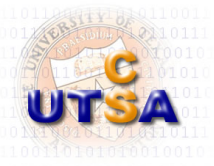
CS4833: Embedded Systems

Communication

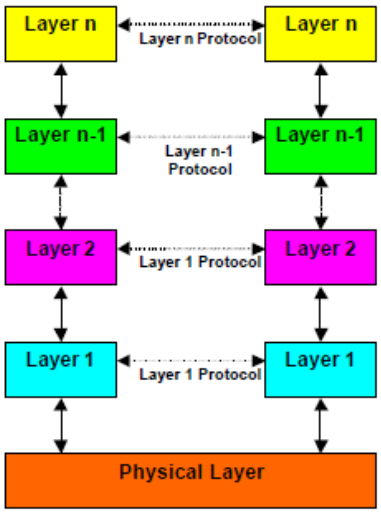


Outline

- Communication protocols
- Parallel communication
  - Peripheral Component Interconnect (PCI)
- Serial communication: RS232
  - UART, I2C, USB and PCIe
- Real time communication
  - Event vs. time driven; CAN, FlexRay etc.
- Wireless communication

Communication Protocols

- Number of communication bits: parallel vs. serial
- Timing: asynchronous vs. asynchronous
- Layering
  - Lower levels provide services to higher level
  - Easier to design
  - Physical layer: lowest level in hierarchy
  - Medium to carry data from one actor (device or node) to another



Interface with "Remote" Devices

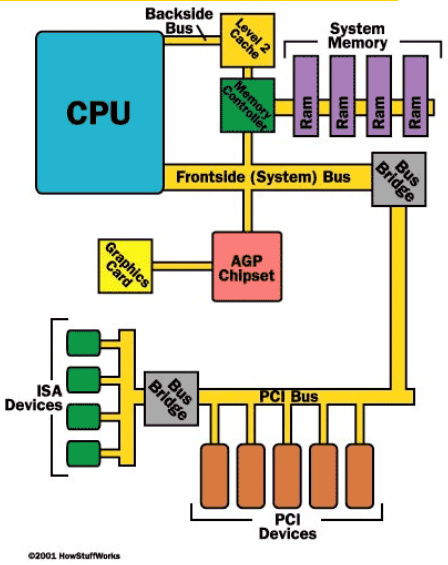
- Layering techniques:
  - Break communication into pieces easier to design and understand
  - Lower levels provide services to higher level
    - ✓ Lower level might work with bits while higher level might work with packets of data
  - Physical layer
    - ✓ Lowest level in hierarchy
    - ✓ Medium to carry data from one actor (device or node) to another
- **Parallel communication**
  - Physical layer capable of transporting multiple bits of data *simultaneously*
- **Serial communication**
  - Physical layer transports one bit of data at a time

Parallel Communication

- Multiple data, control, and power wires
  - One bit per wire
- High data throughput with short distances
- Typically used when connecting devices on same IC or same circuit board
  - Bus must be kept short
  - Long parallel wires result in high capacitance values that require more time to charge/discharges
  - Data misalignment between wires as length increases
- Higher cost, bulky

Parallel protocols: PCI Bus

- Peripheral Component Interconnect (PCI)
  - High performance bus designed by Intel in the 1990's
  - Interconnects CPUs, expansion boards, memory
  - Data transfer rates up to 1GBs for 64 bit addresses
  - Synchronous bus architecture
  - Multiplexed data/address lines
- Old printers: parallel cables



Parallel protocols: ARM Bus

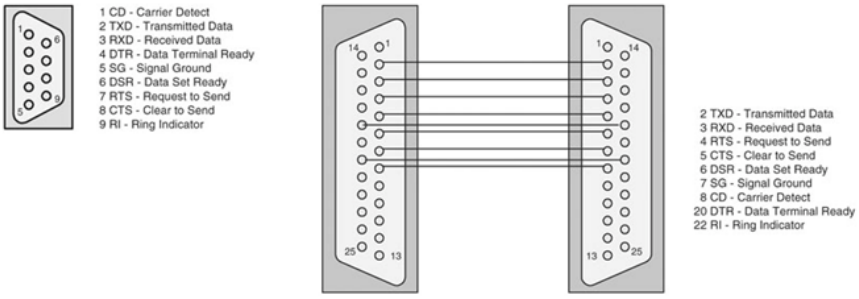
- Many IC design companies have own bus protocol
  - Intellectual proprietary
- ARM Bus
  - Proprietary
  - Designed and used internally by ARM Corporation
  - Interfaces with ARM line of processors
  - Data transfer rate is a function of clock speed
  - 32-bit addressing

