Local Area Networks (LANs)

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Local Area Networks

- Wide Area Networks (WANs) connect devices together using links or networks over large geographical area
  - Connect campuses, office buildings, networks together, across cities, between cities, across countries and the world
  - A WAN can be a single link (e.g. between campuses) or a network (e.g. using switching and routing techniques)
  - Often owned and operated by organisations on behalf of users
    - Telecommunications operators (CAT, TOT, AIS) and Internet Service Providers (TT&T, Pacific, Loxinfo)
    - Leased (rented) to users such as universities, companies, other ISPs, and individuals
- Local Area Networks (LANs) connect end user devices over a small area such as campus, building, office, home
  - Often owned and operated by the organisation using the network
    - SIIT owns and operates the LAN in Bangkadi and Rangsit campus (but rents a WAN link between campuses)
  - Typically support higher data rates than WANs, because of greater internal communications

An Aside: Networks and Layers

- We have covered link communications
  - Focus on Physical and Data Link Layer
- We have introduced communication networks
  - Circuit Switching: implemented in Physical (and Data Link) layer
  - Virtual Circuit Packet Switching: often in Data Link layer
  - Datagram Packet Switching: often in Network layer
- What about LANs?
  - Typically defined at Physical layer and Data Link layer

LAN Design Elements

Topologies

LAN Design Elements

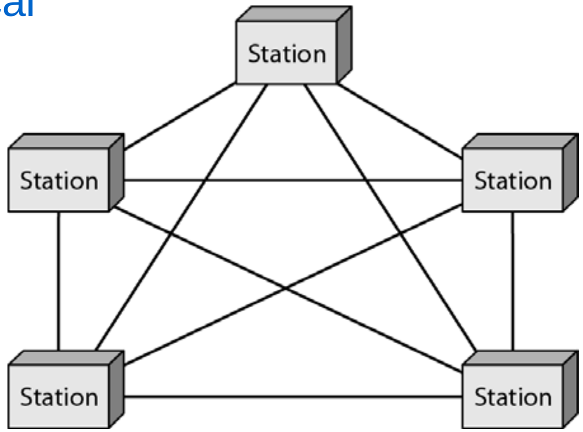
- Important design considerations for LANs include:
  - Topology: what is the arrangement of connections between nodes?
  - Transmission medium: what medium is used for the links?
  - Medium access control: how to control access for stations on a shared medium?

Network Topology

- Link configuration (from “Data Transmission” lecture):
  - Point-to-point: 2 devices share the medium
  - Multipoint: more than 2 devices share the medium
- There are different types of network topologies (in general this applies to any network, not just LANs):
  - Mesh Topology: every station has a point-to-point link to every other station
  - Star Topology: every station has a point-to-point link to a central hub
  - Bus Topology: every station is connected via a multi-point link
  - Ring Topology: every station has a point-to-point link to the 2 nodes either side of it, to create a ring between stations
  - Hybrid Topology: combines two or more of the above topologies
    - E.g. Tree Topology is a star topology, however each link in the star is replaced by a bus network

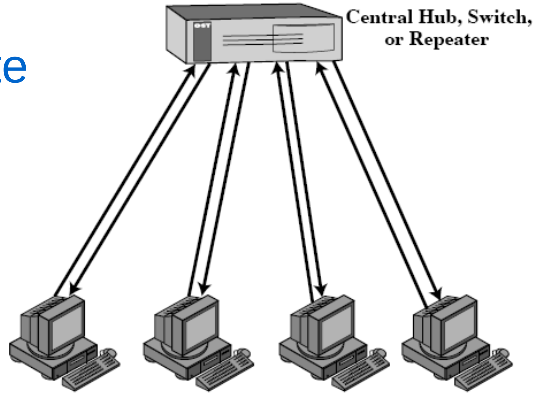
Mesh Topology

- Fully connected mesh has each station connected to every other station
- With *n* stations, if using duplex links, need $n(n-1)/2$ links
- Advantages:
  - Do not have to share link between multiple stations
  - If one link fails, the other stations in network can still communicate
  - Data between any pair of stations is private; not seen by other stations
- Disadvantages:
  - Large number of links and interfaces needed
    - Complex installation, not enough room in physical locations, expensive for network equipment to support large number of connections
- Applications:
  - Not used in LANs (or other networks)
    - Except sometimes when connecting LANs together, e.g. 3 hubs connected together



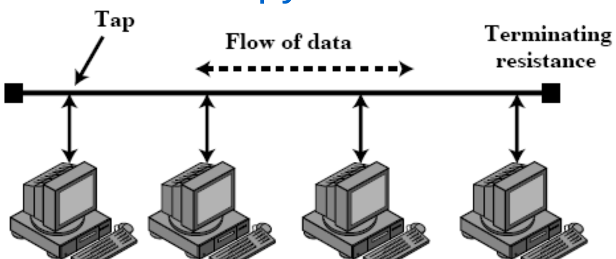
Star Topology

- Each station is directly connected to common central node
  - Traffic between stations goes via the central node
- Usually two point-to-point links between station and central node (one for transmit, one for receive) or duplex link
- Frames needed addresses so hub knows where to send them
- Advantages:
  - Less expensive than mesh, because less links and interfaces needed
  - Easy to install
  - If one link fails, the other stations in network can still communicate
- Disadvantages:
  - If central node fails, no stations can communicate
- Applications:
  - Commonly used in today's LANs



Bus Topology

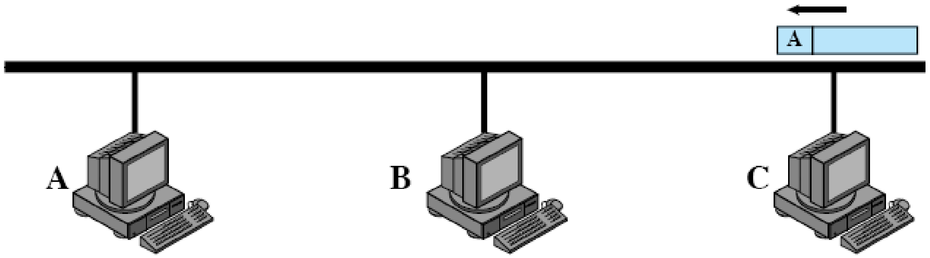
- Bus topology uses a multipoint link configuration
  - A single multipoint link connects all stations; Each station is connected to this link via a *tap*
  - Transmission propagates throughout medium and is heard by all stations
  - Terminator absorbs frames at end of medium/cable
- Frames need addresses so a station knows if it is destined to it
  - If a frame is destined to a station, that station will make a copy of the frame as it passes along the bus



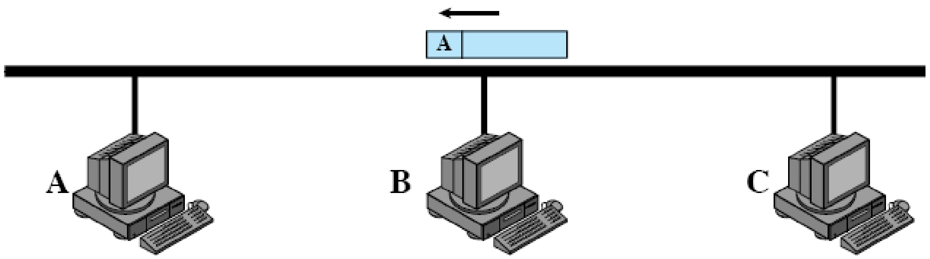
(a) Bus

- Advantages:
  - Easy installation
- Disadvantages:
  - Requires protocols to share access to the medium (only 1 station transmit at a time)
  - A fault in link stops all transmissions
  - Limited number of stations and distance of link due to energy loss at taps
- Applications:
  - Used in early Ethernet networks, but mainly replaced by star topology

