Data and Computer Communications

Chapter 15 – Local Area Network
Overview

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by William Stallings

Lecture slides by Lawrie Brown
Local Area Network Overview

The whole of this operation is described in minute detail in the official British Naval History, and should be studied with its excellent charts by those who are interested in its technical aspect. So complicated is the full story that the lay reader cannot see the wood for the trees. I have endeavored to render intelligible the broad effects.

—The World Crisis, Winston Churchill
LAN Applications (1)

- personal computer LANs
  - low cost
  - limited data rate

- back end networks
  - interconnecting large systems (mainframes and large storage devices)
    - high data rate
    - high speed interface
    - distributed access
    - limited distance
    - limited number of devices
storage area networks (SANs)

- separate network handling storage needs
- detaches storage tasks from specific servers
- shared storage facility
  - eg. hard disks, tape libraries, CD arrays
- accessed using a high-speed network
  - eg. Fibre Channel
- improved client-server storage access
- direct storage to storage communication for backup
Storage Area Networks

(a) Server-based storage

(b) Storage area network
LAN Applications (3)

- high speed office networks
  - desktop image processing
  - high capacity local storage
- backbone LANs
  - interconnect low speed local LANs
  - reliability
  - capacity
  - cost
LAN Architecture

- topologies
- transmission medium
- layout
- medium access control
LAN Topologies

(a) Bus
(b) Tree
(c) Ring
(d) Star
Bus and Tree

- used with multipoint medium
- transmission propagates throughout medium
- heard by all stations
- full duplex connection between station and tap
  - allows for transmission and reception
- need to regulate transmission
  - to avoid collisions and hogging
- terminator absorbs frames at end of medium
- tree a generalization of bus
- headend connected to branching cables
Frame Transmission on Bus LAN

C transmits frame addressed to A

Frame is not addressed to B; B ignores it

A copies frame as it goes by
Ring Topology

- A closed loop of repeaters joined by point to point links
- Receive data on one link & retransmit on another
  - Links unidirectional
  - Stations attach to repeaters
- Data in frames
  - Circulate past all stations
  - Destination recognizes address and copies frame
  - Frame circulates back to source where it is removed
- Media access control determines when a station can insert frame
Frame Transmission
Ring LAN
Star Topology

- each station connects to central node
  - usually via two point to point links

- either central node can broadcast
  - physical star, logical bus
  - only one station can transmit at a time

- or central node can act as frame switch
Choice of Topology

- reliability
- expandability
- performance

needs considering in context of:

- medium
- wiring layout
- access control
Bus LAN
Transmission Media (1)

- twisted pair
  - early LANs used voice grade cable
  - didn’t scale for fast LANs
  - not used in bus LANs now

- baseband coaxial cable
  - uses digital signalling
  - original Ethernet
Bus LAN

Transmission Media (2)

- **broadband coaxial cable**
  - as in cable TV systems
  - analog signals at radio frequencies
  - expensive, hard to install and maintain
  - no longer used in LANs

- **optical fiber**
  - expensive taps
  - better alternatives available
  - not used in bus LANs

- less convenient compared to star topology

- **twisted pair**

- **coaxial baseband still used but not often in new installations**
Ring and Star Usage

- **ring**
  - very high speed links over **long distances**
  - single link or repeater failure disables network

- **star**
  - uses natural layout of wiring in building
  - best for **short distances**
  - high data rates for small number of devices
Choice of Medium

- constrained by LAN topology
- capacity
- reliability
- types of data supported
- environmental scope
Media Available

- **Voice grade unshielded twisted pair (UTP)**
  - Cat 3 phone, cheap, low data rates

- **Shielded twisted pair / baseband coaxial**
  - More expensive, higher data rates

- **Broadband cable**
  - Even more expensive, higher data rate

- **High performance UTP**
  - Cat 5+, very high data rates, switched star topology

- **Optical fibre**
  - Security, high capacity, small size, high cost
LAN Protocol Architecture

OSI Reference Model
- Application
- Presentation
- Session
- Transport
- Network
- Data Link
- Physical

IEEE 802 Reference Model
- Upper Layer Protocols
  - Logical Link Control
  - Medium Access Control

IEEE 802 Standards

Logical Link Access Procedure (LLC) Service Access Point (LSAP) Scope
IEEE 802 Layers (1)

- Physical
  - encoding/decoding of signals
  - preamble generation/removal
  - bit transmission/reception
  - transmission medium and topology
IEEE 802 Layers (2)

- **Logical Link Control**
  - interface to higher levels
  - flow and error control

- **Media Access Control**
  - on transmit assemble data into frame
  - on receive disassemble frame
  - govern access to transmission medium
  - for same LLC, may have several MAC options
LAN Protocols in Context

Application data

TCP Layer

IP Layer

LLC Layer

MAC Layer

TCP segment

IP datagram

LLC protocol data unit

MAC frame
Logical Link Control

- transmission of link level PDUs between stations
- must support multiaccess, shared medium
- but MAC layer handles link access details
- addressing involves specifying source and destination LLC users
  - referred to as service access points (SAP)
  - typically higher level protocol
LLC Services