Serial Communication

- Single data wire: one bit at a time
  - May have/need control wires
- Target at long distance transmission
  - Less average capacitance: more bits per unit of time
  - Higher data throughput
- Complex protocol and interfacing logic
  - Sender needs to decompose word into bits
  - Receiver needs to recompose bits into word
  - Control signals often on the same wire -> increasing protocol complexity

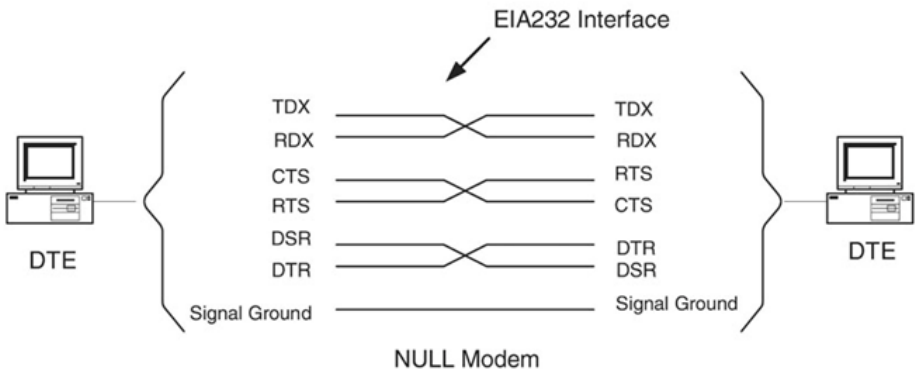
RS232/EIA-232 Standard

- **Asynchronous** serial communication
- Physical connections DB-9 or DB-25
  - TXD, RXD, SG
  - CTS, RTS etc.



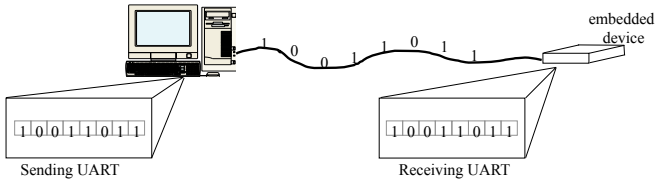
RS232/EIA-232 Signal Connections

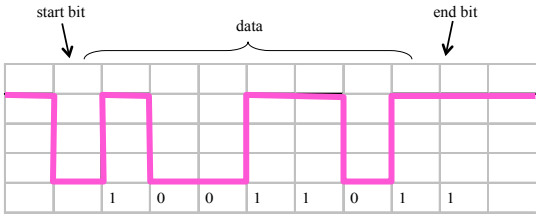
- Cross over connections



Serial Protocol: 8251 UART

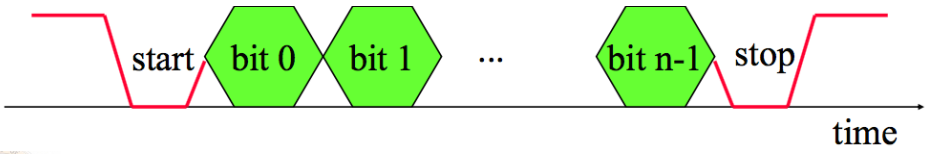
- Universal asynchronous receiver transmitter (UART)
  - Parallel data → transmits serially at up to max 450 Kbps
  - 8251 chip functions are integrated into PC interface chip





UART: Basic Parameters

- Basic parameters
  - Baud (bit) rate (e.g., speed)
  - Number of bits per character
  - Parity/no parity
  - Even/odd parity
  - Length of stop bit (1, 1.5, 2 bits)
  - **Quiescent state: high !!!**



