Data Link Technology (3)

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Media Access Control (MAC)
Access Channel

- Two types of “links”:
  - Point-to-point
    - PPP for dial-up access
    - Point-to-point link between Ethernet switch and host
  - Broadcast (shared wire or medium)
    - Traditional Ethernet
    - 802.11 wireless LAN
MAC Protocols (1)

- Single shared broadcast channel
  - Two or more simultaneous transmissions by nodes: interference
  - Collision if node receives two or more signals at the same time

- Ideal Media Access Protocol
  - When one node wants to transmit, it can send at rate $R$
  - When $M$ nodes want to transmit, each can send at average rate $\frac{R}{M}$
  - Fully decentralized:
    - No special node to coordinate transmissions
    - No synchronization of clocks, slots
  - Simple
MAC Protocols (2)

Three techniques:

- **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
  - Nodes with more to send can take longer turns
TDMA (1)

- **Time Division Multiple Access**
  - Access to channel in "rounds"
  - Divide the medium into different time slots
  - Each station gets fixed length slot
    - Length = packet transmission time in each round
  - A single frame is composed of $N$ slots
  - Terminal uses a specific slot
  - Unused slots go idle

![Diagram of TDMA](image)
TDMA (2)

● Slot reservation and release
  – Easy: Statistically multiplexing
    • Assigned by administrator beforehand
  – Dynamic assignment is complex
    • Special function is necessary in terminals

● Time synchronization
  – Slot is determined on a time basis
  – Time synchronization between terminals and switching nodes is necessary
TDMA (3)

Time-Division fails with heterogeneous traffic
From TDMA to ATM (digression)

- TDMA is a widely used medium access technology
  - It is simple as it is multiplexing technology
  - Can guarantee its performance
  - TDMA is still used in many products
    - Based on STM (Synchronous transfer mode)
    - Synchronous networks were widely used until now

- TDMA has hardships to accommodate LAN traffic
  - No guarantee for terminal’s time synchronization
  - Unable to estimate bandwidth used by terminal beforehand

- Arrival of ATM
  - Accepts LAN traffic
  - Aims at performance using multiplexing like TDMA
  - Asynchronous Transfer Mode
## 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

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>
FDMA (2)

Frequency-Division fails with bursty traffic
OFDM

- Orthogonal Frequency Division Multiplexing
- State-of-the-art high bandwidth digital communication use OFDM
  - Terrestrial Video Broadcasting in Japan and Europe
  - ADSL High Speed Modem
  - WLAN such as IEEE 802.11a/g/n
  - WiMAX as IEEE 802.16d/e
  - 4G
Digital Modulation Basics

- Digital modulation modulates three parameters of sinusoidal signal.
  - $A$, $\theta_k$, $f_c$,

\[
s(t) = A \cdot \cos(2\pi f_c t + \theta_k)
\]

- Three type digital modulation:
  - ASK : Amplitude Shift Keying
  - PSK : Phase Shift Keying
  - FSK : Frequency Shift Keying

- OFDM uses combination of ASK and PSK such as
  - Quadrature Amplitude Modulation (QAM)
Symbol Waveform

Digital Information

carrier

ASK

PSK

FSK

Symbol length
Japan Terrestrial Television Broadcasting (1)

- Integrated Services Digital Broadcasting for Terrestrial Television Broadcasting (ISDB-T)
- Full service area coverage on 2006
  - Analog Service ended in 2011
- 5.6MHz BW is divided into 13 OFDM segments (~430 kHz BW)
  - HDTV or SDTV: 12 segments
  - Mobile TV: 1 segment
Japan Terrestrial Television Broadcasting (2)

Random Access Protocols

- When node has packet to send
  - Transmit at full channel data rate $R$
  - No \emph{a priori} coordination among nodes
  - Classical shared-medium problem: radio antenna
- Two or more transmitting nodes $\rightarrow$ “collision”
- Random access MAC protocol specifies:
  - How to detect collisions
  - How to recover from collisions
- Example of protocols:
  - ALOHA
  - Slotted ALOHA
  - CSMA
    - CSMA/CD
    - CSMA/CA
Pure ALOHA (1)

- History
  - Developed in the ALOHA system at the University of Hawaii
  - Two wireless lines
    - Terminal -> host (uplink)
    - Host -> terminal (downlink)
  - Develop shared medium access for two wireless lines

