AOT LAB

Agent and **O**bject **T**echnology **Lab**
Dipartimento di Ingegneria dell'Informazione
Università degli Studi di Parma

Computer Network

Embedded Network

Prof. Agostino Poggi

Protocol Stacks for Embedded Systems

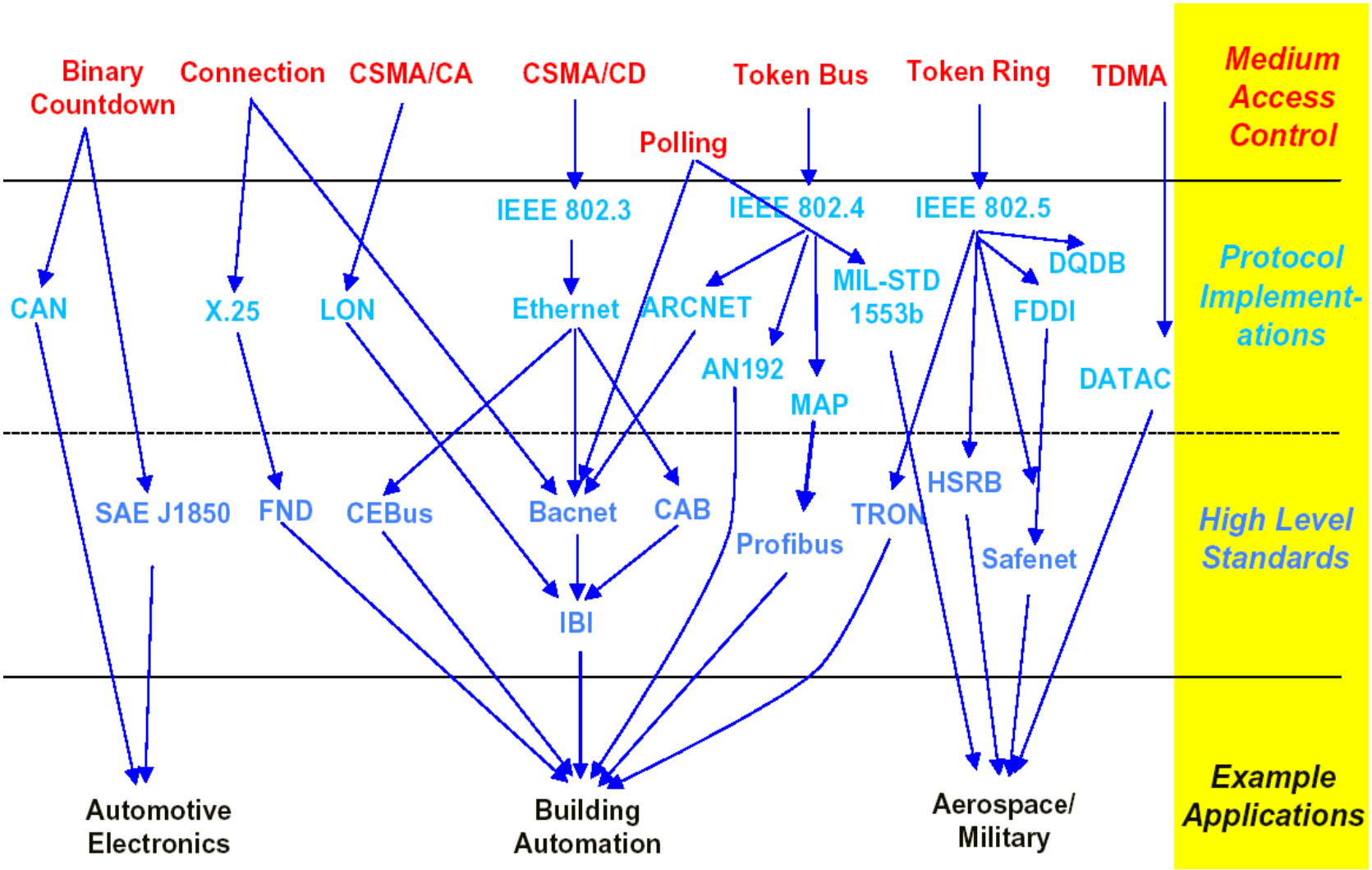
- Heart of a each protocol stack is its MAC mechanism
  - Determinism
  - Efficiency
  - Priority
  - Optimization
  - Complexity
  - Cost
- Two directions
  - Adapt general protocols for embedded systems
  - Build specialized protocols