Serial Protocol: I2C

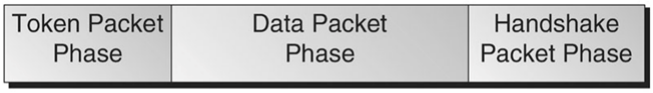
- Inter-IC (I2C)
  - Two-wire serial bus protocol developed by Philips Semiconductors nearly 20 years ago
  - Enables peripheral ICs to communicate using simple communication hardware
    - ✓appropriate for peripherals where simplicity and low manufacturing cost are more important than speed
  - Normal mode: 100 Kbps with 7-bit address
  - Fast mode: 3.4 Mbpbs with10-bit address
  - Common devices capable of interfacing to I2C bus
    - ✓EPROMS, Flash, and some RAM memory, real-time clocks, watchdog timers, and microcontrollers

Serial Protocol: Universal Serial Bus (USB)

- Easier connection between PC and peripherals
- USB 1.1 has 2 data rates:
  - 12 Mbps for increased bandwidth devices
  - 1.5 Mbps for lower-speed devices (joysticks, game pads)
- USB 2.0 runs at 480 Mbps; USB 3.0 up to 5 Gbps
- Tiered star topology can be used
  - One USB device (hub) connected to PC
  - Up to 127 USB devices can be connected to hub
- USB host controller
  - Manages and controls bandwidth and driver software required by each peripheral
  - Dynamically allocates power downstream according to devices connected/disconnected

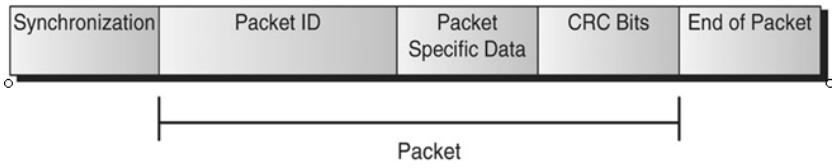
USB Transactions

- Three phases



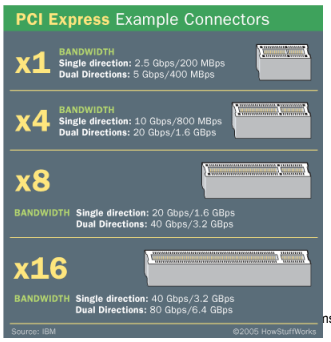
Single Transaction

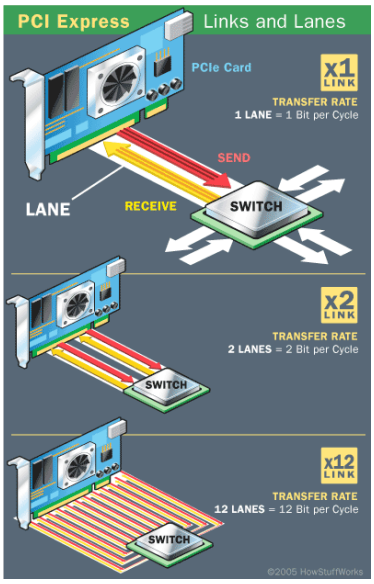
- Packet format



PCI Express (PCIe)

- **Serial**, point-to-point protocol
- Bandwidth is very scalable: 1x-16x links
- Max 6.4GBps: on x16
- Switches for different devices





Real-Time Communication & Protocols

Requirements:

- Control systems: real-time behavior
- Bandwidth and delay
- Efficient and economical
- Robustness and fault tolerance
- Maintainability and diagnosability
- Safety and Security

Real-Time Behavior

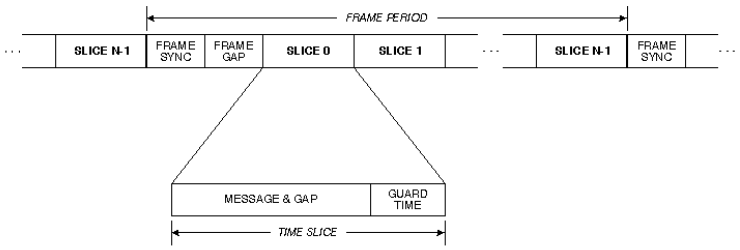
- Token rings/bus: high priority nodes are ok
  - Carrier-sense mult.-access/collision-avoidance: CSMA/CA
    - ✓Each partner gets an ID (priority). After each bus transfer, all partners try setting their ID on the bus; partners detecting higher ID disconnect themselves from the bus. Highest priority partner gets guaranteed response time; others only if they are given a chance.
- Ethernet: no timing guarantees
  - Carrier-sense mult.-access/collision-Detection: CSMA/CD
- Field bus
  - Family of industrial computer network protocols for RT-distributed control

