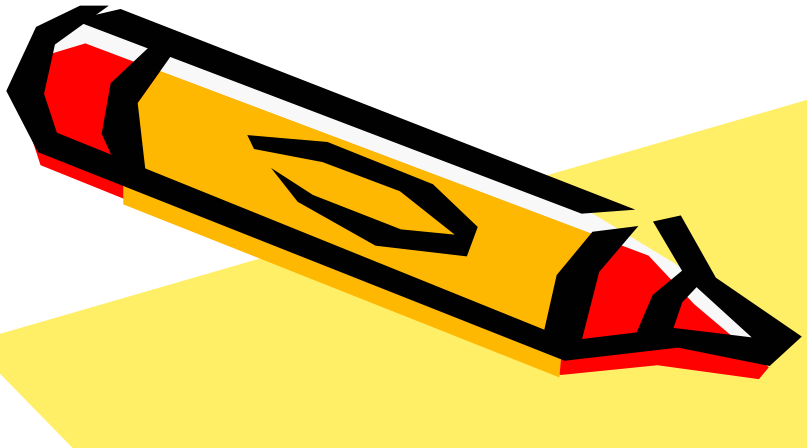


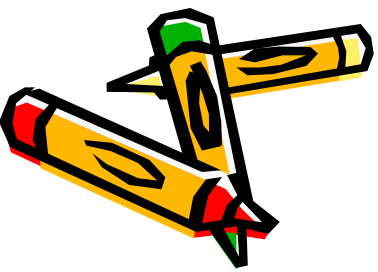
Real-Time Netowrks using Ethernet?

by

Anthony Keane, PhD

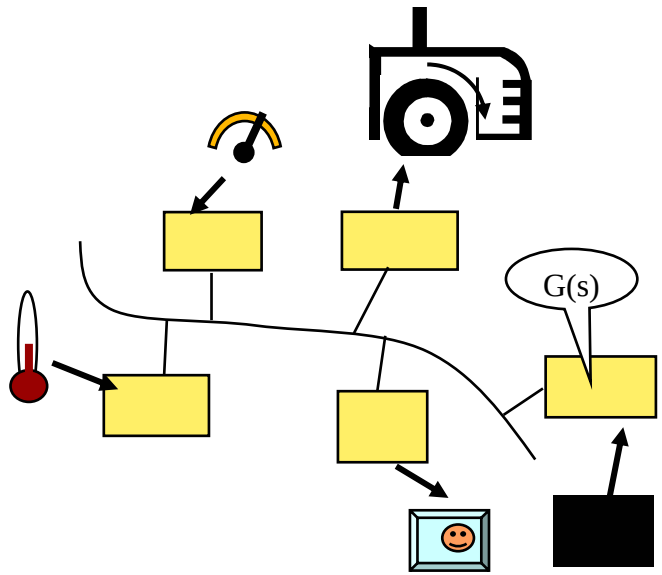
Overview

- Motivation for Presentation
- What do we mean by Real-Time?
- Real-Time Network Requirements
- Overview of Ethernet
- Ethernet and Real-Time
- Real-Time Efforts with Ethernet
- Current Research
- Conclusions



Motivation for Presentation

- Embedded Design Projects at ITB
- Networked Intelligent Devices
- Communications with other Applications
- Standard Development Language
- Standard Network Interface
- Usual suspects
  - Real-time operating system
  - Ethernet
  - TCP/IP
  - Sockets API



What do we mean by Real-Time?