- Basic idea:
  - Each terminal runs independently
  - Transmission as soon as a terminal has data to send
  - Receiver sends ACK for data
    - ACKs sent on separate frequency, so never collide
    - If ACK is not returned within the RTT (Round Trip Time), it is treated as a packet collision
  - Back off process
    - Generation of a random number in \([0,K]: r\)
    - Retransmission after \(r\) seconds
Pure ALOHA (2)

- Collision
  - Wait random amount of time and resend
  - Randomization is essential
Pure ALOHA (3) – weakness

- Each terminal autonomously accesses the medium
  - Performance is naturally bad due to the chaotic access
  - Systematic order leads to a complexity of the system
- Frequent collisions cause performance degradation
  - Increase of the number of access terminals
  - Increase of the traffic load
- Back-off time
  - K
  - Affects communication performance
Slotted ALOHA (1)

- Slotted ALOHA
  - Enhanced version of pure ALOHA
  - Transmission time is divided into time slots
  - Transmission from terminals is made to follow time slots
  - Employing “systematic order”
  - Chaotic line access collision becomes slot contention
  - Reduces occurrence of contention
  - Improves performance (throughput 18.4% → 36.8%)
Slotted ALOHA (2)

- Basic idea:
  - All frames same size
  - Time is divided into equal size slots, time to transmit 1 frame
  - Nodes start to transmit frames only at beginning of slots
  - Nodes are synchronized
  - If 2 or more nodes transmit in slot, all nodes detect collision
  - Frames delayed until beginning of the next slot
Pure ALOHA vs Slotted ALOHA

● Both use randomization after collision
● Slotted reduces probability of collision
  – If frame is ready in middle of period:
    • In Pure ALOHA, I will begin sending and destroy any currently sending frames
    • In Slotted ALOHA, I will wait and only destroy other waiting frames
CSMA (1)

- **Carrier Sense Multiple Access**
- Senses the medium to confirm whether it is used before transmission
  - If the medium is not being used, data is transmitted ASAP
  - Collision unfortunately occurs due to transmission delay
  - If another terminal transmits a packet within RTT/2, collision occurs
    - Time for the transmission spreads along the medium
CSMA (2)

● In case a carrier is detected
  – 1-persistent
    • channel free: send immediately
    • channel busy: send once it is free
  – non-persistent
    • channel free: send immediately
    • channel busy: send after random amount of time
  – (slotted) p-persistent CSMA
    • channel free: transmit with prob \( p \)
    • channel busy: repeat algorithm next slot

● In case a collision occurs
  – Wait some time (randomly determined), sense the medium again
CSMA (3)

- CSMA also comes in two flavours
  - Collision Detection (/CD)
    - Can ascertain if two data frames have collided
    - Used in Ethernet 802.3 protocol family
  - Collision Avoidance (/CA)
    - Channel is reserved using special frames
    - Data frames will never collide
    - Used in Wireless LAN 802.11 protocol family
MAC Throughput Performance

The graph illustrates the throughput performance of different MAC protocols as a function of the number of attempts per packet time. The x-axis represents the number of attempts per packet time (G), while the y-axis shows the throughput per packet time (S).

Key protocols and their performance levels are as follows:
- Nonpersistent CSMA
- 0.01-persistent CSMA
- 0.1-persistent CSMA
- 0.5-persistent CSMA
- Slotted ALOHA
- Pure ALOHA
- 1-persistent CSMA

Each line on the graph represents the performance of one of these protocols, showing how their throughput changes with the number of attempts per packet time.
Taking Turn MAC Protocols

- Channel partitioning MAC protocols:
  - Share channel efficiently and fairly at high load
  - Inefficient at low load:
    - Delay in channel access
    - 1/N bandwidth allocated even if only 1 active node

- Random access MAC protocols
  - Efficient at low load:
    - Single node can fully utilize channel
  - High load:
    - Collision overhead

- Taking turns protocols
  - Two implementations: Polling & Token
Token Passing

- Employed in 802.4 (Token Bus), 802.5 (Token Ring)
- FDDI is also a type of Token Passing (more complex)
- Method
  - a token is passed around between nodes in a certain order
  - a node with the token can communicate
  - token holding timer
- Characteristics
  - unlike contention type data link, degradation is not enforced during high load periods
  - for this reason, token bus and token ring are preferred
Historical Transition