Event vs. Time Triggered

- Event Triggered (ET):
  - Comp./communication triggered by an external event
  - Generated by (primarily) state changes in the environment
    - ✓ Efficient — only do things when they need to be done; rest and save energy/cpu time/bandwidth
  - High peak-load if multiple events happen at once
  - Hard to analyze due to asynchronous nature of events
- Time Triggered (TT):
  - Comp./comm. triggered by progress of a system clock
  - Events happen according to a fixed schedule
    - ✓ Inefficient — does things periodically, whether needed or not
  - Enhanced analizability due to easily characterizable load, predictable interaction sequences, bus use, etc.

Time Division Multiple Access

- Each connected node is assigned a fixed time slot
  - Master sends sync.
  - Some waiting time
  - Each slave transmits in its time slot
  - Variations: truncating unused slots, several slots/slave etc.



http://users.ece.cmu.edu/~koopman/jtdma/jtdma.html

TDMA vs. Priority-Driven Schemes

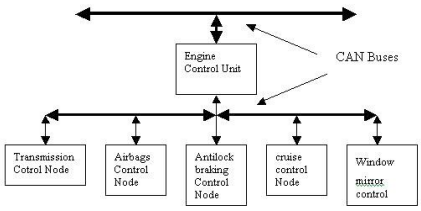
- Can provide QoS guarantees
  - TDMA resources have a very deterministic timing behavior
  - TDMA resources support temporal composability, by separating resource access of different subsystems
- Can be made fault tolerant
- Support for error detection
- Support for error contention
  - a faulty subsystem does not affect the correct behavior of the remaining system

Field Busses: Profibus

- More powerful and expensive than sensor interfaces
- Mostly serial; apps transmit a few bytes at a time
- Example: Process Field Bus (Profibus)
  - Designed for factory and process automation.
  - Focus on safety; comprehensive protocol mechanisms
  - Token passing
  - Speed and range: ≦93.75 kbit/s (1200 m);1500 kbits/s (200m);12 Mbit/s (100m)
  - Integration with Ethernet via Profinet.
  - 20% market share for field busses.

Controller Area Network (CAN)

- Designed by Bosch and Intel in 1981; Key concept:
  - every device can be connected by a single set of wires;
  - A device can exchange data w. any connected device
- Originally designed for automobiles/cars
  - Now also for: elevator controllers, medical instruments etc.
- Binary countdown arbitration (CSMA/CD)
  - Start from MSB, transmit each bit of priority
  - highest priority wins
  - Low and high-priority signals
    - ✓maximum latency of 134 μs for high priority
- Throughput:10kbit/s - 1 Mbit/s

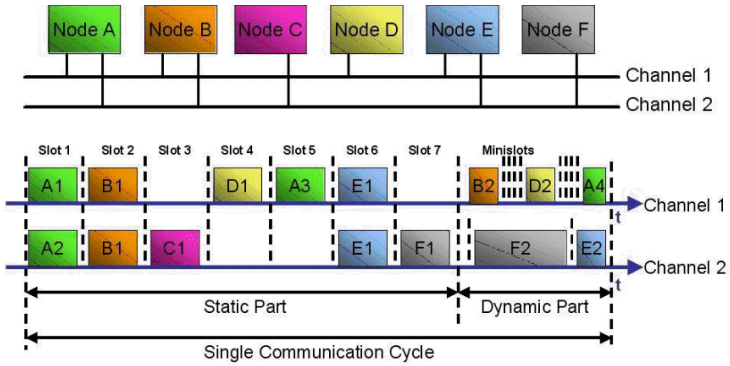


FlexRay

- Objective: robust, scalable, deterministic, and fault-tolerant digital serial bus system designed for use in automotive applications
  - Developed by consortium: BMW, Ford, Bosch, Daimler-Chrysler, etc.; Specified in SDL; finalized in 2009
- Built as extension to TTP and Byteflight protocols.
  - Improved error tolerance and time-determinism
  - TDMA (Time Division Multiple Access) protocol: Fixed time slot with exclusive access to the bus
  - Cycle subdivided into a static and a dynamic segment.
  - Meets requirements with transfer rates >> CAN
    - ✓initially targeted for ~ 10Mbit/sec;
    - ✓design allows much higher data rates