Message Priority

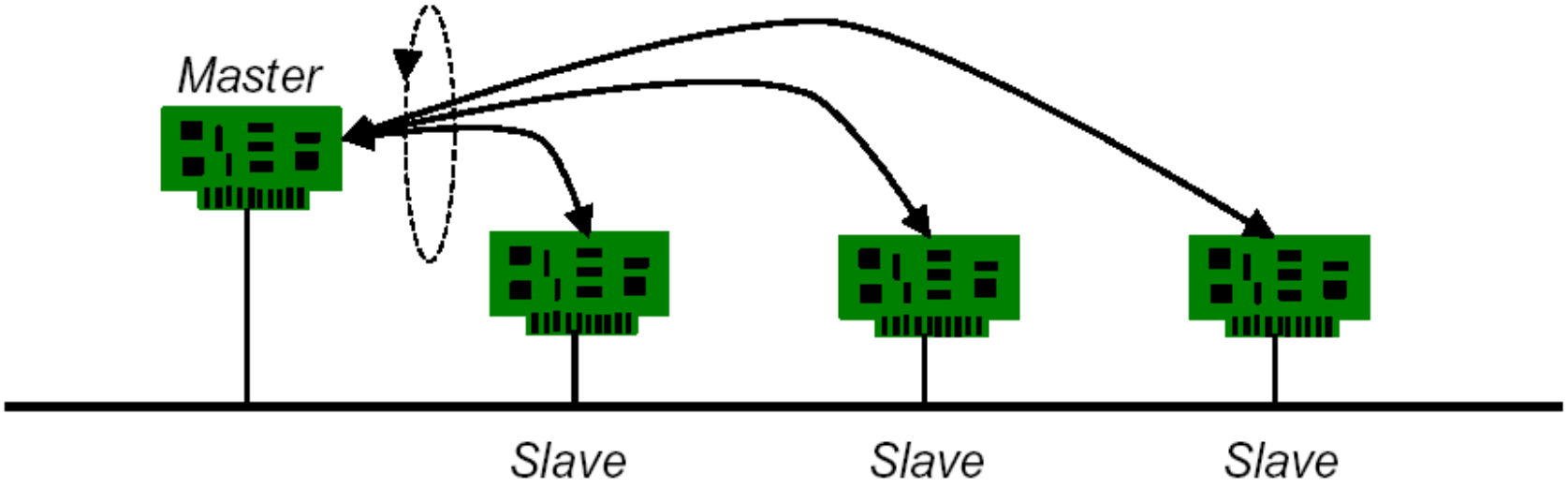
- Local priority
  - Each node can transmit its highest priority message when it gets a turn on the bus
  - Or, it can implement some form of round-robin message transmission, ...
- Global priority
  - Which node gets the next turn on the bus?
  - Could be a function of round-robin selection of nodes?
  - Could be a function of the node's inherent priority?
  - Could be a function of the priority of the highest message on the node – a "global message priority" scheme?
- Fundamental tension
  - Reducing latency for high-priority nodes/messages
  - Or, ensuring fairness/no starvation for low-priority nodes/messages