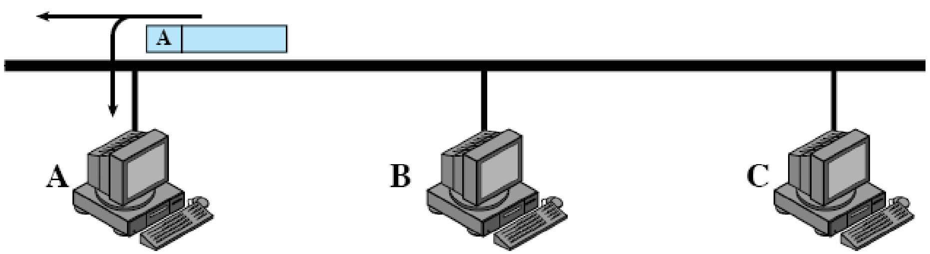
Frame Transmission on Bus Topology



C transmits frame addressed to A



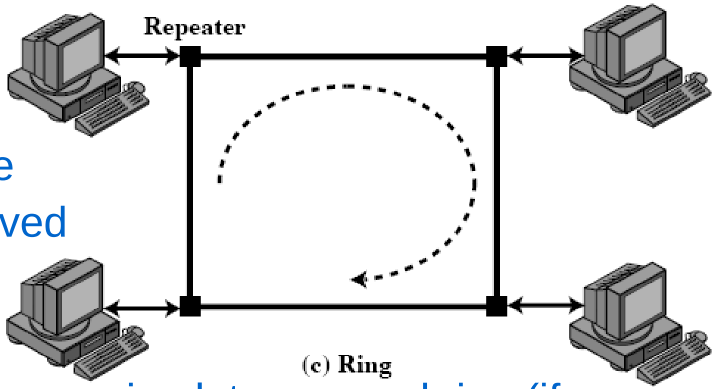
Frame is not addressed to B; B ignores it



A copies frame as it goes by

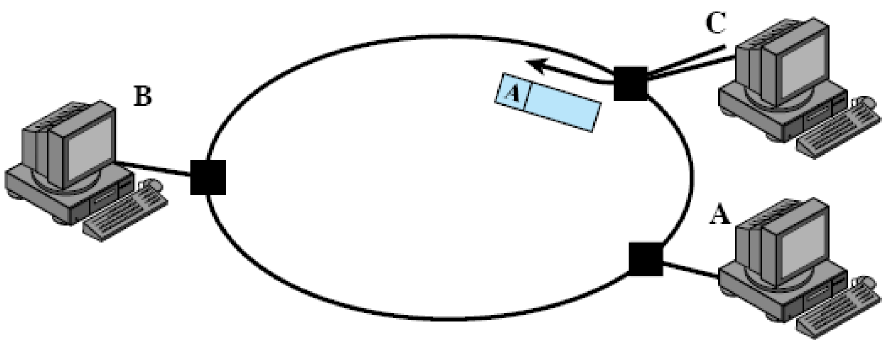
Ring Topology

- Point-to-point links between stations to form a loop
  - Receive data on one link and retransmit on another
  - Links are unidirectional
  - Stations attach to repeaters
- Frames circulate past all stations
  - Destination recognizes address and copies frame
  - Frame circulates back to source where it is removed
- Advantages:
  - Simple to install and reconfigure
  - Easy to identify faults, since generally a signal always circulates around ring (if doesn't arrive at a station, fault is detected)
- Disadvantages:
  - Requires protocols to share access to the medium
  - Traffic flows in one direction – performance can be a problem
- Applications:
  - Used in old LANs: IBM's Token Ring networks; replaced mainly by star
  - Used in Metropolitan Area Networks and WANs

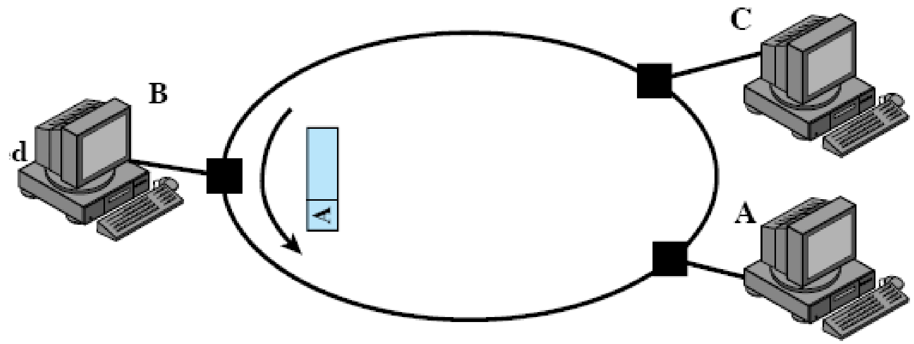


Frame Transmission on Ring Topology

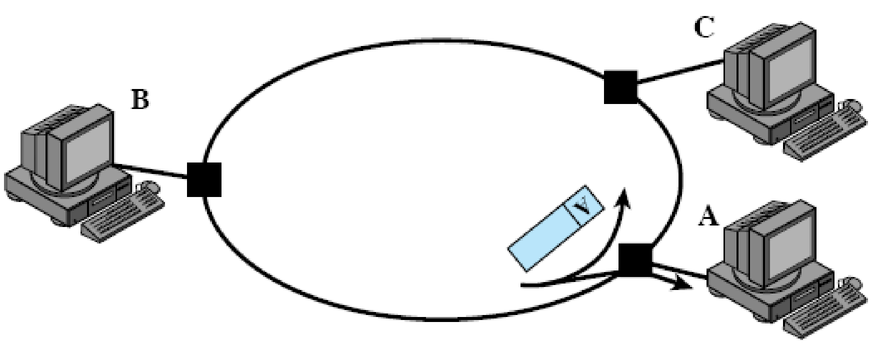
1. C transmits frame addressed to A



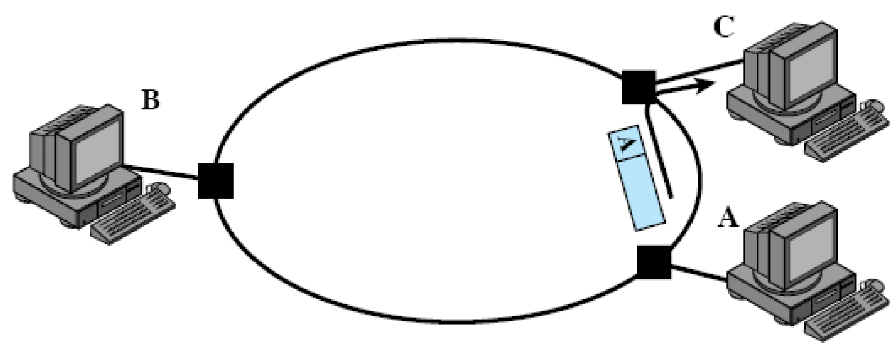
2. Frame is not addressed to B; B ignores it