Pure ALOHA

Slotted ALOHA

CSMA

CSMA/CD (Ethernet)

Token Ring

FDDI (gone)

TDMA

ATM (gone)
Ethernet (IEEE 802.3 Family)
Ethernet

- LAN technology based on CSMA/CD
- Standardized as IEEE802.3
  - 10Mbps, base-band transmission
  - 1500octet MTU
  - Designed and developed as bus type LAN
    - Coaxial cable and Transceiver
    - 10Base5, 10Base2
- Emergence of 10BaseT technology using UTP cables
  - Cabling in star topology
  - Emerging hub and switch
Fast Ethernet

- 100Mbps Ethernet
  - Medium is UTP/CAT5 as well as optical fiber
  - Direct switchover from 10 Mbps Ethernet environment
  - Bidirectional 100BaseT
    - Wider bandwidth due to bidirectional data transmission
  - Auto-sense / Auto-negotiation
    - Connection type is automatically determined
  - 10BaseT/100BaseT, Unidirectional / Bidirectional
    - Interoperability
Gigabit Ethernet (IEEE802.3z)

- 1Gbps
- Bidirectional data channel technology
  - Half-channel is 1Gbps
  - Full duplex
- Transmission medium is optical fiber
  - 1000Base-SX (Short-wavelength), 1000Base-LX (Long-wavelength)
- Most of the current products today obey IEEE802.3z standard
  - Interoperability deployment is progressing steadily
  - NICs altogether with switches are widespread
Gigabit Ethernet (IEEE802.3ab)

- New Gigabit Ethernet standard
  - 1000Base-T
  - UTP
  - 1Gbps Ethernet
  - Maximum 100m
Ethernet Family Strengths

- Rapid spread of Fast Ethernet
  - Simple switchover from 10BaseT
  - Many cheap products
  - Substitute 10BaseT networks for Fast Ethernet

- Does not require special network management
  - Plug-and-play
  - Significant difference with ATM
## Comparison of Ethernet Technology

<table>
<thead>
<tr>
<th></th>
<th>Ethernet</th>
<th>Fast Ethernet</th>
<th>Gigabit Ethernet</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data Rate</strong></td>
<td>10Mbps</td>
<td>100Mbps</td>
<td>1Gbps</td>
</tr>
<tr>
<td><strong>CAT 5 UTP</strong></td>
<td>100m</td>
<td>100m</td>
<td>100m (CAT5+/6)</td>
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<tr>
<td><strong>STP/Coax</strong></td>
<td>500m</td>
<td>100m</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Multi-mode Fiber</strong></td>
<td>2Km</td>
<td>412m (hd*)</td>
<td>550m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2Km (fd*)</td>
<td></td>
</tr>
<tr>
<td><strong>Single-mode Fiber</strong></td>
<td>25Km</td>
<td>20Km</td>
<td>&gt; 5Km</td>
</tr>
</tbody>
</table>

*IEEE half duplex/full duplex
note: IEEE 802.3z
Ethernet’s address

- 6 octet (48 bit)
- First three octets defined by IEEE, identify the vendor
- The following three octets are assigned by the vendor
- IEEE MAC address
- “00:a0:cc:7c:47:16”
10Gbps Ethernet

- IEEE802.3ae
  - Standardized by IEEE on June 2002
- Divided into WAN use and LAN use
  - WAN PHY
    - Using SONET frame
      - Considering interoperability with SONET/SDH
    - ~300m, wavelength: 850nm
    - 10km, wavelength: 1310nm
    - 40km, wavelength: 1550nm
  - LAN PHY
    - Using Ethernet Frame
    - ~300m, wavelength: 850nm
    - 10km, wavelength: 1310nm
    - 40km, wavelength: 1550nm
    - 10km, wavelength: 1310nm
  - Introduced in the market in 2002
    - 10GBASE-LR serial (1310nm)
    - 10GBASE-EX4(1550nm WWDM)
    - Transmission distance: 10Km – 50Km
40Gbps/100Gbps Ethernet

- IEEE802.3ba
  - Standardized by IEEE on June 2010

- Goal: To support fast networks over 10Gbps
  - Only supports full-duplex communication
  - Preserves the current standard framesize
  - Supports a transmission quality characterized by a BER (Bit Error Rate) better or equal to $10^{-12}$ at the interface with upper layers
  - Supports OTN (Optical Transport Network)