AOT LAB

Embedded Protocol Family Tree



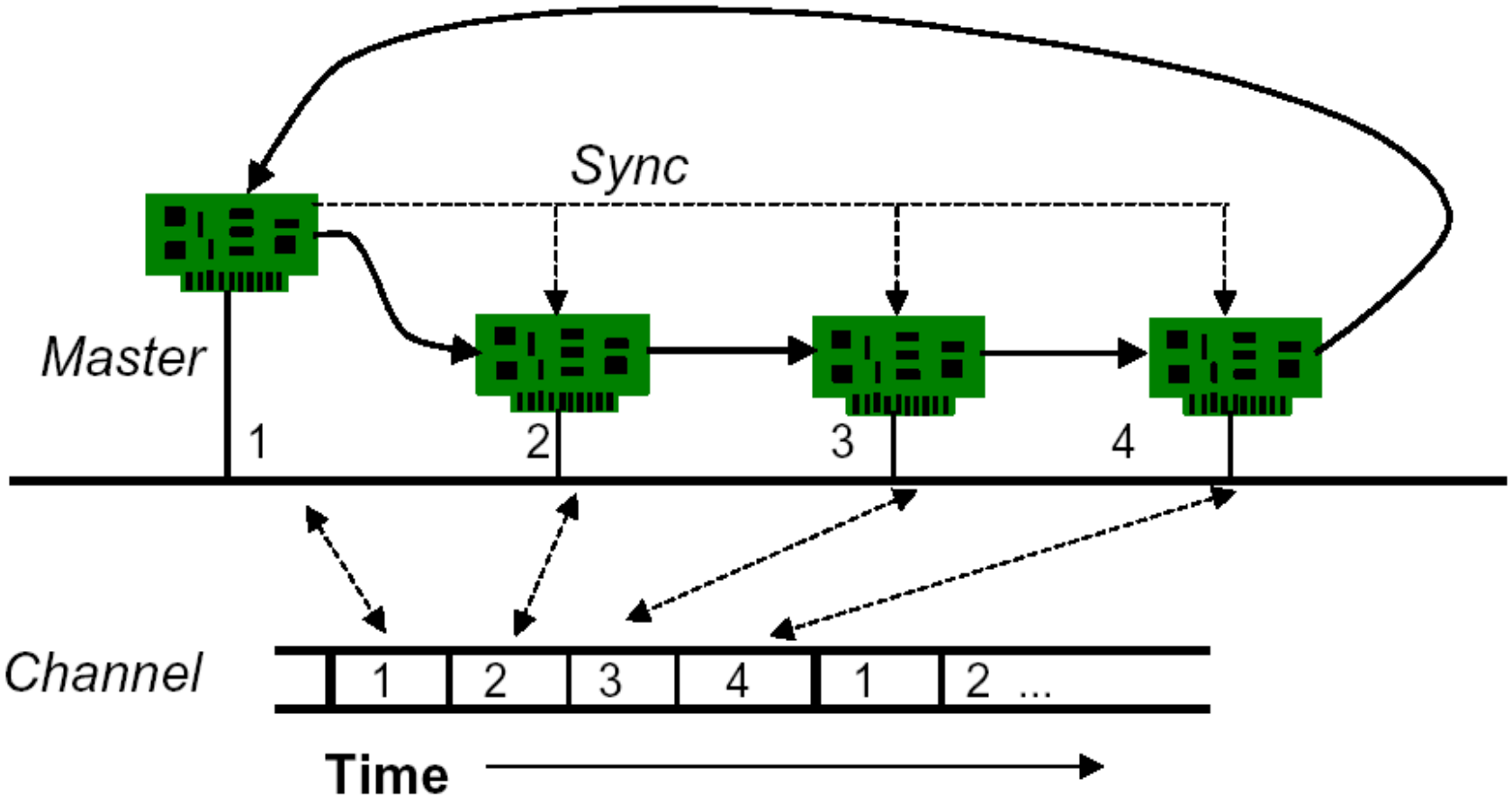
Polling



Polling

- Advantages
  - Simple protocol to implement
  - Historically very popular
  - Bounded latency for real-time applications
- Disadvantages
  - Single point of failure from centralized master
  - Polling consumes bandwidth
  - Network size fixed during installation (not robust)
    - Or, master must discover nodes during reconfiguration
  - Prioritization is local to each node
    - But can use centralized load balancing
    - Polling need not be in strict order; it could be, for example: 1, 2, 1, 3, 4, 1, 5, 1, 3, 1, 6, … (repeats)

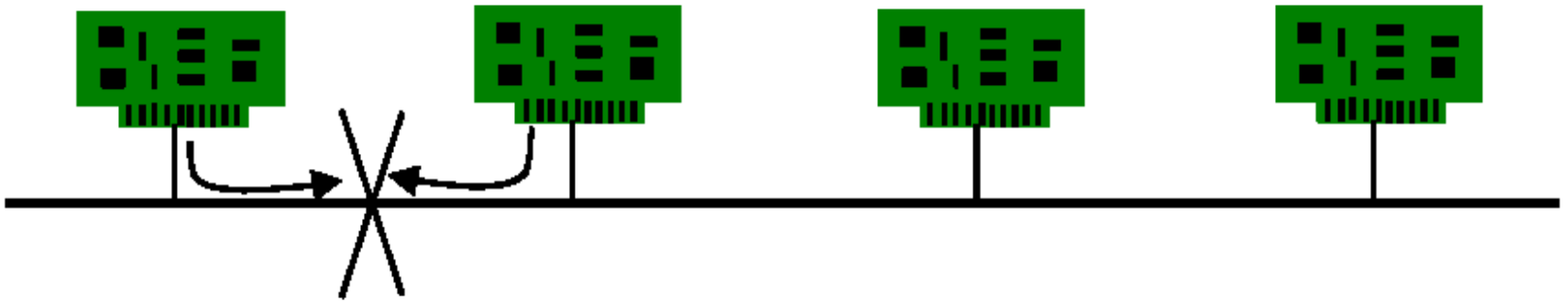
TDMA



TDMA

- Advantages
  - Simple protocol to implement
  - Deterministic response time
  - No wasted time for master polling messages
- Disadvantages
  - Single point of failure from the bus master
  - Wasted bandwidth when some nodes are idle
  - Requires stable clocks
  - Network size fixed during installation (not robust)
  - Prioritization is local to each node
    - Can use centralized load balancing
- Variation: Variable Length TDMA (~Implicit Token)
  - Unused time slices are truncated to save time
  - More efficient use of bandwidth

