Telematics I

Chapter 6
Internetworking

(Acknowledement: These slides have been compiled from H. Karl's set of slides)

Goals of This Chapter

- So far: we can communicate between nodes all connected directly to the same medium
- How to grow beyond a single medium?
- What options exist to interconnect local networks into larger configurations?
  - Repeaters, hubs, bridges, switches, routers, gateways
- What are their limitations?
- How does it relate to the networking layer in the ISO/OSI stack?

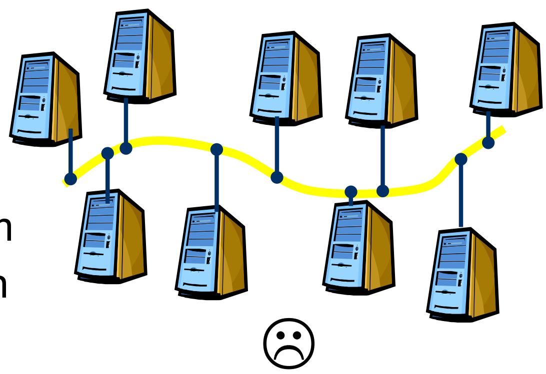
Overview

- ***LAN interconnection***
- Physical-layer interconnects
- Data-link-layer interconnects
- Higher-layer interconnects

The Problem

- Let's start from classic Ethernet
  - Single wire, single collision domain
- Works fine for a limited number of stations
- Collapses when number of nodes becomes too large
  - CSMA/CD will not keep up, limited bandwidth

! Multiple LANs are necessary
  - Not an inherent Ethernet problem
  - Will happen on any medium, with any protocol



Several Reasons for Multiple LANs

- Limited number of users/throughput in a single LAN
- Historical reasons
  - Different groups started out individually setting up networks
  - Usually heterogeneous
- Geographic distribution of different groups over different buildings, campus, …
  - Impractical/impossible to use a single LAN because of distance
  - Long round-trip delay will negatively influence performance
- Reliability
  - Don't put all your eggs into one basket
  - "Babbling idiot" problem
- Security
  - Promiscuous operation – contain possible damage

Several Options to Overcome Some of These Limitations

- Can be classified according to the layer in which they work

Application layer	Application gateway
Transport layer	Transport gateway
Network layer	Router
Data link layer	Bridge, switch
Physical layer	Repeater, hub

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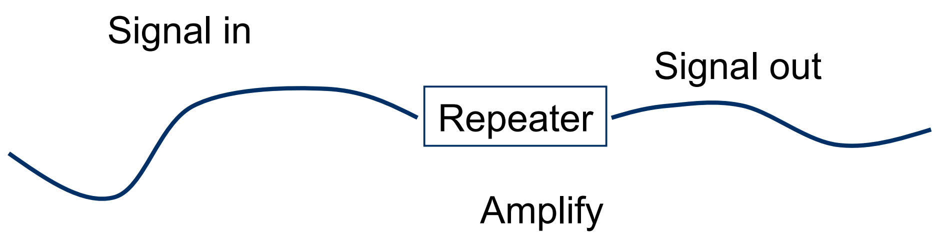
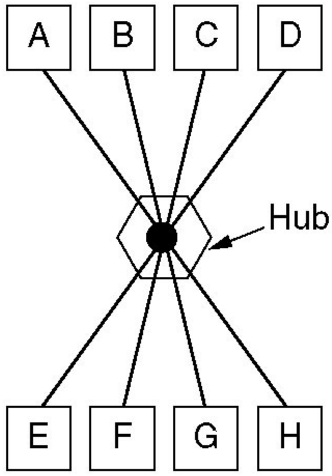
Repeaters

- Simplest option: Repeater
  - Physical layer device
  - Connected to two cables
  - Amplifies signal arriving on either one, puts on the other cable
  - Essentially an analog amplifier to extend physical reach of a cable
  - Combats attenuation
  - Neither understands nor cares about *content (bits)* of packets



Hub

- Similar to repeaters: Hubs
  - Connects multiple cables electrically, not just two
  - Usually, does not amplify the signal
  - Also physical layer device
  - Also does not understand or process *content* of packets
  - All connected cables form a single collision domain



Physical Layer Solutions Not Satisfactory

- Physical layer devices – repeater, hub – do not solve the more interesting problems
  - E.g., how to handle load
- Some knowledge of the data link layer structure is necessary
  - To be able to inspect the content of the packets/frames and *do* something with that knowledge

! Link-layer solutions
  - Bridge & switch
  - Switch: Interconnect several *terminals*
  - Bridge: Interconnect several *networks*
  - But terms sometimes used interchangeably