In Real-Time Systems the *time of service delivery* is as important as the *functionality of the service.*

- Predictability of code execution
- Temporal constraints
- Precedence constraints

Hard Real-time

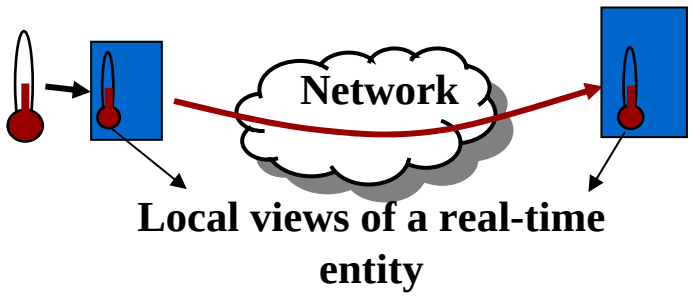
failure to meet a timing constraint is disaster

Soft Real-time

can recover from a temporal deadline failure

Real-Time Networks

"*real-time messages* must be transmitted within precise *time-bounds* to assure coherence between senders and receivers concerning their *local views* of the respective real-time entities"



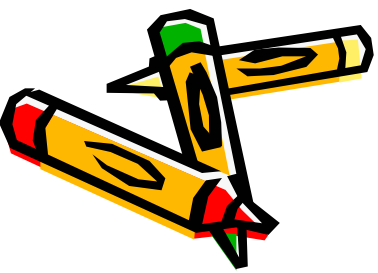
In the diagram, we want a *consistent view* of the temperature but network delays can cause difference views to be held.

Messages can be:

- **Event triggered** networks have messages carrying entity data generated by event occurrence – asynchronous – unpredictable network load if arrival rate of events can not be bounded

- **Time-triggered** networks introduce the notion of network time. Here transactions triggered by predefined time instants – periodic traffic handled in static fashion – predictable network loading

- Combinations of both either
  - do not maintain the properties of TT
  - handle aperiodic traffic inefficiently



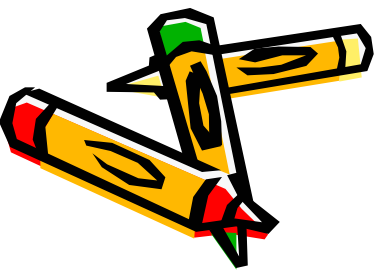
Real-Time Systems

- **Real-time communications** are necessary and used extensively in process control and manufacturing industries, e.g. from embedded command/control systems to image processing and monitoring systems.
- **Requirements** are different and sometimes opposite to office environments
- **Special purpose networks** have been developed over last 20 years called *fieldbuses* – designed to support frequent exchanges of small amounts of data under time, precedence and dependability constraints.

Today, there are **many different networks** with real-time capabilities, aiming at different application domains:

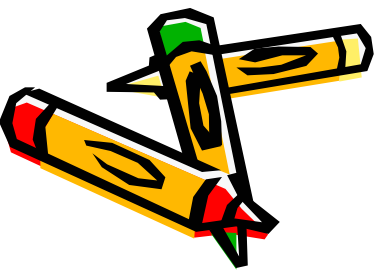
- ✓ ARINC629, SwiftNet, SAFEbus – **avionics**
- ✓ WorldFIP, TCN – **trains**
- ✓ CAN, TT-CAN, TTP, FlexRay – **cars**
- ✓ ProfiBus, WorldFIP, P-Net, DeviceNet, FF-HSE/H1, Ethernet/IP – **automation**
- ✓ Firewire – **multimedia**

- Overtime, the quantity, complexity and functionality of the nodes in distributed embedded networks have been increasing steadily.
- As a consequence, amount of information has also increased both for configuration and operational purposes.
- Currently at limit of traditional fieldbus technology where bandwidth is limited between 1 and 5 Mbps.
- Alternatives needed to support higher bandwidths requirements
  - FDDI and ATM both have real-time capabilities but have higher costs and complexities
  - Ethernet bandwidth/cost looks good but is non-deterministic



Introduction to Ethernet

- Invented at Xerox Palo Alto Research Center (PARC) in 1976 by Robert Metcalfe and David Boggs
- Developed from 2.9 Mbps to 10 Mbps, later 100 and 1000 Mbps
- Bandwidth of 10 Gbps is now available
- physically started as bus topology on thick coaxial cable
- in 1980s moved to star topology on cat 5 UTP
- this allows for better structuring and fault-tolerance
- basic fundamental properties are:
    - collision & broadcast domains
    - arbitration mechanism CSMA/CD