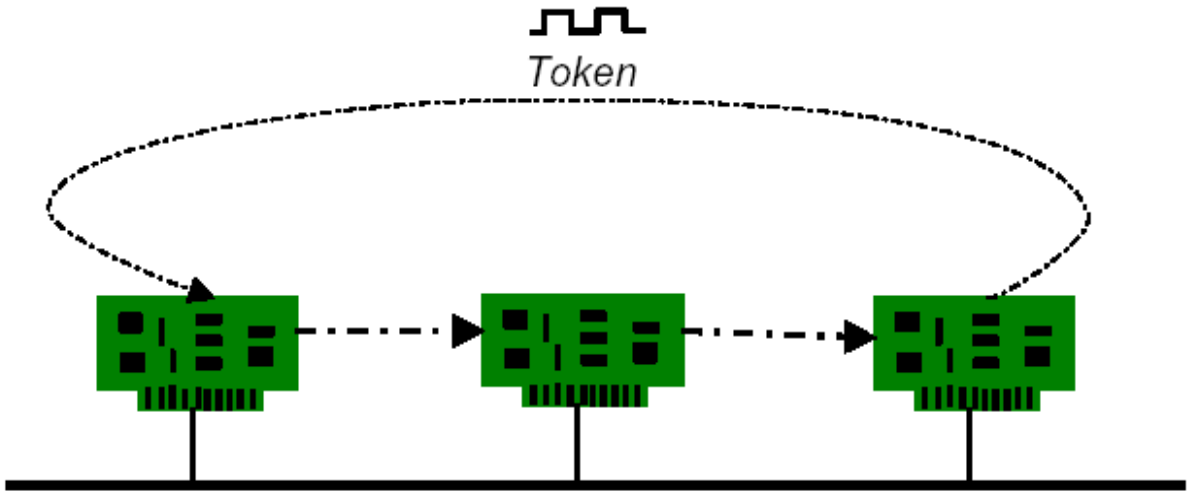
CSMA/CD



CSMA/CD

- Advantages
  - Small latency for low traffic load
  - Network initialization/configuration is not required
  - Node can enter or leave the network without any interruption
  - Supports many nodes
  - Probabilistic global prioritization is possible
  - Extensive installed base and support
- Disadvantages
  - Designed for aperiodic traffic - not ideal for synchronized control loops
  - Collision detection is an analog process which is not always practical
  - Unbounded individual message latency
  - Poor efficiency under heavy loads

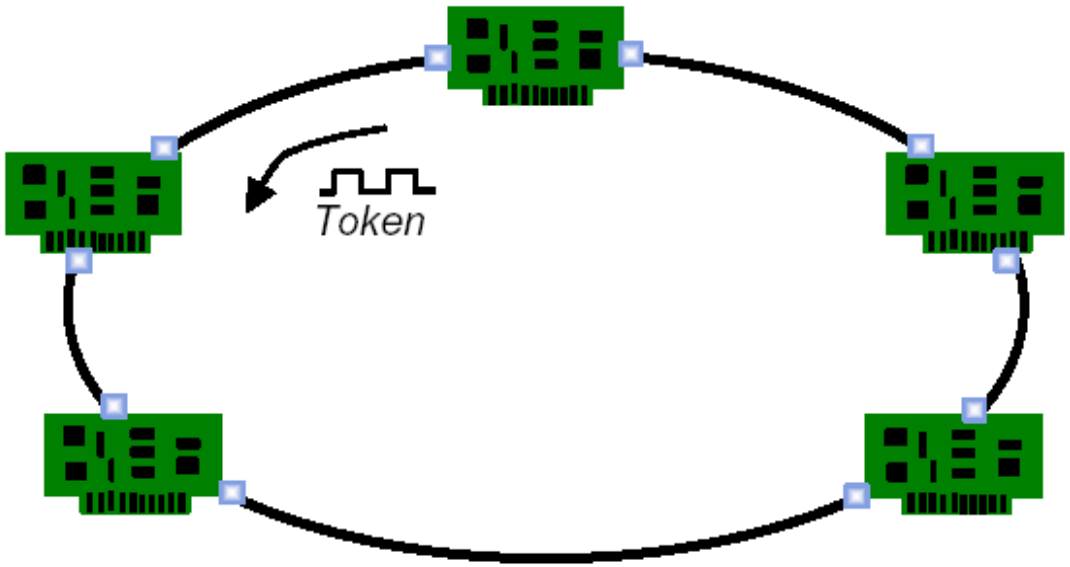
Token Bus



Token Bus

- Advantages
  - Bounded latency for real-time control applications
  - High throughput during heavy traffic
  - On-the-fly reconfiguration
- Disadvantages
  - Token passing latencies under light traffic conditions
  - Prioritization local to each node
  - Lengthy reconfiguration process
  - Token initialization, loss, and duplication recovery overhead
  - Collisions may occur during initialization and reconfiguration
  - Complex protocol (especially at MAC sub-layer)

