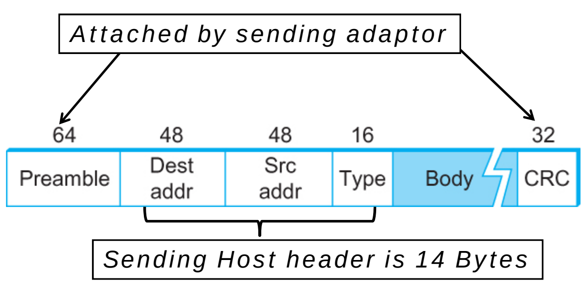
Ethernet Frame

Chapter 2



Ethernet Frame Format

Link to Slide 22

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Ethernet Addresses

Chapter 2

- Each host on an Ethernet (in fact, every Ethernet host in the world) has a unique Ethernet Address.
- The address belongs to the adaptor, not the host.
  - It is usually burnt into ROM.

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Ethernet Addresses (MAC-48)

Chapter 2

- Ethernet addresses are typically printed in a human readable format
  - As a sequence of six numbers separated by colons.
  - Each number corresponds to 1 byte of the 6 byte address
  - Each number is given by a pair of hexadecimal digits, one for each of the 4-bit nibbles in the byte
  - Leading 0s are dropped.
  - For example, 8:0:2b:e4:b1:2 is
    - 00001000 00000000 00101011 11100100 10110001 00000010

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Ethernet Addresses

Chapter 2

- To ensure that every adaptor gets a unique address,
  - each manufacturer of Ethernet devices is allocated a different prefix
  - Manufacturer prefix is prepended to the address on every adaptor they build
  - AMD has been assigned the 24bit prefix 8:0:20
- Number of addresses: 2^{48} = 281.47E12
- Number of manufacturers: 2^{24} = 16.78E6
- Number of addresses/manufacturer: 2^{24}
- Everything that connects to a network has a MAC-48 address

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Ethernet Addresses

Chapter 2

- MAC-48 is now being called EUI-48 (Extended Unique Identifier)
- Every device that connects to a network has a MAC address
- EUI-48 is projected to be exhausted in 2100
- EUI-64 is being used with firewire, IPv6To and Zigbee/802.15.4/6LoPAN (wireless personal network)

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Ethernet Addresses

Chapter 2

- Each frame transmitted on an Ethernet is received by every adaptor connected to that Ethernet.
- Each adaptor recognizes those frames addressed to its address and passes only those frames on to the host.
- *Unicast* address – frame is addressed to one individual host
- *broadcast* address – frame is addressed for all hosts
- *multicast* address – frame is addressed to multiple hosts

Ethernet Addresses

Chapter 2

- In addition, to *unicast* address, an Ethernet address consisting of all 1s is treated as a *broadcast* address.
  - All adaptors pass frames addressed to the *broadcast* address up to the host.
- Similarly, an address that has the first bit set to 1 but is not the *broadcast* address is called a *multicast* address.
  - A given host can program its adaptor to accept some set of *multicast* addresses.

Ethernet Addresses

Chapter 2

- To summarize, an Ethernet adaptor receives all frames and accepts
  - Frames addressed to its own address
  - Frames addressed to the broadcast address
  - Frames addressed to a multicast address if it has been instructed
  - All packets if it is placed in promiscuous mode

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Ethernet Transmitter Algorithm

Chapter 2

- When the adaptor has a frame to send and the line is idle, it transmits the frame immediately.
  - The upper bound of 1500 bytes in the message means that the adaptor can occupy the line for a fixed length of time.
- When the adaptor has a frame to send and the line is busy, it waits for the line to go idle and then transmits immediately.
- The Ethernet is said to be 1-persistent protocol because an adaptor with a frame to send transmits with probability 1 whenever a busy line goes idle.
  - p-persistent protocol is one where an adaptor transmits with probability p

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Ethernet Transmitter Algorithm

Chapter 2

- Since there is no centralized control it is possible for two (or more) adaptors to begin transmitting at the same time,
  - Either because both found the line to be idle,
  - Or, both had been waiting for a busy line to become idle.
  - Using p-persistent mode helps alleviate this problem
- When this happens, the two (or more) frames are said to *collide* on the network.

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Ethernet Transmitter Algorithm

Chapter 2

- Since Ethernet supports collision detection, each sender is able to determine that a collision is in progress.
- When an adaptor detects that its frame is colliding with another,
  - it first makes sure to transmit a 32-bit jamming sequence
  - Then it stops transmission.
  - A transmitter will minimally send 96 bits in the case of collision
    - 64-bit preamble + 32-bit jamming sequence
    - 32-bit jamming sequence is used to ensure a CRC failure

Link to slide 12

MORGAN KAUFMANN 22

Ethernet Transmitter Algorithm

Chapter 2

- One way that an adaptor will send only 96 bit (called a *runt frame*) is if the two hosts are close to each other.
- For hosts farther apart,
  - The hosts transmit longer,, and thus send more bits, before detecting the collision.