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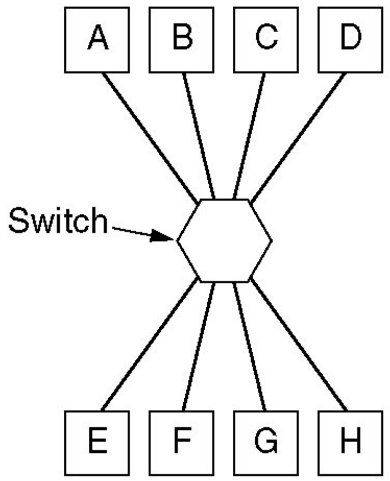
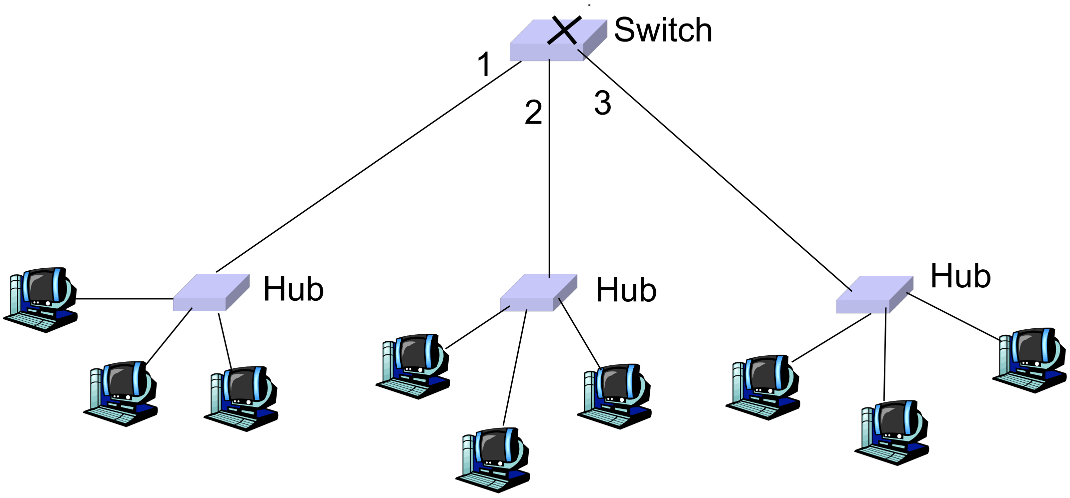
Switch

- Use a switch to connect several terminals *without* forming a single collision domain
- A switch:
  - Stores and forwards link layer frames (e.g. Ethernet)
  - When frame is to be forwarded on segment, uses CSMA/CD to access segment
  - Inspects an arriving packet's addresse and forwards its *only* on the right cable
    - Does not bother the other terminals
    - Needs: buffer, knowledge *where* which terminal is connected



Forwarding



- How do determine onto which LAN segment to forward frame?
- Looks like a routing problem...

Determining Directions: Self Learning

- A switch has a switch table
- Entry in switch table:
  - (MAC Address, Interface, Time Stamp)
  - Stale entries in table dropped (TTL can be 60 min)
- Switch *learns* which hosts can be reached through which interfaces
  - When frame received, switch "learns" location of sender: incoming LAN segment *("backward learning")*
  - Records sender/location pair in switch table

Filtering/Forwarding

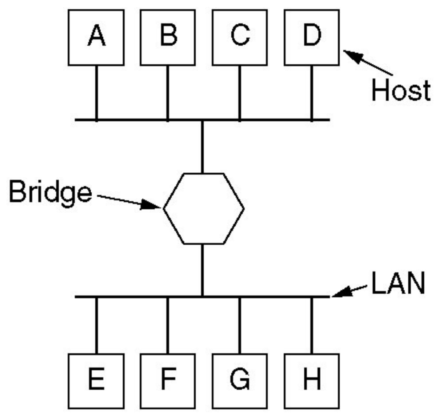
When switch receives a frame:

index switch table using MAC dest address
if entry found for destination
    then{
    if dest on segment from which frame arrived
        then drop the frame
        else forward the frame on interface indicated
    }
else flood