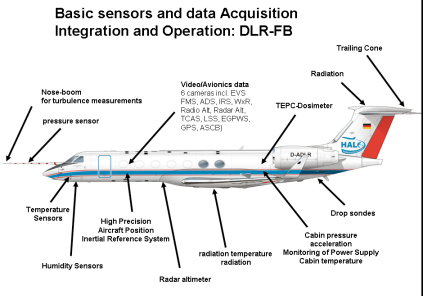
TDMA in Flexray

- Exclusive bus access for short time in each case.
- Dynamic segment for variable length information.
  - Fixed priorities: Minislots for each potential sender.
  - Bandwidth used only when it is actually needed.



Aircraft Communication Systems

- Control platform: sampling and data transmission
  - Data: values of analog parameters: e.g. speed; height etc.
  - No response is expected, but:
    - ✓Time, integrity and availability are the key drivers
    - ✓The stability of the flight relies on this transmission
  - Aeronautical response: ARINC 429 protocol
- Information exchange
  - e.g. digital map, flight plan, etc.
  - Response: e.g., ack
  - higher speed data link needed



Wireless Communication

- Infrared (IR)
  - Frequencies just below visible light spectrum
  - Diode emits infrared light to generate signal
  - Infrared transistor detects signal
  - Cheap to build but need line of sight, limited range
  - Data transfer rate of 9.6 kbps and 4 Mbps
- Radio frequency (RF)
  - Electromagnetic wave frequencies in radio spectrum
  - Analog circuitry and antenna needed on both sides
  - Line of sight not needed, transmitter power determines range

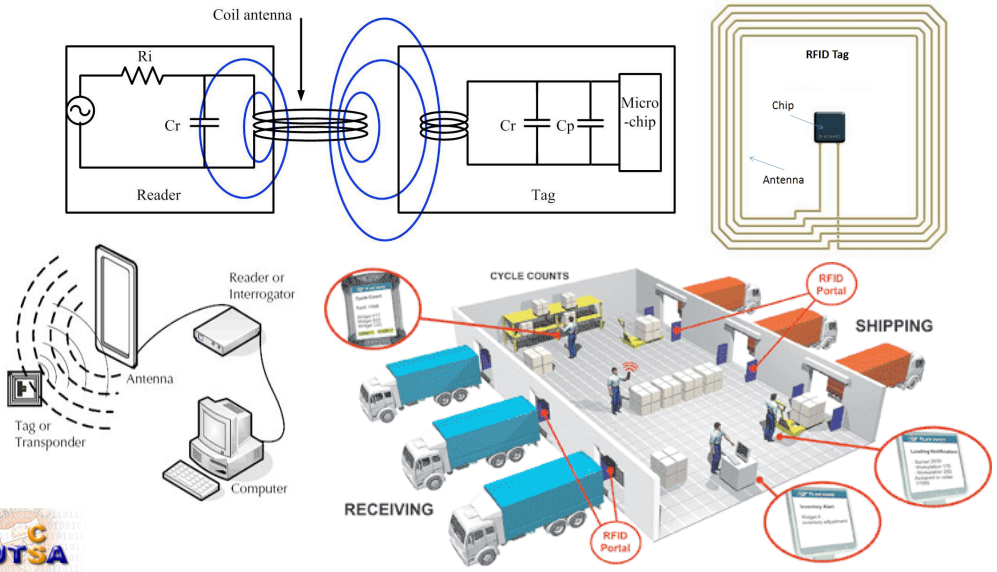
Wireless Protocols: 802.11

- IEEE 802.11
  - Standard for wireless LANs
  - Specifies parameters for PHY and MAC layers of network
- PHY layer
  - handles transmission of data between nodes
  - operates in 2.4 / 5 GHz frequency band (RF)
  - data transfer rates up to 600 Mbit/s for 802.11n
- MAC layer: medium access control layer
  - protocol responsible to maintain order in shared medium
  - collision avoidance/detection