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Ethernet Transmitter Algorithm

Chapter 2

- The worst case collision scenario happens when the two hosts are at opposite ends of the Ethernet.
- To know for sure that the frame its just sent did not collide with another frame, the transmitter may need to send as many as 512 bits.
  - Every Ethernet frame must be at least 512 bits (64 bytes) long.
    - 14 bytes of header + 46 bytes of data + 4 bytes of CRC
    - Does not include the preamble of 8 Bytes – otherwise minimum frame is 576 bits – which is mentioned in some literature

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Ethernet Transmitter Algorithm

Chapter 2

- Why 512 bits? Why is its length limited to 2500 m?
- The farther apart two nodes are, the longer it takes for a frame sent by one to reach the other, and the network is vulnerable to collision during this time
- On 10 Mbps ethernet, 512 (576) bits is 51.2 uS (57.6 uS)
  - Round trip delay of approximately 51.2 uS has been determined for 2500 meter length and 4 repeaters
  - Want to keep the latency to a reasonably small value
  - Typical latency in actual networks is well below these values

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Ethernet Transmitter Algorithm

Chapter 2

- A begins transmitting a frame at time t
- d denotes the one way link latency (1/2 RTT)
- The first bit of A's frame arrives at B at time $t + d$
- Suppose an instant before host A's frame arrives, host B begins to transmit its own frame
- B's frame will immediately collide with A's frame and this collision will be detected by host B
- Host B will send the 32-bit jamming sequence
- Host A will not know that the collision occurred until B's frame reaches it, which will happen at $t + 2 * d$
- Host A must continue to transmit until this time in order to detect the collision
  - Host A must transmit for $2 * d$ (or 1 RTT) to be sure that it detects all possible collisions

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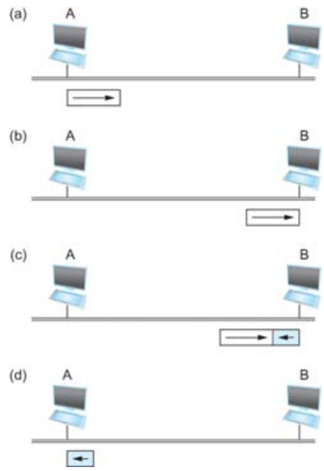
Ethernet Transmitter Algorithm

Chapter 2



Worst-case scenario: (a) A sends a frame at time *t; (b) A's frame arrives* at B at time *t + d; (c) B begins transmitting at time t + d and collides with A's frame;* (d) B's runt (32-bit) frame arrives at A at time *t + 2d.*

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Ethernet Transmitter Algorithm

Chapter 2

- A maximally configured Ethernet
  - is 2500 meters long,
  - May contain up to four repeaters between any two hosts,
  - the round trip delay has been determined to be 51.2 μs
  - On 10 Mbps Ethernet 51.2 μs corresponds to 512 bits or 64 Bytes
- The other way to look at this situation,
  - Limit the Ethernet's maximum latency to a fairly small value (51.2 μs) for the access algorithm to work
    - Hence the maximum length for the Ethernet is on the order of 2500 m.

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Ethernet Transmitter Algorithm

Chapter 2

- Once an adaptor has detected a collision, and stopped its transmission, it waits a certain amount of time and tries again.
- Each time the adaptor tries to transmit but fails, it doubles the possible amount of time it waits before trying again.
- This strategy of doubling the delay interval between each retransmission attempt is known as *Exponential Backoff*.

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Ethernet Transmitter Algorithm

Chapter 2

- After first collision, the adaptor delays either 0 or 51.2 μs, selected at random.
- If a second collison occurs, it then waits 0, 51.2, 102.4, 153.6 μs (selected randomly) before trying again;
  - This is k * 51.2 for k = 0, 1, 2, 3
- After the third collision, it waits k * 51.2 for $k = 0 \ldots 2^3 - 1$ (again selected at random).
- In general, the algorithm randomly selects a k between 0 and $2^n - 1$ and waits for k * 51.2 μs, where n is the number of collisions experienced so far.
- After a successful transmission, n may be reset to 0 or reduced by some factor (1, ½, ¼, etc)

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Experience with Ethernet

Chapter 2

- Ethernets work best under lightly loaded conditions.
  - Under heavy loads (typically >30% utilization), too much of the network's capacity is wasted by collisions.
- Most Ethernets are used in a conservative way.
  - Have fewer than 200 hosts connected to them which is far fewer than the maximum of 1024.
- Most Ethernets are far shorter than 2500m with a round-trip delay of closer to 5 μs than 51.2 μs.

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Experience with Ethernet

Chapter 2

- Why Ethernet has been successful
  - Ethernets are easy to administer and maintain.
  - There are no switches that can fail and no routing and configuration tables that have to be kept up-to-date.
  - It is easy to add a new host to the network.
  - It is inexpensive - Cable is cheap, and only other cost is the network adaptor on each host.