3. A copies frame as it goes by



4. C absorbs returning frame



Comparing Installation of Topologies

- Consider a LAN at SIIT that needs to connect all the ICT faculty, staff and graduate students on the one network
  - Assume 40 stations across two floors of ICT Building
- Mesh Topology
  - Each station must have 39 interfaces (e.g. LAN cards) and 780 cables are required
- Star Topology
  - Each station has a single interface; 40 cables connect a 40-interface central node (hub)
- Bus Topology
  - Each station has a single interface (connected to tap); a single cables passes by each of the 40 stations
- Ring Topology
  - Each station has two interfaces, with 40 cables connecting the stations in a ring

Other Design Elements for LANs

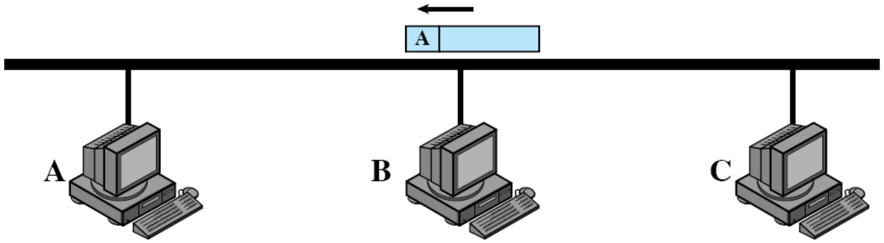
- Transmission Media
  - Many factors impact on the most appropriate transmission medium for a LAN: reliability, expandability, performance, building layout, medium availability
  - Some common cases (although not always the case):
    - Coaxial cable often used for bus topology
    - Optical fibre for ring topology; usually the highest speed networks
    - Twisted pair for star topologies; often well-suited for LANs in buildings (cheap, easy to install)
- Medium Access Control
  - Except for Mesh (and special cases of Star), the medium is shared between stations
    - This is also true in wireless networks, e.g. wireless LAN (WiFi) and Bluetooth
  - Therefore, transmissions of nodes must be coordinated, otherwise one transmission may interfere with the other
  - Called *Medium Access Control* (MAC)

LAN Design Elements

Medium Access Control

Medium Access Control

- In a shared medium, if two (or more) stations transmit at the same time, there is a chance the two transmissions will interfere with each other



  - Frame transmitted from C to A is passing B
  - If B transmits a frame (e.g. to A) at the same time, the signals of the two frames may interfere
    - Terminology: the two frames collide with each other; a *collision* occurs
  - A will not successfully receive *either* frame – this is BAD (e.g. retransmissions will be needed)
- Medium Access Control techniques are designed to allow one station to use the shared medium at a time
  - Thereby avoiding collisions between frames
  - MAC techniques tell stations when they are allowed to transmit

MAC: Where is the Control Point?

- Centralised: a single node in the network (usually a special node) controls who transmits and how
  - Advantages:
    - Each station (except central node) is simple
    - Avoids problems of distributing information between stations
    - Greater control over providing priority (e.g. A gets 2 times more opportunities to transmit than B)
  - Disadvantages:
    - Single point of failure; if central node fails, MAC won't work
    - Central node may become a bottleneck, reduce performance
- Distributed: all stations collectively make decisions on who transmits and how
  - Advantages:
    - If one station fails, then the others can continue communicating
    - There is no central point that may become a bottleneck
  - Disadvantages:
    - Each station needs relatively complex protocol implementation
    - Stations may have to share information with each other, creating extra overheads
    - Difficult to give priority or guarantees in network

MAC: How to Perform Control?

- Synchronous (fixed)
  - Each station is given a fixed set of opportunities as to when they can transmit
    - If the opportunities are not used, they are wasted (inefficient)
  - Similar in concept to FDM and Synchronous TDM
  - Not very good for LANs because requires accurate prediction of how much traffic a station needs to send (this is very difficult)
- Asynchronous (dynamic)
  - Each station is given opportunities to transmit on demand (when they need)
  - Similar in concept to Statistical TDM
  - Typically used in LANs, because hard to predict how much traffic needs to be sent
  - Techniques can be subdivided into: Round Robin; Reservation; Contention

Round Robin MAC

- Each station in turn is given the opportunity to transmit
  - E.g. Station 1 has an opportunity to transmit, then station 2 has an opportunity and then station 3 and so on
  - If a station accepts the opportunity, it can transmit up to a maximum amount of time (or maximum amount of data)
  - The station may reject the opportunity (e.g. if it has no data to transmit); then the next station is given the opportunity
- Efficient when:
  - Many stations have data to transmit over a long period of time
    - Inefficient if only some stations have data to transmit, because waste time switching between stations
- Example – Token Based Distributed Round Robin MAC:
  - A station can only transmit if it has the special token
  - The token is sent to the next station after transmitting a DATA frame
  - If a station has the token, but no DATA to send, then the token is passed to next station
- Applications: Token Ring LANs (not used much today)

Reservation-based MAC

- Time is divided into slots, and stations reserve future slots for an extended or even indefinite period
  - E.g. If we have ten slots per second, then a station may reserve the second slot for the next 5 seconds
    - Note that it is different than Synchronous (fixed) MAC in that the slots are reserved over a relatively short period of time (milliseconds, seconds). With Synchronous (fixed) MAC, the slots are typically pre-assigned for periods of minutes, hours and longer
  - Reservations may be centralised or distributed
  - Suitable for stream traffic since data needs to be transmitted at regular, known intervals
    - Voice/video calls, audio/video streaming
- Example: Centralised Reservation MAC
  - A station sends special reservation requests to a central node; reserves time slots over next period (msec to sec); the central node confirms this to all nodes
- Applications: not used very often because of complexity, except in some of the latest wireless LAN standards