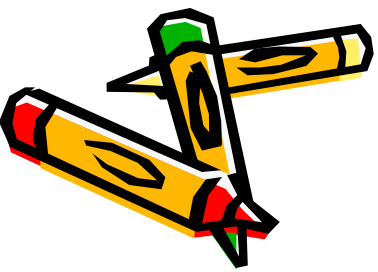
Arbitration Mechanism

Ethernet network interface has two stage bus arbitration scheme

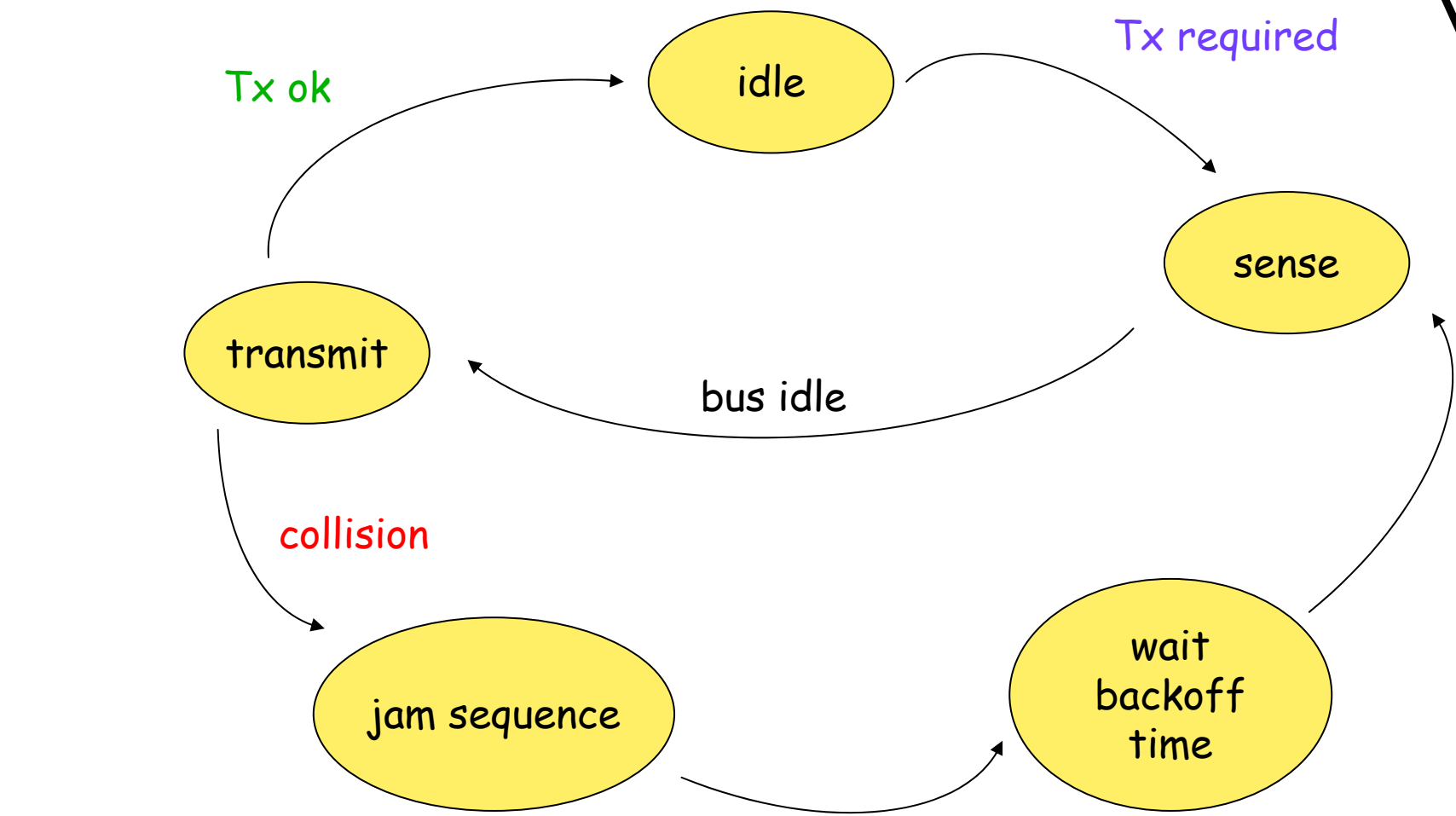
- Carrier-Sense Multiple Access (CSMA)
- Collision Detection