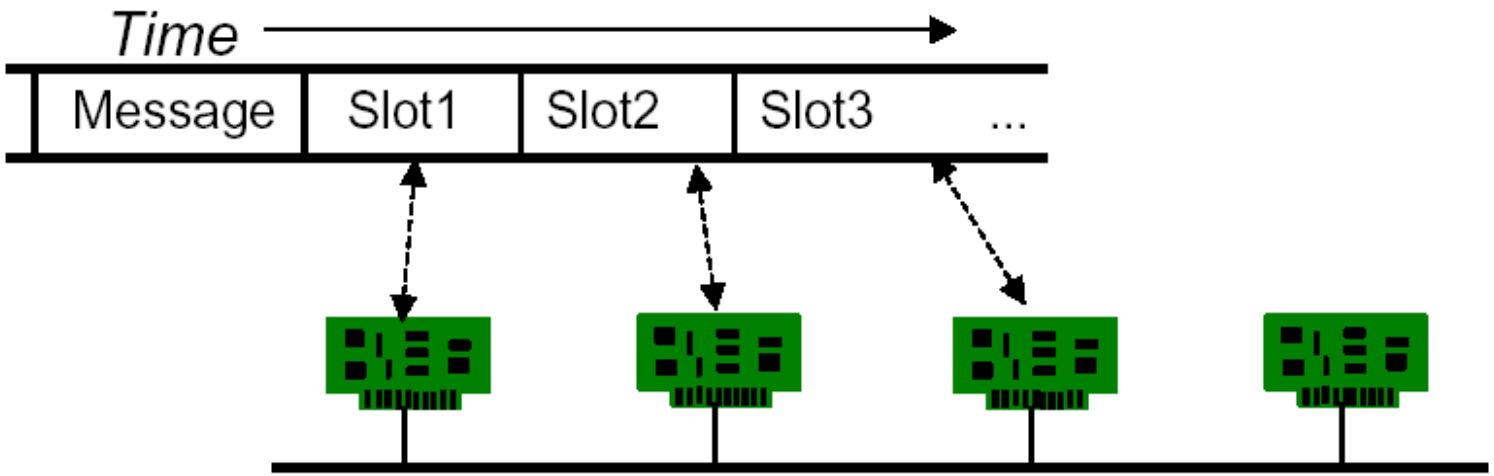
Token Ring



Token Ring

- Advantages
  - Bounded latency for real-time control applications
  - High throughput during heavy traffic
  - Global and local priority mechanism available
  - On-the-fly reconfiguration with node bypass hardware
  - Well suited for fiber optic media
  - Each station acts as a repeater - strengthens the signal
- Disadvantages
  - Moderate latency for light traffic (token passing overhead)
    - Not as bad as token bus
  - Centralized monitor (designated at initialization)
  - Token initialization, loss, and duplication recovery overhead
  - Propagation delay is based on the number of nodes
  - Cut in the wire disables the entire network