Contention-based MAC

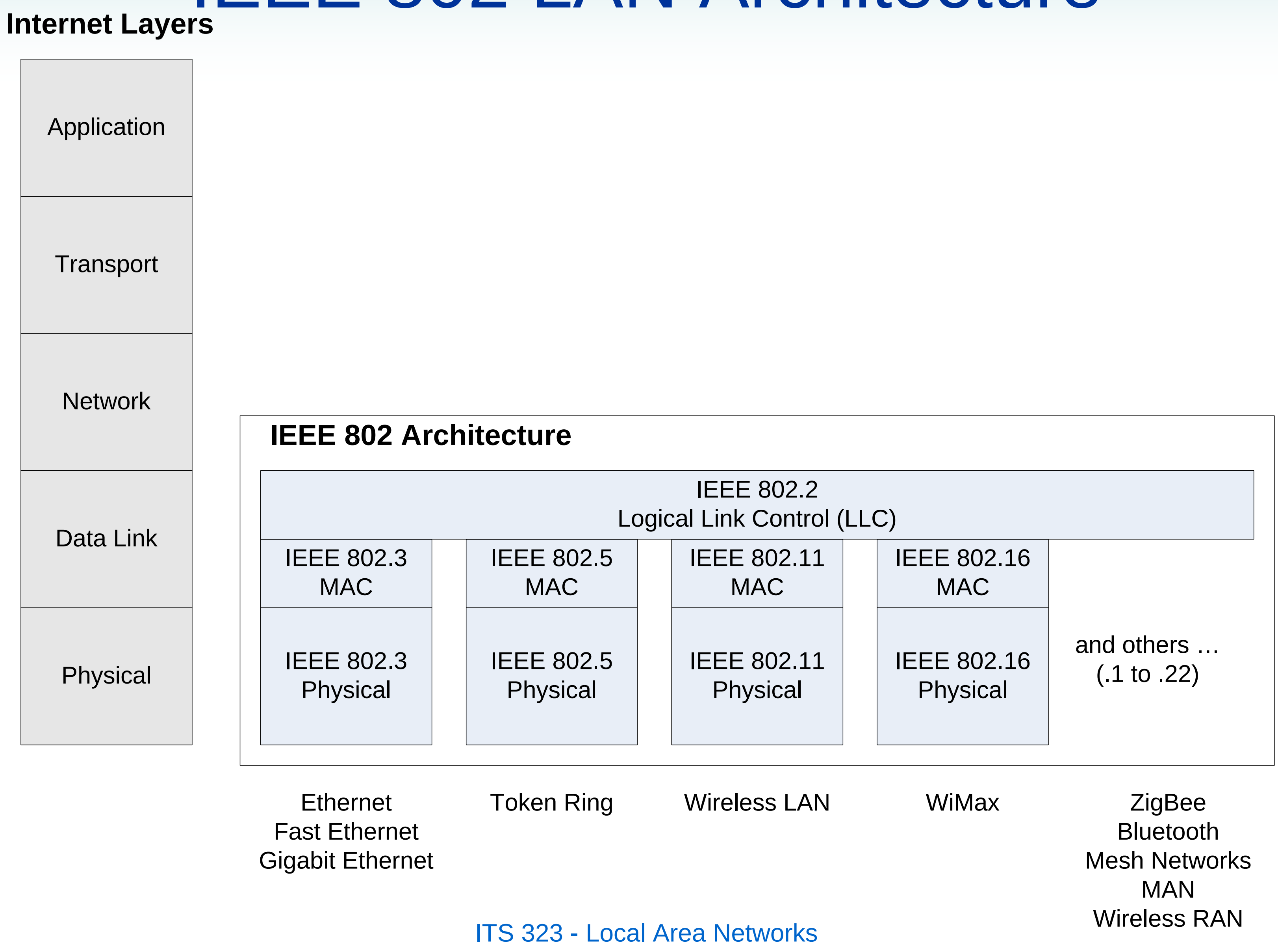
- No control over stations; each station contends (or “fights”) for its chance to transmit
  - Example: Random Access MAC
    1. If a station has data to send, and no-one else is transmitting, then the station transmits;
    2. If someone else is transmitting, then wait for them to finish, and then wait a random period (within some limit), then revert to step 1
  - Works well for bursty traffic (data arrives at unknown intervals, and sometimes in bursts)
    - Simple to implement
    - Distributed – each station follows its own rules
    - Efficient for light to moderate amounts of traffic
- Applications: used extensively on older bus and star based LANs (original Ethernet, hubs) and in wireless LANs (WiFi, IEEE 802.11)

IEEE 802 LANs

IEEE 802 LAN Architecture

- IEEE 802 LAN/MAN standards committee has developed the majority of the LAN standards in use including:
  - Ethernet, Fast Ethernet, Gigabit Ethernet, Token Ring, …
- The 802 series of standards follow a common architecture
  - Standardised only at Physical layer and Data Link layer
    - Data Link layer is broken into two sub-layers: Medium Access Control (MAC) and Logical Link Control (LLC)
  - Assumes any upper layers (e.g. any Network layer, including IP)
  - Data Link layer must support multiple nodes accessing the link
  - 802 can support many MAC/Physical protocols, and uses one common LLC protocol
    - E.g. 802.2 defines the LLC; 802.3 defines MAC and Physical protocols for Ethernet; 802.11 defines the MAC and Physical protocols for wireless LAN

IEEE 802 LAN Architecture



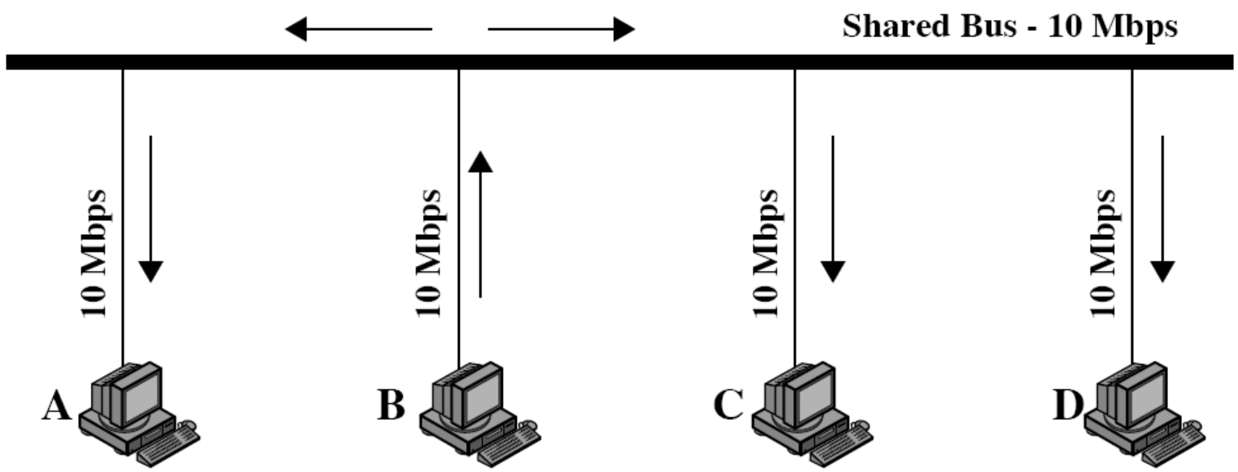
IEEE 802.3: Ethernet

- IEEE 802.3 defines one of the most commonly used LAN standards in the world
  - Ethernet was developed in 1970's and standardised as IEEE 802.3
  - IEEE 802.3 has had various improvements since then, often referred to as:
    - Fast Ethernet, Gigabit Ethernet, 10Gbs Ethernet and future systems
  - Each variant also supported multiple different physical transmission media (unshielded twisted pair, shielded twisted pair, coaxial cable, optical fibre, …)
- The original popular Ethernet was:
  - Bus topology
  - Coaxial cable for transmission
  - 10Mb/s
  - Contention-based MAC
  - Half-duplex transmission

Ethernet Contention-based MAC

- Carrier Sense Multiple Access (CSMA) with Collision Detection (CD)
  - Each station operates independently of other stations
  - A station:
    - "Senses" the bus medium: it listens if another station is transmitting (medium busy) or not (medium idle)
      - Station listens for random period (within some limit)
    - If Idle (no-one else transmitting), transmit a frame and wait for an ACK
    - If Busy (some-one else transmitting), wait until they finish and then revert to step 1
  - The intended result is only one station transmits on the bus at a time
    - Avoid collisions of frames
- CSMA/CD performance:
  - With CSMA/CD the utilisation is less than 80% for more than 5 nodes; hence throughput of 10Mb/s Ethernet is typically between 5 and 8Mb/s
  - This is shared between stations: with 10 stations, each station gets 800kb/s