forward on all but the interface on which the frame arrived

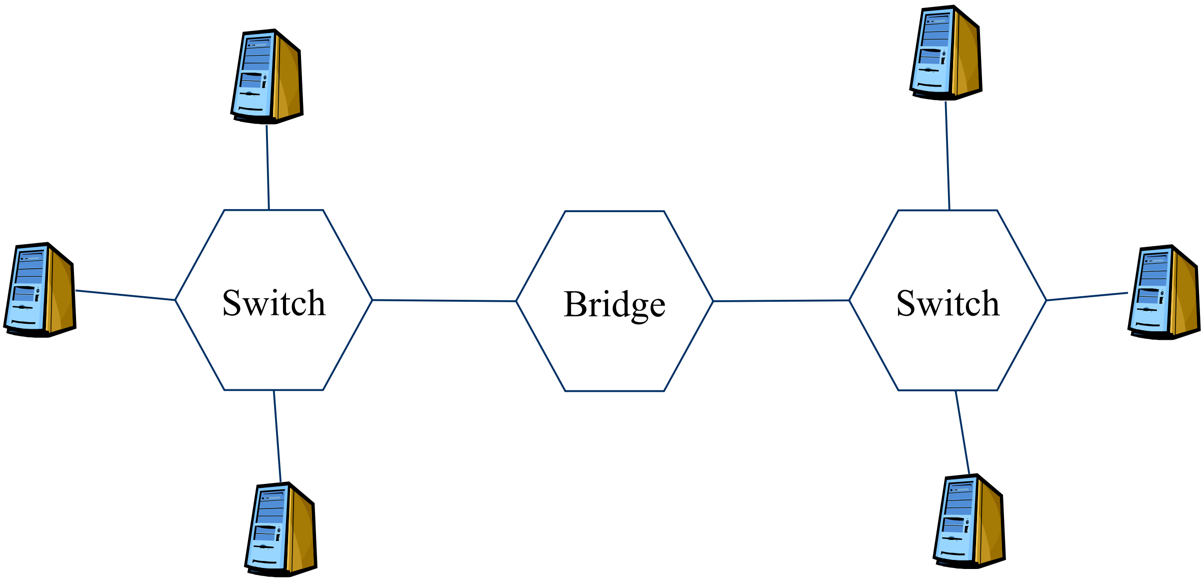
Bridges

- Switches are limited in that they connect simple terminals
- Sometimes, entire networks have to be connected: Bridges
- Bridge also inspects incoming packet and forwards only towards destination
  - How to learn here where destination is? Does simple “backward” learning suffice?
- Each network connected to a bridge is a separate collision domain
- Bridges can also interconnect different LAN types
  - Not possible on physical layer only



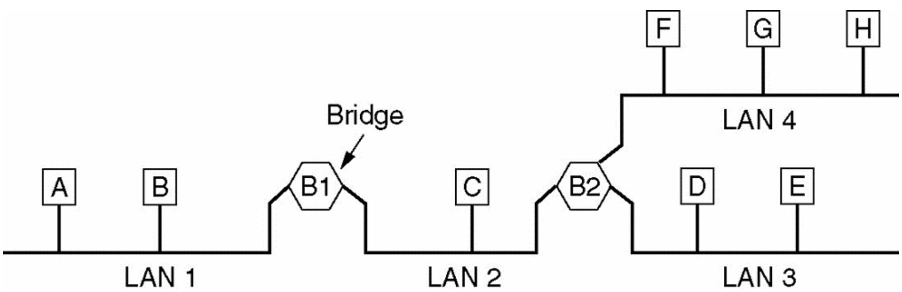
Switches & Bridges

- Typical combination: Bridge as "just another terminal" for a switch



Backward Learning in Bridges

- Backward learning is trivial in a switch – how about a bridge?
- Example: A sends packet to E
  - Suppose bridges B1 and B2 know where E is
  - B2 will see A's packet coming from LAN2
  - Since B2 does not know about LAN1, B2 will assume A to be on LAN2
  - Which is fine! B1 will forward any packet destined to A arriving at LAN2 to LAN1, so that works out nicely

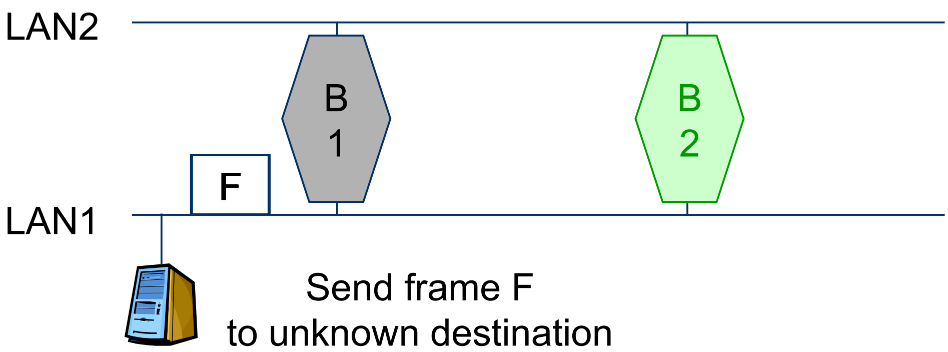


Backward Learning in Bridges – Bootstrapping

- In previous example:
  - How does bridge B2 know initially where node E is?
- Answer: It does NOT know
  - Option 1: Manual configuration – not nice!
  - Option 2: Do not care – simply forward the data everywhere for an unknown address
    - Except to the network where it came from
- Algorithm is thus:
  - flood if not known, or
  - discard if known to be not necessary, or
  - forward specifically if destination is known

Flooding by Bridges – Problems

- Previous “backward learning by flooding” is simple, but problematic
- Consider example topology:
  - Second bridge for reliability



- When B2 hears packets flooded from B1 it will flood them as well...
  ... and vice versa!
- How to avoid such packet loops?