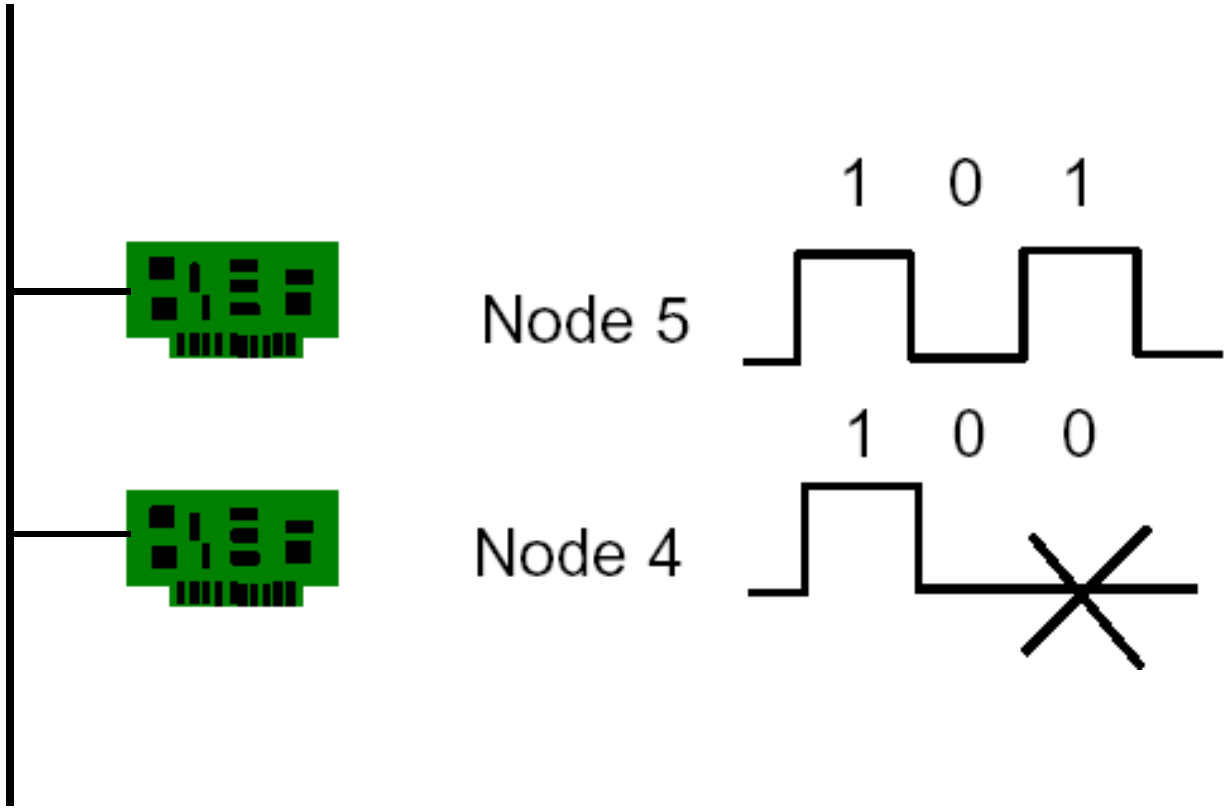
Reservation CSMA/CA



Reservation CSMA/CA

- Advantages
  - Small latency for light traffic
  - Good throughput under heavy traffic
  - Global prioritization through fixed slots – prioritized implicit token passes
  - Bounded latency through rotating slots – non-prioritized implicit token passes
- Disadvantages
  - Restarting time slots from an idle bus can be difficult
    - Send dummy messages to avoid idle state
  - Collisions can occur

Binary Countdown (Bit Dominance)



Binary Countdown (Bit Dominance)

- Each node is assigned a unique identification number
- All nodes wishing to transmit compete for the channel by transmitting a binary signal based on their identification value
- A node drops out the competition if it detects a dominant state while transmitting a passive state
- Thus, the node with the highest identification value wins

Binary Countdown (Bit Dominance)

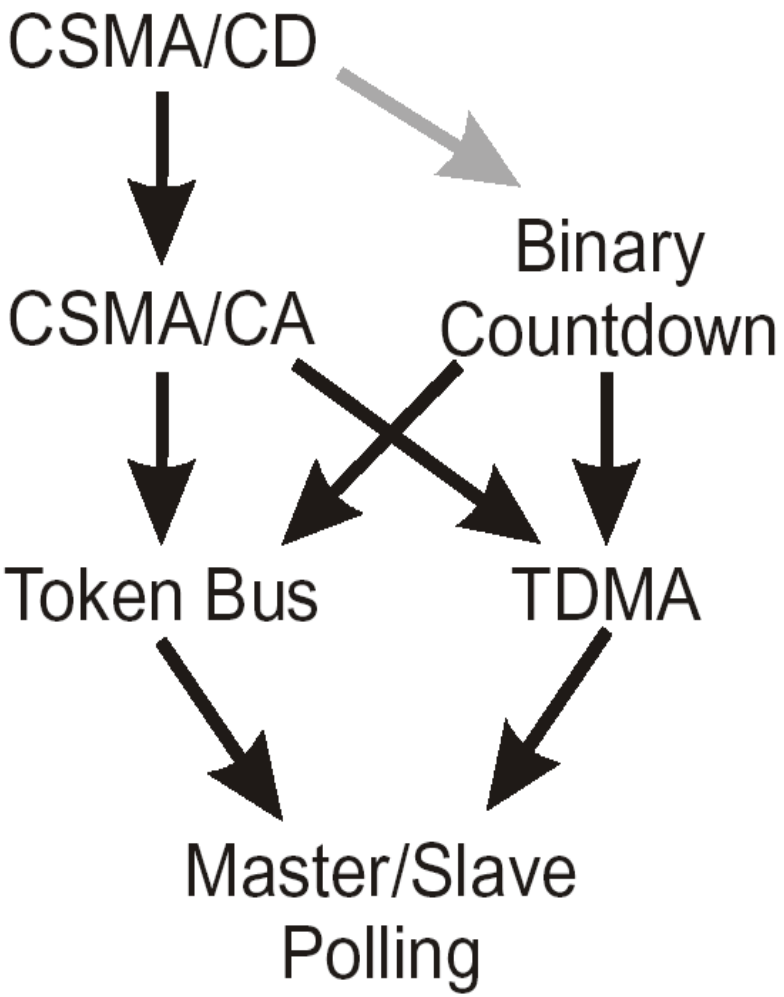
- Advantages
  - High throughput under light loads
  - Local and global prioritization possible
  - Arbitration is part of the message - low overhead
- Disadvantages
  - Propagation delay limits bus length (2 times the propagation delay of a bit)
  - Unfair access - node with a high priority can "hog" the network
  - Poor latency for low priority nodes

Key Overall Tradeoff Issues

- Protocols are optimized for different operating scenarios
  - Collision-based
    - High number of possible transmitters
    - Low number of active transmitters
    - Arbitration overhead proportional to activity
  - Token-based, time-multiplexed & polled
    - Moderate number of total transmitters
    - Handles worst case activity without a problem
    - Arbitration overhead relatively constant
  - Binary countdown
    - Moderately large number of message types
    - Arbitration overhead constant
    - Global prioritization (but no mechanism for fairness)