- Provides physical layer specifications which support 40Gbps operation over:
  - SMF >10km
  - OM3 MMF >100m
  - Copper cable assembly >7m
  - Backplane >1m

- Provides physical layer specifications which support 100Gbps operation over:
  - SMF >40km or >10km
  - OM3 MMF >100m
  - Copper cable assembly >7m
40Gb/s Ethernet Single-mode Fibre PMD

- IEEE802.3bg
  - Standardized by IEEE on March 2011
  - PMD: Physical Medium Dependent

- Improvements:
  - Support a BER better than or equal to $10^{-12}$ at the MAC/PLS service interface
  - Support a MAC data rate of 40 Gb/s
  - Use the 40GBASE-R PCS and PMA
  - Use only existing electrical and logical interfaces from IEEE Std 802.3 as modified by IEEE P802.3ba
  - Provide Physical Layer specification which support 40 Gb/s operation over at least 2 km on SMF.
  - Provide optical compatibility with existing carrier 40Gb/s client interfaces (OTU3/STM-256/OC-768/40G POS).
Future of Ethernet

- **Terabit Ethernet**
  - P802.3bj under discussion
  - 4x25G Multi-mode fiber links for up to 100m
  - Single-mode fiber link is under consideration to increase distance of 2km

- **Network Partitioning**
  - “Switch agnostic” NIC Partitioning (NPAR)
  - Up to four virtual ports per physical port
    - Virtual ports: NIC, FCoE, or iSCI

- **OpenFlow**
  - Create research control plane
  - Fast provisioning of virtual networks
  - Speed up innovation in networking
Requirements for the Data Link
Today’s data link requirements

- Wide bandwidth
- Large scale
- Virtualization
- Coverage expansion
Development of data link technologies

- Wide bandwidth
- Large scale
- Virtualization
- Coverage expansion
- Switched media
- Bridges
- VLAN
- Broadband wireless, residential access, etc.
Wide bandwidth: shared media $\rightarrow$ switched media

- High-bandwidth and commodity LAN
- Spread of Processor Interconnect Technology
Shifting to switched media

- Confusing switched media and shared media carries out significant problems
- Failure of demonstration is caused by this

<table>
<thead>
<tr>
<th>Year</th>
<th>Voice</th>
<th>Video (MPEG2)</th>
<th>Video (MotionJPEG)</th>
<th>Video (D1)</th>
<th>Video (HD D1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>Voice</td>
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<tr>
<td>1998</td>
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<td>Video (MPEG2)</td>
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<td>2000</td>
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<td>Video (MotionJPEG)</td>
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<tr>
<td>2002</td>
<td></td>
<td></td>
<td>Video (D1)</td>
<td></td>
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<td>2004</td>
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<td>Video (HD D1)</td>
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<td>2006</td>
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Large scale: Bridges

- Compatibility between physical limitations and LAN convenience
  - Coverage, capacity

Wiring in floor: coax
(∼100m)

Wiring between buildings: optical fiber
(∼5km)
Bridge basics: Transparent bridge

- Host is not aware of the bridge
- Transparent bridge
  - No modification of MAC frame
  - Promiscuous: capture all flowing packets
  - Administrator builds the bridge forwarding table

<table>
<thead>
<tr>
<th></th>
<th>Fwd to 1</th>
<th>Fwd to 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>A, B</td>
<td>A, B, C, D</td>
<td></td>
</tr>
<tr>
<td>C, D</td>
<td>E, F, G, H</td>
<td></td>
</tr>
</tbody>
</table>
Learning bridge

- When a frame destined to an unknown MAC is received
  - Forward to other ports (flooding)
  - Record source host → register to the forwarding table
- When a frame destined to a known MAC is received
  - Forward to appropriate port
- Broadcast transmission
  - Received by all active hosts in a same medium

Construct a table with learning
Loops in learning bridges

- Based on the previous algorithm, what would happen if A sends a frame to G?
Spanning tree bridges

- Spanning tree

R: root port
D: designated port
A: alternative port
More various technologies

- VLAN
  - Network virtualization
  - Nowadays, VLAN is frequently used
  - Single medium, multiple-network installation

- WDM
- MPLS
- Broadband wireless, residential access, WiMAX, …

- Keep on studying more and if you are interested…