Ethernet (Bus) Performance



Ethernet in Bus Topology: only one station can transmit at a time (because a transmission goes everywhere on the bus) therefore stations must share the LAN capacity. Each station gets 2.5Mb/s

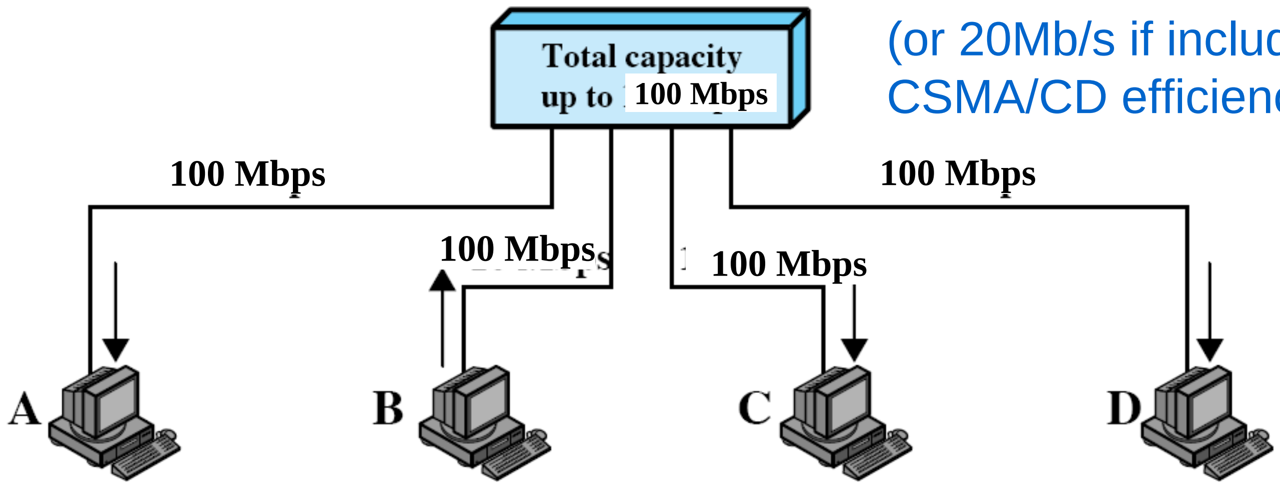
However, using CSMA/CD the efficiency is approximately 50-80%

Example: 80% efficiency gives LAN throughput of 8Mb/s, which is shared between 4 stations. Therefore each station has 2Mb/s.

Fast Ethernet

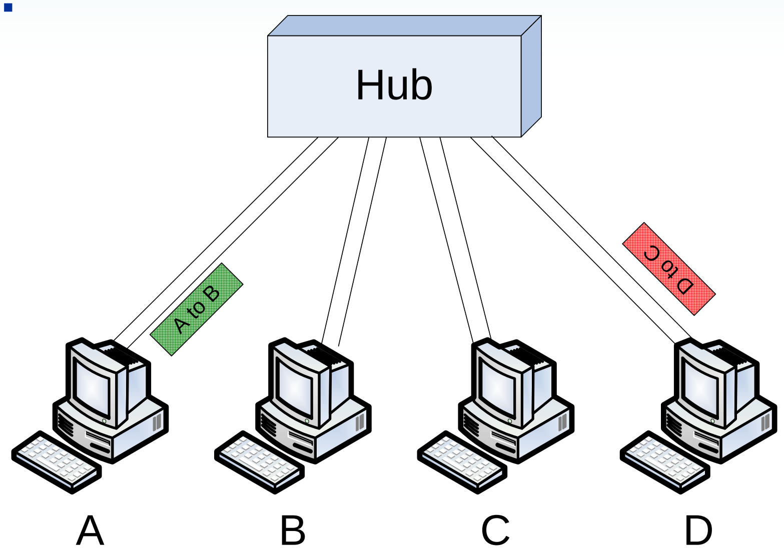
- The 10Mb/s Ethernet was improved for a faster data rate, different topologies and different transmission media. The most popular:
  - Star topology
  - Unshielded Twisted Pair
  - 100Mb/s
  - CSMA/CD MAC
  - Half-duplex or full duplex transmission
- The hub receives a frame and sends a copy to all other output links
- Still have a shared medium

Each station still has 25Mb/s (or 20Mb/s if include best case CSMA/CD efficiency)

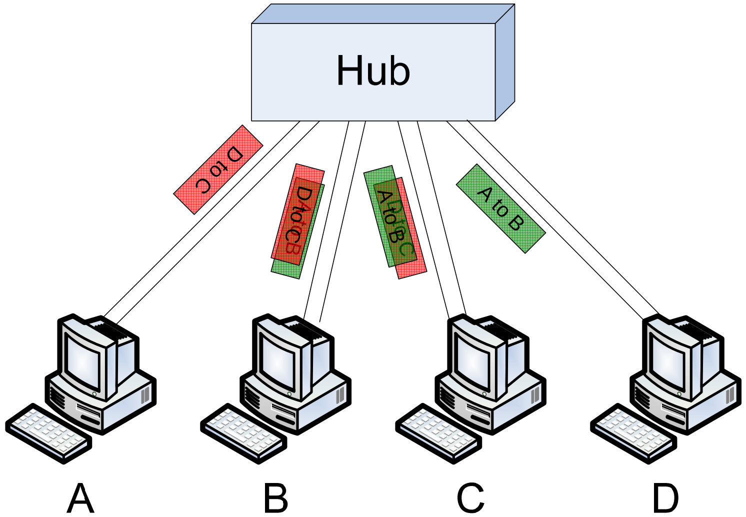


Why do we need CSMA/CD when using a Hub?

- Consider a case if we did not use CSMA/CD, and two stations transmit at the same time …
  - A transmits frame to B and C transmits frame to D



- Since a frame is sent to every other output link (independent of the destination), there will be collisions
  - On link to B and on link to C