Emulation

- You can use one protocol to emulate another
- Use Ethernet (CSMA/CD) to emulate:
  - Master/slave polling – slaves only respond when polled
  - Token bus – use explicit token messages; application only transmits when it has the token
  - TDMA – slaves measure time from message from master and transmit appropriately
- But, there is no free lunch
  - "Slot" time involves round-trip through OS – longer than a couple bit times
- "Slice" time must account for CPU/OS jitter, not just HW oscillator drift



Real-Time Ethernet

- Ethernet is becoming a low cost hardware
- A lot of embedded systems include
  - RTOS
  - Ethernet, TCP/IP and socket API
  - Data communication has not real-time constraints
    - Exchange of data is not critical
    - Exchange rate is low
- Some embedded systems need real-time communication
- Ethernet is not suitable for real-time performance
  - Ethernet MAC is CSMA/CD
  - CSMA/CD is not deterministic

Real-Time Ethernet

- Real-Time Ethernet protocol does not inhibit CSMA/CD
- Real-Time Ethernet protocol places restrictions on the higher level software (application) which controls access to the medium
  - Only proprietary nodes on the net
  - Devices are divided into two sets
    - One device acts as controller node
    - All other devices act as remote nodes
  - Remote nodes may access the network bus until the controller sends a request to it
  - Remote nodes have a fixed amount of time to respond to a controller request

Real-Time Ethernet

- Advantages
  - Deterministic
  - Easy to be implemented
  - Support TCP/IP and socket API
  - Low cost
- Pitfalls
  - Centralized control
  - Reduced performance

Home Networking

- Installation problems
  - Difficulties to add cables
  - Need of moving devices
- Solutions
  - Wireless network
  - Reuse pre-existing cables
    - Phone cables
    - Power cables

Phoneline

- Home Phoneline Network Alliance (HomePNA) uses phone lines as transport medium
- Frequency-division multiplexing (FDM) puts digital data on separate frequencies from the voice signals being carried by the phone line
- Operates at a constant rate even when the phone is in use

Phoneline

- HomePNA uses different technologies that support Ethernet protocol on phone lines
  - First standard
    - Tut Systems technology (1 Mbps)
  - Second standard
    - Epigram technology (10 Mbps)
  - Third standard
    - Planned (100 Mbps)
- Physical connection between computer and phone line network uses Universal Serial Bus (USB) adapter or HomePNA PCI card

Phoneline

- Advantages
  - Cabling is not necessary
  - Support TCP/IP and socket API
  - Moderate cost
- Pitfalls
  - CSMA/CD is not deterministic
    - Phoneline technologies are not appropriate for systems with tight timing deadlines

PowerPacket

- Intellon's PowerPacket technology uses power line as transport medium
- Orthogonal Frequency-Division Multiplexing with forward error-correction puts digital data
  - Electrical subsystem frequencies (4.3 - 20.9 MHz) are split into 84 separate carriers
  - OFDM sends packets of data simultaneously along several of the carrier frequencies
    - Speed and reliability are increased
  - If noise or a surge in power usage disrupts one of the frequencies
    - PowerPacket chip will sense it and switch that data to another carrier

PowerPacket

- Works independently from line voltage and frequency of power line used
- PowerPacket technology supports Ethernet protocol on power lines
  - First standard
    - Passport technology (350 Kbps)
  - Second standard
    - PowerPacket technology (14 Mbps)
  - Third standard
    - Planned (100 Mbps)
- Physical connection between computer and powerline network uses USB or Ethernet Interface

- Advantages
  - Cabling is not necessary
  - Support TCP/IP and socket API
  - Moderate cost
- Pitfalls
  - CSMA/CD is not deterministic
    - PowerPacket technologies are not appropriate for systems with tight timing deadlines

IEEE 802.11

- Is the wireless version of Ethernet
  - Encrypts data to offer an equivalent level of privacy to insecure wired LAN
- Offers Wired Equivalent Privacy (WEP) security
- IEEE 802.11b supports
  - CSMA/CA
  - PCF

- Point Coordination Function (PCF) offers time critical services

- Point Coordination nodes manage traffic
  - CSMA/CA traffic is blocked
  - PC has a list of nodes requiring contention free services
  - PC coordinates nodes access via polling
  - After a certain interval without transmission nodes are removed from list

- Advantages
  - Cabling is not necessary
  - Support TCP/IP and socket API
  - Equivalent level of privacy to insecure wired LAN
  - Moderate cost
- Pitfalls
  - CSMA/CA is not deterministic
  - Deterministic traffic control is centralized