- based on HDLC
- unacknowledged connectionless service
- connection mode service
- acknowledged connectionless service
LLC Protocol

- modeled after HDLC
- asynchronous balanced mode
  - connection mode (type 2) LLC service
- unacknowledged connectionless service
  - using unnumbered information PDUs (type 1)
- acknowledged connectionless service
  - using 2 new unnumbered PDUs (type 3)
- permits multiplexing using LSAPs
MAC Frame Format

The diagram shows the structure of a MAC (Media Access Control) frame, which consists of the following fields:

- **MAC Control**: 1 octet
- **Destination MAC Address**: 1 octet
- **Source MAC Address**: 1 or 2 octets
- **LLC PDU**: Variable length
- **CRC**: 2 octets

The LLC PDU contains:

- **DSAP**: 1 octet
- **SSAP**: 1 octet
- **LLC Control**: 1 or 2 octets
- **Information**: Variable length

The LLC Address Fields include:

- **I/G**: Individual/Group
- **DSAP value**: 1 octet
- **C/R**: Command/Response
- **SSAP value**: 1 octet

The diagram illustrates how these fields are structured within the MAC frame.
Media Access Control

where

• central
  • greater control, single point of failure
• distributed
  • more complex, but more redundant

how

• synchronous
  • capacity dedicated to connection, not optimal
• asynchronous
  • in response to demand
Asynchronous Systems

- **round robin**
  - each station given turn to transmit data

- **reservation**
  - divide medium into slots
  - good for stream traffic

- **contention**
  - all stations contend for time
  - good for bursty traffic
  - simple to implement
  - tends to collapse under heavy load
MAC Frame Handling

- MAC layer receives data from LLC layer
- Fields:
  - MAC control
  - Destination MAC address
  - Source MAC address
  - LLC
  - CRC
- MAC layer detects errors and discards frames
- LLC optionally retransmits unsuccessful frames
Bridges

- connects similar LANs
- identical physical / link layer protocols
- minimal processing
- can map between MAC formats
- reasons for use
  - reliability
  - performance
  - security
  - geography
Bridge Function

LAN A

Station 1  Station 2  Station 10

Frames with addresses 11 through 20 are accepted and repeated on LAN B

Bridge

LAN B

Station 11  Station 12  Station 20

Frames with addresses 1 through 10 are accepted and repeated on LAN A
Bridge Design Aspects

- **no modification** to frame content or format
- **no encapsulation**
- exact bitwise copy of frame
- minimal buffering to meet peak demand
- contains routing and address intelligence
- may connect more than two LANs
- bridging is **transparent** to stations
Bridge Protocol Architecture

- **IEEE 802.1D**
- MAC level
- bridge does not need LLC layer
- can pass frame over external comms system
  - capture frame
  - encapsulate it
  - forward it across link
  - remove encapsulation and forward over LAN link
  - e.g. WAN link
Connection of Two LANs

(a) Architecture

(b) Operation
Bridges and LANs with Alternative Routes
Fixed Routing

- complex large LANs need alternative routes
  - for load balancing and fault tolerance
- bridge must decide whether to forward frame
- bridge must decide LAN to forward frame to
- can use fixed routing for each source-destination pair of LANs
  - done in configuration
  - usually least hop route
  - only changed when topology changes
  - widely used but limited flexibility
Spanning Tree

- bridge automatically develops routing table
- automatically updates routing table in response to changes
- three mechanisms:
  - frame forwarding
  - address learning
  - loop resolution
Frame Forwarding

- maintain **forwarding database** for each port
  - lists station addresses reached through each port

- for a frame arriving on port X:
  - search forwarding database to see if MAC address is listed for any port except X
  - if address not found, forward to all ports except X
  - if address listed for port Y, check port Y for blocking or forwarding state
  - if not blocked, transmit frame through port Y
Address Learning

- can preload forwarding database
- when frame arrives at port X, it has come form the LAN attached to port X
- use source address to update forwarding database for port X to include that address
- have a timer on each entry in database
- if timer expires, entry is removed
- each time frame arrives, source address checked against forwarding database
  - if present timer is reset and direction recorded
  - if not present entry is created and timer set
Spanning Tree Algorithm

- address learning works for tree layout
- in general graph have loops
- for any connected graph there is a spanning tree maintaining connectivity with no closed loops
- IEEE 802.1 Spanning Tree Algorithm finds this
  - each bridge assigned unique identifier
  - exchange info between bridges to find spanning tree
  - automatically updated whenever topology changes
Loop of Bridges
Spanning Tree Algorithm

- Address learning mechanism is effective if the topology of the internet is a **tree**

- **Terminology**
  - **Root bridge**: Lowest value of bridge identifier
  - **Path cost**: Associated with each port
  - **Root port**: Port to the root bridge
  - **Root path cost**: Cost of the path to root bridge
  - **Designated bridge/port**
  - Any active port that is not a root port or a designated port is a **blocked port**
Spanning Tree Algorithm (cont)

- **Determine the root bridge**
  - All bridges consider themselves to be the root bridge. Each bridge will broadcast a **BPDU** on each of its LAN the asserts this fact.
  - Only the bridge with the lowest-valued identifier will maintain its belief.
  - Over time, as BPDU propagate, the identity of the lowest-valued bridge identifier will be known to all bridges.
Spanning Tree Algorithm (cont)

- **Determine the root port** on all other bridges
  - The root bridge will regularly broadcast the fact that it is the root bridge on all of the LANs; It allows the bridges on those LANs to determine their root port and the fact that they are directly connected to the root bridge.
  - Each of these bridges turn broadcasts a BPDU on the other LANs to which it attached, indicating that it is one hop away from the root bridge.