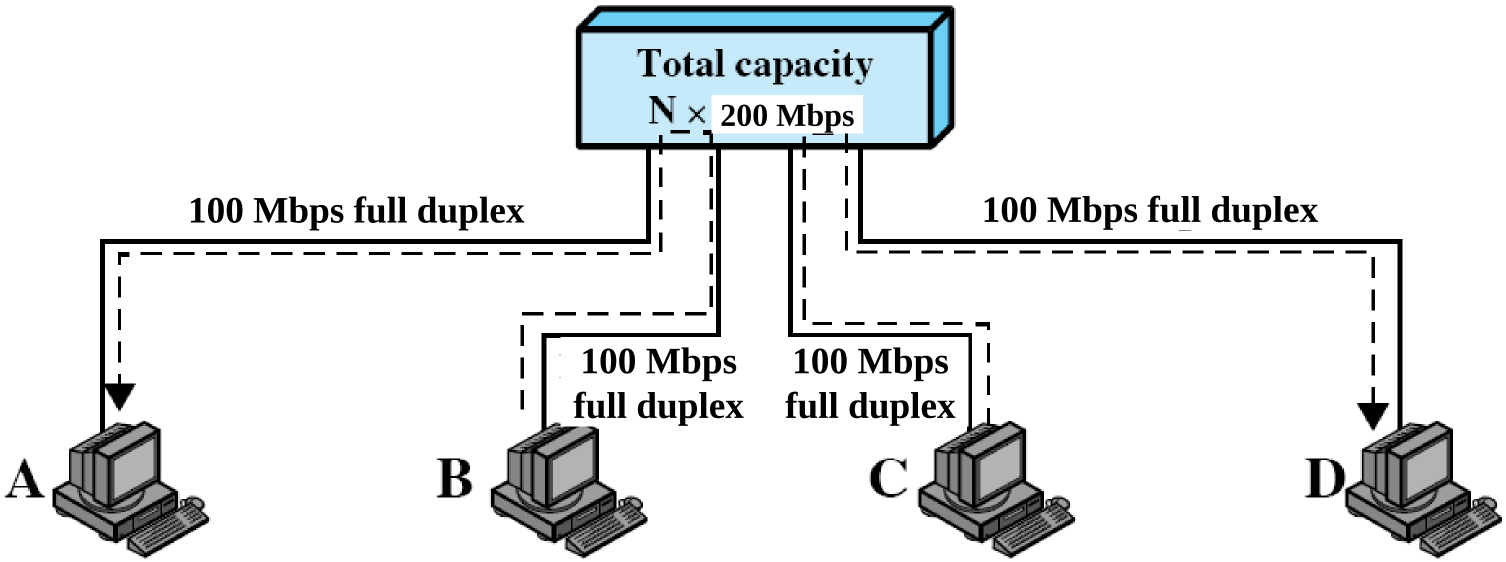
- Hence use CSMA/CD when using Hub, so only one node transmits at a time

Switched Fast Ethernet

- A further improvement in performance is achieved by using a “switch” instead of a “hub”
  - Hub: receives a frame on an input link, and transmits a copy of that frame on all other output links
  - Switch: receives a frame on an input link, looks at the destination address, and transmits the frame on the intended output link
    - More complex than a hub: requires the switch to associate output links with addresses, and also process the frame. Therefore originally cost more than a hub
    - Today, the cost of a switch is about the same as a hub (both relatively cheap), so almost all LANs use Switched Fast Ethernet
- Using a switch means multiple stations can transmit at same time, without collisions
  - If using full duplex, no need for CSMA/CD – efficiency is above 90% (main overheads due to headers)
  - No longer a shared medium
  - However, some method is needed for a switch to associate output links with destination addresses

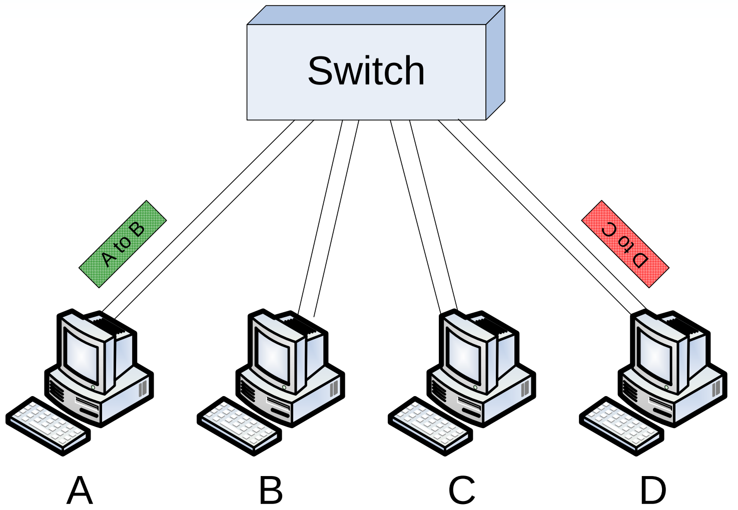
Switched Fast Ethernet

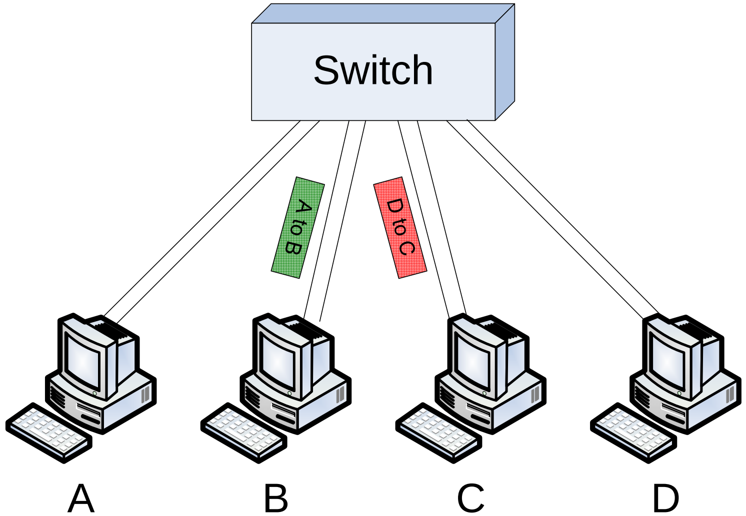
- Station B can transmit to A, while at the same time, C transmits to D
  - Assumes the speed of switch is fast enough to process all frames
  - Assumes the switch knows the address of the station attached to each link



Why is CSMA/CD NOT needed with a Switch?

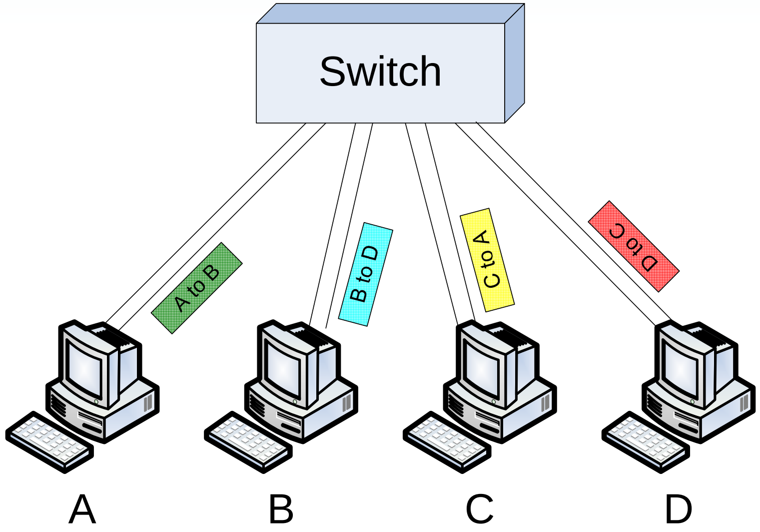
- Since the switch only sends frames to the output link that the destination is attached to, no collisions if two nodes transmit at same time