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Wireless Links

- Wireless links transmit electromagnetic signals
  - Radio, microwave, infrared
- Wireless links all share the same “wire” (so to speak)
  - The challenge is to share it efficiently without unduly interfering with each other
  - Most of this sharing is accomplished by dividing the “wire” along the dimensions of frequency and space
- Exclusive use of a particular frequency in a particular geographic area may be allocated to an individual entity such as a corporation

Wireless Links

- These allocations are determined by government agencies such as FCC (Federal Communications Commission) in USA
- Specific bands (frequency) ranges are allocated to certain uses.
  - Some bands are reserved for government use
  - Other bands are reserved for uses such as AM radio, FM radio, televisions, satellite communications, and cell phones
  - Specific frequencies within these bands are then allocated to individual organizations for use within certain geographical areas.
  - Finally, there are several frequency bands set aside for “license exempt” usage (Bands in which a license is not needed)

Wireless Links

Chapter 2

- Devices that use license-exempt frequencies are still subject to certain restrictions
  - The first is a limit on transmission power
  - This limits the range of signal, making it less likely to interfere with another signal
    - For example, a cordless phone might have a range of about 100 feet.

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Wireless Links

Chapter 2

- The second restriction requires the use of **Spread Spectrum** technique
  - Idea is to spread the signal over a wider frequency band
    - So as to minimize the impact of interference from other devices
    - Originally designed for military use
- ***Frequency hopping***
  - Transmitting signal over a random sequence of frequencies
  - First transmitting at one frequency, then a second, then a third…
  - The sequence of frequencies is not truly random, instead computed algorithmically by a pseudorandom number generator
  - The receiver uses the same algorithm as the sender, initializes it with the same seed, and is
  - Able to hop frequencies in sync with the transmitter to correctly receive the frame

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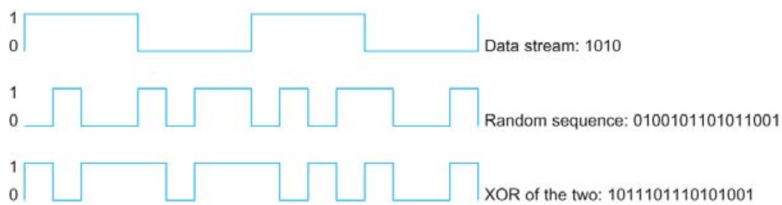
Wireless Links

- A second spread spectrum technique is called ***Direct sequence***
  - Represents each bit in the frame by multiple bits in the transmitted signal.
  - For each bit the sender wants to transmit It actually sends the exclusive OR of that bit and *n* random bits
  - The sequence of random bits is generated by a pseudorandom number generator known to both the sender and the receiver.
  - The transmitted values, known as an ***n*-bit chipping code**, spread the signal across a frequency band that is *n* times wider

Wireless Links



Example 4-bit chipping sequence

Wireless Links

- Wireless technologies differ in a variety of dimensions
  - How much bandwidth they provide
  - How far apart the communication nodes can be
  - See Table 2.4 on page 130
- Four prominent wireless technologies
  - Bluetooth (802.15)
  - Wi-Fi (more formally known as 802.11)
  - WiMAX (802.16) (**Worldwide Interoperability for Microwave Access**)
  - 2G/3G/4G cellular wireless

Wireless Links

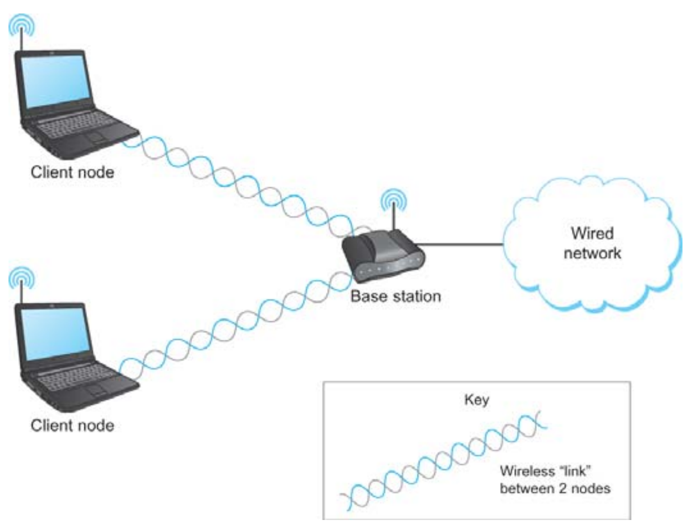
	Bluetooth (802.15.1)	Wi-Fi (802.11)	3G Cellular
Typical link length	10 m	100 m	Tens of kilometers
Typical data rate	2 Mbps (shared)	54 Mbps (shared)	Hundreds of kbps (per connection)
Typical use	Link a peripheral to a computer	Link a computer to a wired base	Link a mobile phone to a wired tower
Wired technology analogy	USB	Ethernet	DSL

Overview of leading wireless technologies (Table 2.4)

Wireless Links

- Most widely used wireless links today are usually asymmetric
  - Two end-points are usually different kinds of nodes
  - One end-point usually has no mobility, but has wired connection to the Internet (known as base station)
  - The node at the other end of the link is often mobile

Wireless Links



A wireless network using a base station