Solution 1: Somehow Restrict Flooding

- Unrestricted, brute-force flooding evidently fails
- Avoid packet looping indefinitely by ***remembering*** which packets have already been forwarded
  - If already seen and forwarded a packet, simply drop it
- Requires: State & uniqueness
  - Bridges have to remember which packets have passed through
  - Packets must be uniquely identifiable – at least source, destination, and sequence number are necessary to distinguish packets
- Big overhead!
  - State is a problem, as is time to search this amount of state
  - Usually not used

Note: Restricted flooding is still important – for control packets, in wireless networks, …

Solution 2: Spanning Trees

- Packet loops are caused by cycles in the graph defined by the bridges
  - Think of bridges as edges, LANs as nodes in this graph
  - Redundant bridges form loops in this graph
- Idea: Turn this into a loop-free, acyclic graph
- Simplest approach: Compute a spanning tree on this LAN-bridge graph
  - Simple, self-configured, no manual intervention
  - But not optimal: actual capacity of installed bridges might not be fully exploited

Definition spanning tree: Given a graph G=(V,E), a ***spanning tree*** $T=(V, E_T)$ is a subgraph of V, $E_T \subseteq E$, which is a tree (in particular, connected and acyclic)

Convergence: Switch and Bridge

- Traditionally, distinction between switch and bridge made sense
  - Bridges need more memory for storing addresses
  - Bridges need to implement spanning tree algorithm
- Today: most devices contain both types of functionality

- Often more a marketing distinction than a technical one

Overview

- LAN interconnection
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- Data-link-layer interconnects
- ***Higher-layer interconnects***

Routers

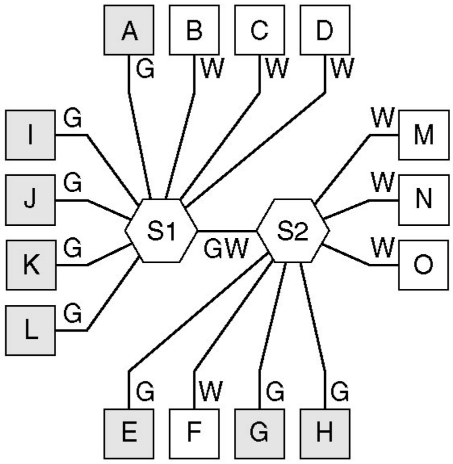
- All devices so far either ignored addresses (repeaters, hubs) or worked on MAC-layer addresses (switches, bridges)
- For interconnection *outside* a single LAN/connection of LAN, these simple addresses are insufficient
  - Main issue: "flat", unstructured addresses do not scale
  - In spanning tree, there is an entry for *every* device's designated output port!
- Need more sophisticated addressing structure and devices that operate on it
- Routers and routing!
  - Treated in the next chapter

Gateways

- If even routers will not do, higher-layer interconnection is necessary: ***Gateways***
  - Work at transport level and upwards
  - E.g., application gateways transforming between HTML and WML/HTTP and WAP
  - E.g., transcoding gateways for media content

Further Topic in LAN/LAN Interconnection: VLAN

- Problem: LANs/switches are geared towards physical proximity of devices
- But: LANs should respect *logical* proximity
  - Connect devices of working groups together, irrespective where they happen to be located
- Idea: put a ***virtual LAN*** on top of an existing physical LAN
- Switches (or bridges) need configuration tables which port belongs to which VLAN
  - Only forward packets to ports of correct VLAN
- Membership of *incoming* packets determined by port, MAC address! VLAN mapping, or IP address ! VLAN mapping
  - Buzzword: IEEE 802.1Q



Conclusions

- Single LANs are insufficient to provide communication for all but the simplest installations
- Interconnection of LANs necessary
  - Interconnect on purely physical layer: Repeater, hub
  - Interconnect on data link layer: Bridges, switches
  - Interconnect on network layer: Router
  - Interconnect on higher layer: Gateway
- Problems
  - E.g., redundant bridges can cause traffic floods; need spanning tree algorithm
  - Simple addresses do not scale; need routers