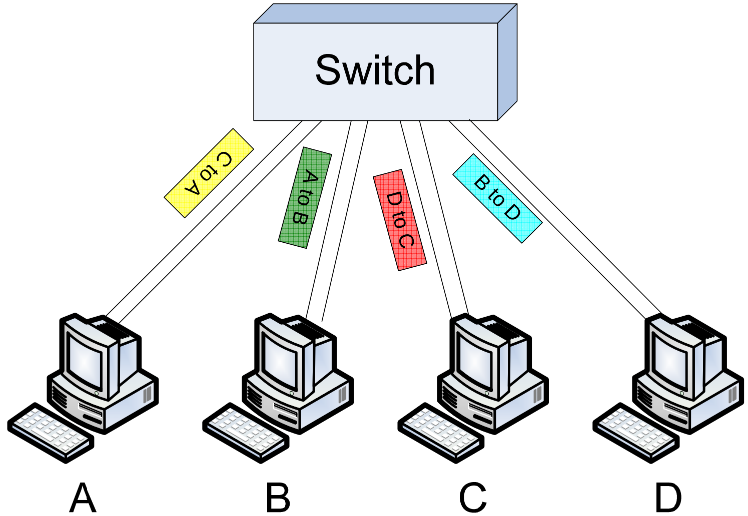




Performance of Switched LANs

- What is the maximum network throughput we can achieve?
  - Each station transmitting at 100Mb/s
  - Total of 400Mb/s for network



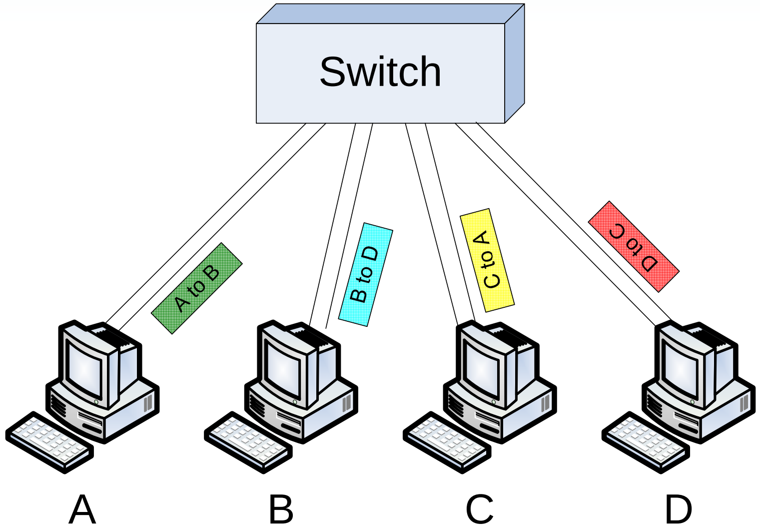


  - And then each station receives at 100Mb/s
  - Total of 400Mb/s for network

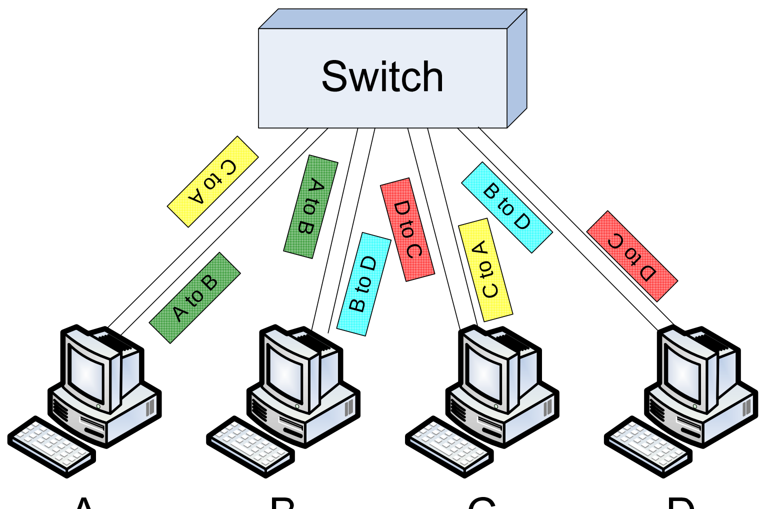
- A station can send *or* receive at 100Mb/s

Performance of Switched LANs

- But we can do better!
  - Since using full duplex, a station can be sending at the same time as receiving
  - In example, stations are sending packets

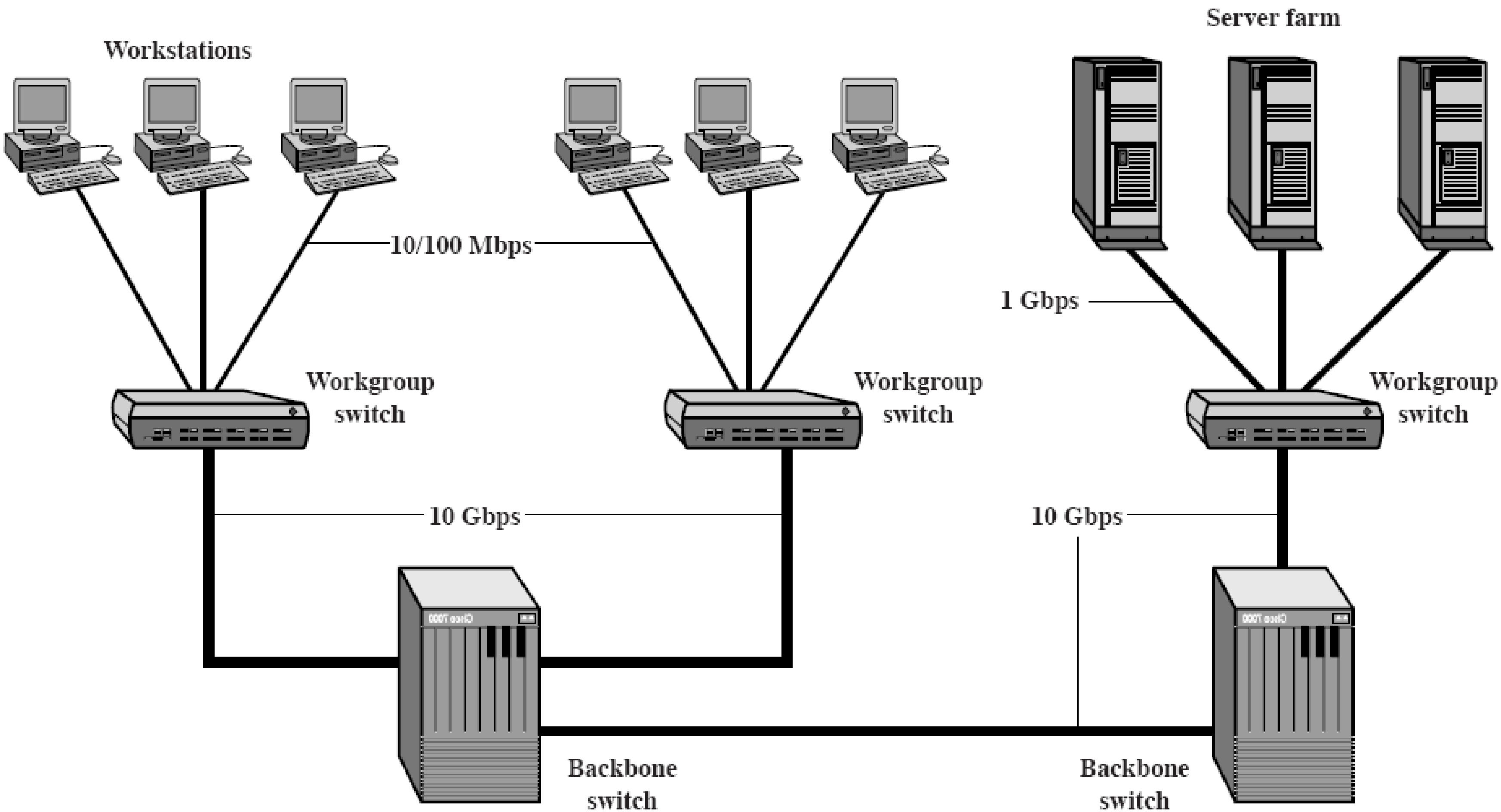


  - Then while receiving that packet, the stations are also sending the next packet