RFID: Radio Frequency ID

- Use EM field to transfer data, to identify & track tags attached to objects; no need for line of sight
- Active vs. passive tags
  - Active transmits ID, they are low power (~10-100uA) but higher cost ($10-$200/unit retail)
  - Passive - no intrinsic power (powered by EM induction) and cheaper ($0.20-0.40)
- RFID Readers: $100+ to $1000s: read & smart track
- Using RFID for real-time location systems (RTLS)
  - Active tags: 100m+ in line of sight, or 1-20m obstructed
  - Battery: 1Y on a single charge @ <1Hz transmission rate
  - Location accuracy as close as 30cm with reader presence

RFID Tags and Example



Bluetooth, BLE and Zigbee

Bluetooth

- IEEE 802.15.1
- Developed and licensed by the Bluetooth Special Interest Group (SIG)

BLE

- Adopted into Bluetooth specification
- *Bluetooth Low Energy Technology*

ZigBee

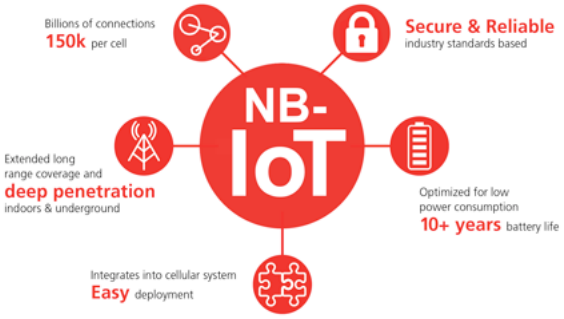
- IEEE 802.15.4
- Maintained and published by the ZigBee Alliance

Comparison: Side by Side

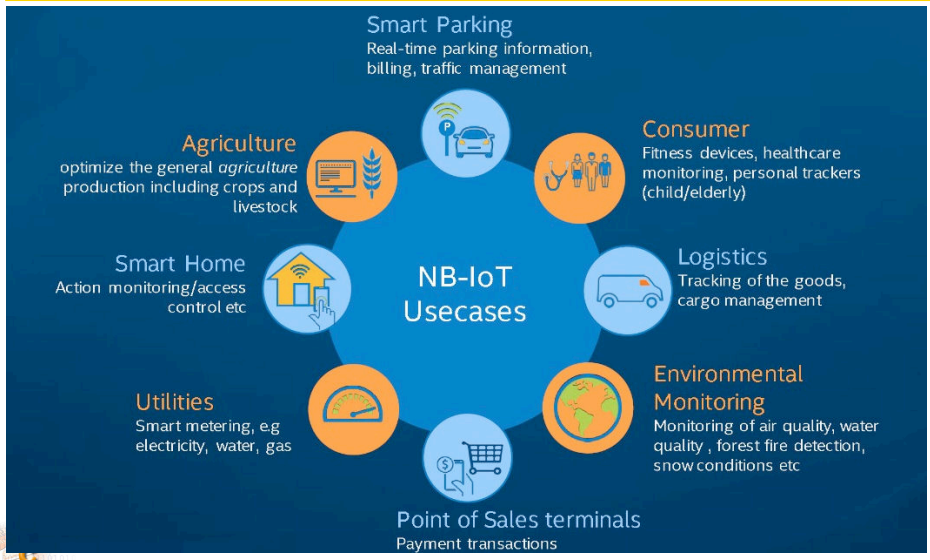
	Bluetooth	BLE	ZigBee
Band	2.4GHz	2.4GHz	2.4GHz, 868MHz, 915MHz
Antenna/HW	Shared		Independent
Power	100 mW	~10 mW	30 mW
Battery Life	Days – months	1-2 years	6 months – 2 yrs
Range	10-30 m	10 m	10-75 m
Data Rate	1-3 Mbps	1 Mbps	25-250 Kbps
Network Topologies	Ad hoc, point to point, star	Ad hoc, point to point, star	Mesh, ad hoc, star
Time to Wake and Transmit	3s	3ms	15ms
Security	128-bit encryption	128-bit encryption	128-bit encryption

NBIoT: Narrowband Internet of Things

- NBIoT: Low Power WAN (LPWAN) radio technology
  - Developed by 3GPP, subset of LTE standard
  - Enable a wide range of cellular devices and services
  - low cost, long battery life, and high connection density



Use cases of NB-IoT



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