LonTalk

- Developed by Echelon
  - Used for a broad variety of applications
- Different types of transmission medium
  - Twisted pair, optical fiber, coaxial cable
  - Powerline
  - Radio
  - Infrared
- Operates up to 1.25 Mbps
- Uses small packets
  - Max payload is 229 bytes

LonTalk MAC

- MAC is based on CSMA/CA
  - Collisions are possible
  - Collisions can be reduced by increasing the number of random slots
- LonTalk MAC predicts the bus traffic
- An optional collision detection circuit aborts communication early when collision is detected

LonTalk

- Advantages
  - Different types of communication medium supported
  - Complete set of communication services
  - Low cost
- Pitfalls
  - CSMA/CA is not deterministic
    - LonTalk is not appropriate for systems with tight timing deadlines

CAN

- Controller Area Network (CAN) has been developed by Bosch
  - Mainly used in industrial control device networks
- Transmission medium is twisted pair
- Operates up to 1 Mbps
- Uses very small packets
  - Max payload is 8 bytes
- Errors are automatically detected by CAN controller

CAN MAC

- MAC is based on CSMA/CD+AMP (Arbitration on Message Priority)
  - Collisions are possible
  - Higher priority messages is guaranteed to gain bus access
- Each message is labeled by a 11 bits identifier
  - Unique through the network
  - Determines priority of message
    - Lower numerical value means higher priority
- Low bits are always dominant on the bus

- Two nodes send at the same time a message
  - Node 1 sends a higher numerical value identifier
    - Listens a low bit while sending a high bit
    - Stops transmission
  - Node 2 sends a low numerical value identifier
    - Listens its message identifier
    - Completes message transmission

CAN

- Advantages
  - Fast, deterministic, prioritized performance with short messages
  - Very reliable for error detection and fault confinement
  - Low cost
- Pitfalls
  - High speeds are only supported for short busses
    - 500m for 125 Kbps, 100m for 500 Kbps and 50m for 1 Mbps
  - Limited set of network services
    - Additional services can be costly and tricky to implement
  - Some applications require electrical isolation between bus and nodes
    - Hardware isolation makes the interface more expensive

FireWire

- Developed by Apple Computer
- Mainly used for multimedia applications
- Standardized as IEEE-1394
- Transmission medium is a three-twisted pair shielded cable
  - Two for data, one for power
- Bus based on point-to-point links between devices
- Operates up to 400 Mbps
- Uses medium size packets
  - Typical payload is 2K bytes
- Synchronous and asynchronous data transfers

FireWire

- Nodes are configured as logical tree
- Time is divided in cycles
- Each node can send a synchronous packet once a cycle
- Root node performs arbitration
  - Nodes send requests to their parent node
  - Node are enabled in an order depending on the distance from root node
- Remaining cycle time is dedicated to asynchronous traffic

- Root node performs the same kind of arbitration used for synchronous
- Nodes can send more than one packet
  - Nearest nodes might always win the arbitration
  - Nodes use fairness interval
- Nodes sending an asynchronous packet
  - Clear their arbitration enable bit
  - Wait for fairness interval deadline without traffic
  - Reset their arbitration enable bit
  - Try to get the bus

FireWire

- Advantages
  - Extremely fast, deterministic, performance
  - Moderate cost
- Pitfalls
  - Short distance between adjacent devices (~4,5 m)

IrDA

- Infrared Direct Access (IrDA) is a standard for devices to communicate using infrared light pulses
- All remote controls use this standard
  - remote from one manufacturer can control a device from another manufacturer
- Infrared light use constraints devices to be in direct line of sight with each other
- All remote controls communicate with a master device
- Remote controls communicate on master request
- Operates up to 4 Mbps

- Advantages
  - Cabling is not necessary
  - Largely used
    - All remote control use this standard
  - Low/moderate cost

- Pitfalls
  - Short distance between adjacent devices
    - Few meters
  - Devices must to be in direct line of sight with each other
    - At least an access point for room

Bluetooth

- Bluetooth technology is a short range radio interface
  - Same purpose of infrared technology
  - Does not require line of sight
- Operates at 2.4 GHz up to 1 Mbps
- Bluetooth network is called piconet
- Two types of data transfer
  - Synchronous connection oriented (SCO) link
  - Asynchronous connection-less (ACL) link

Bluetooth

- A piconet has a master and up to seven slaves
  - Master transmits in even time slots
  - Slaves in odd time slots
- Master reserves a set of slots for SCO links
- Slots not reserved for SCO links can be used for ACL links
  - One master and slave can have a single ACL link
    - point-to-point (master to one slave)
    - broadcast to all the slaves
  - ACL slaves can only transmit when requested by master

Bluetooth

- Advantages
  - Cabling is not necessary
  - Does not require line of sight
  - Privacy guaranteed by using unique public address, two secret keys and random number different for each transaction
  - Moderate cost
- Pitfalls
  - Short distance between adjacent devices (~10 m)
  - Might interfere with other wireless communication