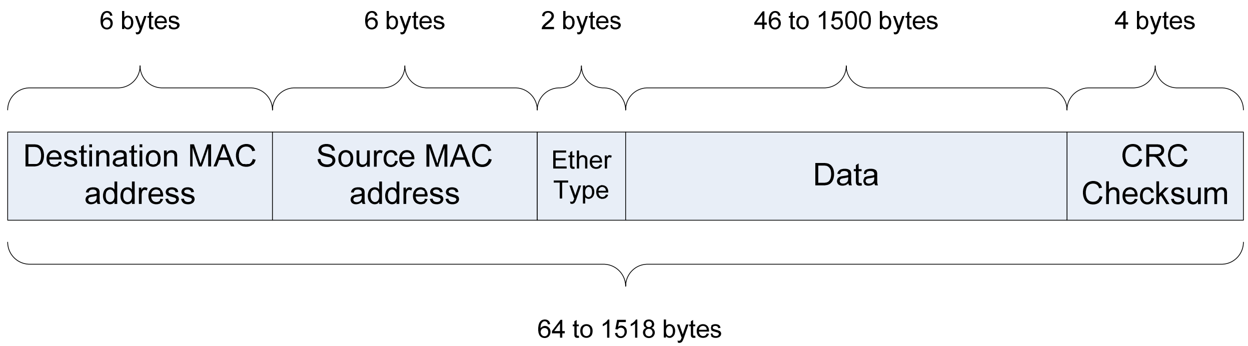
- Each station can send *and* receive at 100Mb/s
  - Effective capacity is 200Mb/s per station

Example LAN Configuration



IEEE 802.3 Specifications

- The IEEE 802.3 standards specify details of different physical layer and MAC layer protocols for LANs
- MAC layer
  - Frame Format is common across all standards; allows compatibility between standards
    - Switch can easily support stations connected using different Physical layers



    - EtherType: indicates type of packet in Data, e.g. IP datagram: Type 8.
    - Maximum frame size is 1518 bytes (1500 bytes of data)
  - CSMA/CD is MAC protocol used
    - However, not needed with switched networks

IEEE 802.3 Specifications

Common name	**Ethernet**	**Ethernet**	**Fast Ethernet**	**Gigabit Ethernet**	**Gigabit Ethernet**	**10Gb Ethernet**
Physical layer	10Base2	10BaseT	100BaseTX	1000BaseT	1000BaseSX	10GBase…
Topology	Bus	Hub	Switched	Switched	Switched	Switched
Media	Coaxial	UTP	UTP	UTP	Optical	Optical/UTP
Signalling	Manchester	Manchester	MLT-3	8B/10B, NRZ	8B/10B, NRZ	…
Data Rate	10Mb/s	10Mb/s	100Mb/s	1Gb/s	1Gb/s	10Gb/s
Max. length	185m	100m	100m	100m	500m	Up to 80km
Status	No longer used	Seldom used, but supported	Common	Supported in most devices	Between buildings, in data centres	Interconnects, WANs

IEEE 802 Addressing

- IEEE 802.3 and all other IEEE 802 standards use the common IEEE 48-bit address format
  - Globally unique: each device has a different address
    - IEEE assigns first 24 bits to companies that manufacture cards (e.g. Intel, 3Com, Dell)
    - Each company assigns last 24 bits to each device they manufacture
  - In practice, they are not globally unique, because individual users can "program" their LAN cards to use any address (this technique has been used in simple security attacks)
  - Usually represented as 6 by 2 digit hexadecimal numbers
- IEEE 48-bit addresses are very common in other standards:
  - Bluetooth, ATM, FDDI, Fibre Channel, …
  - Often referred to in general terms, such as:
    - MAC address, Hardware address, Network Interface Card (NIC) address, Ethernet address
- IEEE 64-bit addresses is a new format used in some systems
  - Firewire, ZigBee/IEEE 802.15.4 and IPv6

IEEE 802 Addressing Example

```
C:\Documents and Settings\Steve>ipconfig /all

Windows IP Configuration

        Host Name . . . . . . . . . . . . : win06v6
        Primary Dns Suffix  . . . . . . . :
        Node Type . . . . . . . . . . . . : Unknown
        IP Routing Enabled. . . . . . . . : No
        WINS Proxy Enabled. . . . . . . . : No

Ethernet adapter Local Area Connection:

        Connection-specific DNS Suffix  . :
        Description . . . . . . . . . . . : Realtek RTL8168/8111 PCI-E Gigabit Ethernet NIC
        Physical Address. . . . . . . . . : 00-17-31-7E-50-7D
        Dhcp Enabled. . . . . . . . . . . : Yes
        Autoconfiguration Enabled . . . . : Yes
        IP Address. . . . . . . . . . . . : 192.168.1.33
        Subnet Mask . . . . . . . . . . . : 255.255.255.0
        Default Gateway . . . . . . . . . : 192.168.1.1
        DHCP Server . . . . . . . . . . . : 192.168.1.1
        DNS Servers . . . . . . . . . . . : 203.121.130.39
                                            203.121.130.40
        Lease Obtained. . . . . . . . . . : Sunday, August 17, 2008 10:03:46 AM
        Lease Expires . . . . . . . . . . : Wednesday, August 20, 2008 10:03:46 AM
```

IEEE 802 MAC address

IEEE 802 Addressing Example

- According to the IEEE public listing of IEEE address allocations available at:

  http://standards.ieee.org/regauth/oui/index.shtml

- The device (LAN adapter) with MAC address 00-17-31-7E-50-7D is manufactured by:

  ASUSTek COMPUTER INC.

  No.5 Shing Yeh Street,Kwei Shan Hsiang,Taoyuan

  Taipei 333

  TAIWAN, REPUBLIC OF CHINA

- (I have an ASUS motherboard, with on-board LAN adapter)
- In binary, the address is:

  00000000 00010111 00110001 01111110 01010000 01111101

- (However, the transmission order is different for some LAN standards)

Summary – LANs

- Local Area Networks are most often used to connect end-users computing devices
  - Owned and operated by the owner/operator of the end-user devices
  - Typically support higher data rates than WANs because of traffic is internal to LAN (only some goes out to the WAN)
    - E.g. SIIT Bangkadi 100Mb/s Fast Ethernet LAN and 54Mb/s Wireless LAN; WAN connections to Rangsit and ISP are about 2 Mb/s
- Topologies include bus, star and ring
- Medium Access Control is used to ensure only one station transmits at a time (avoids collisions of frames)
- Today, the main standard for LANs is based on IEEE 802.3
  - Fast Ethernet (100Mb/s), Gigabit Ethernet (1Gb/s) and beyond
  - Star topology, using switches and full duplex links is most common
    - Effective maximum data rate for each station is 200Mb/s
- Other standards include Wireless LAN (IEEE 802.11) and several non-IEEE fibre LANs
- IEEE 802 MAC addresses are a widely used Data Link layer addressing scheme