- **Determine the designated port** on each LAN
  - On any LAN, the bridge claiming to be the one that is closest (minimum cost path) to the root bridge becomes the designated bridge.
Spanning Tree Algorithm (e.g.)

- LAN 2
  - Bridge 3: C = 10
  - Bridge 4: C = 5
- LAN 5
  - Bridge 5: C = 5
- LAN 1
  - Bridge 2: C = 10
  - Bridge 2: C = 5
- LAN 3
- LAN 4
Spanning Tree Algorithm (e.g.)

Bridge 1
Root Path Cost = 0
C = 10  C = 10

LAN 1
D  D

LAN 2
D  D

Bridge 5
RPC = 5
C = 5

Bridge 4
RPC = 5
C = 5

Bridge 3
RPC = 10
C = 10

LAN 3
D

LAN 4
D

LAN 5
D

R = root port
D = designated port
Interconnecting LANs - Hubs

- active central element of star layout
- each station connected to hub by two UTP lines
- hub acts as a repeater
- limited to about 100 m by UTP properties
- optical fiber may be used out to 500m
- physically star, logically bus
- transmission from a station seen by all others
- if two stations transmit at the same time have a collision
Two Level Hub Topology

Diagram:

- HHUB
- IHUB
- Station

Two cables (twisted pair or optical fiber)

Transmit

Receive
Buses, Hubs and Switches

- **bus configuration**
  - all stations share capacity of bus (e.g. 10Mbps)
  - only one station transmitting at a time

- **hub** uses star wiring to attach stations
  - transmission from any station received by hub and retransmitted on all outgoing lines
  - only one station can transmit at a time
  - total capacity of LAN is 10 Mbps

- can improve performance using a layer 2 switch
  - can switch multiple frames between separate ports
  - multiplying capacity of LAN
Shared Medium Bus and Hub
Layer 2 Switch Benefits

- no change to attached devices to convert bus LAN or hub LAN to switched LAN
  - e.g. Ethernet LANs use Ethernet MAC protocol
- have dedicated capacity equal to original LAN
  - assuming switch has sufficient capacity to keep up with all devices
- scales easily
  - additional devices attached to switch by increasing capacity of layer 2
Types of Layer 2 Switch

- **store-and-forward switch**
  - accepts frame on input line, buffers briefly, routes to destination port
  - see delay between sender and receiver
  - better integrity

- **cut-through switch**
  - use destination address at beginning of frame
  - switch begins repeating frame onto output line as soon as destination address recognized
  - highest possible throughput
  - risk of propagating bad frames
Layer 2 Switch vs Bridge

- Layer 2 switch can be viewed as full-duplex hub
- incorporates logic to function as multiport bridge

**differences between switches & bridges:**
- **bridge** frame handling done in **software**
- **switch** performs frame forwarding in **hardware**
- bridge analyzes and forwards one frame at a time
- switch can handle multiple frames at a time
- **bridge** uses **store-and-forward** operation
- **switch** can have **cut-through** operation

- hence bridge have suffered commercially
Layer 2 Switch Problems

- broadcast overload
  - users share common MAC broadcast address
  - broadcast frames are delivered to all devices connected by layer 2 switches and/or bridges
  - broadcast frames can create big overhead
  - broadcast storm from malfunctioning devices

- lack of multiple links
  - limits performance & reliability
Router Problems

- Typically use subnetworks connected by routers
  - Limits broadcasts to single subnet
  - Supports multiple paths between subnet

- Routers do all IP-level processing in software
  - High-speed LANs and high-performance layer 2 switches pump millions of packets per second
  - Software-based router only able to handle well under a million packets per second
Layer 3 Switches

- **Solution:** layer 3 switches
  - implement packet-forwarding logic of router in hardware

- two categories
  - packet by packet
  - flow based
Packet by Packet or Flow Based

- **packet by packet**
  - operates like a *traditional router*
  - order of magnitude increase in performance compared to software-based router

- **flow-based switch**
  - enhances performance by identifying flows of IP packets with same source and destination
  - by observing ongoing traffic or using a special flow label in packet header (IPv6)
  - a *predefined route* is used for identified flows
Typical Large LAN Organization Diagram
Summary

- LAN topologies and media
- LAN protocol architecture
- bridges, hubs, layer 2 & 3 switches