Steps are:

1. Devices sense if bus is not in use and begins transmitting
2. If bus busy, device waits until wire free – bounded wait
3. Simultaneous transmission by two devices -> collision
4. Backoff algorithm – random delay – unpredictable – try again later
   (for 10Mbps the slot time is 51.2 microseconds = 0.05 millisec)
5. Doubles wait slot each attempt, stops after 10 attempts and declares error after 16 attempts.

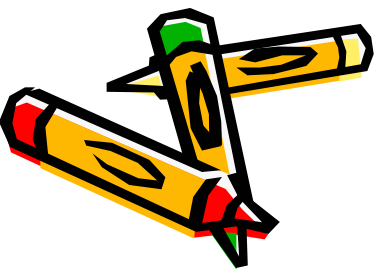


Overview of Arbitration Mechanism



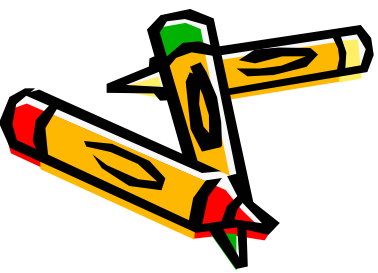
Arguments in favor of using Ethernet for RT networks

- cheap and mass produced
- integration with Internet (TCP/IP stacks over Ethernet widely available)
- Allows use of application layer protocols like ftp, http, etc
- increasing transmission speed
- fieldbus bandwidth becoming exhausted
- availability of people familiar with Ethernet and test equipment
- mature technology



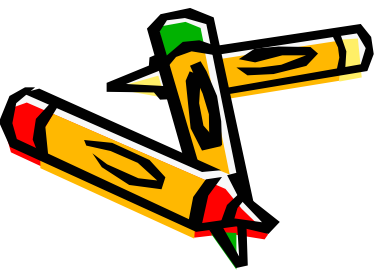
Arguments against using Ethernet

- not designed for time-constrained traffic
- non-deterministic arbitration
  - serious problem for hard RT systems
- fieldbuses have other requirements than bounded transmissions, like
  - temporal consistency indication
  - precedence constraints
  - efficient handling of periodic and sporadic traffic



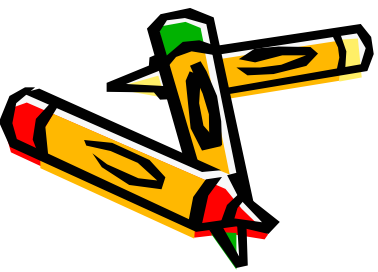
Real-Time Efforts with Ethernet

Ethernet, by itself can not fulfill all the properties expected with real-time networking however .....



Several approaches for real-time communications over Ethernet

- Override Ethernets CSMA/CD medium access control by setting upper transmission control layer that eliminates (or reduces) the occurrence of collisions at the medium access.
- Another approach is to modify CSMA/CD MAC layer so that collisions either seldom occur or when they do, the collision resolution is deterministic and takes a bounded worst-case time.
- other approaches support deterministic reasoning on network access while others allow probabilistic characterization only.



CSMA/CD based protocols

Despite seeming contradictory, this category of protocols achieves (soft) real-time behavior using standard Ethernet network adaptors and relying on the original CSMA/CD contention resolution mechanism.

They exploit the fact that the probability of collisions at the medium access between concurrent nodes is closely related to the traffic properties, namely the bus utilisation factor, message lengths and precedence constraints.

probability of collision related to traffic properties

Can use the traffic properties to compute probability of packet loss or missed deadlines.

***Good with systems where the traffic load is light to moderate and message length is generally short*.**
Here the expected deadline miss ratio is low.

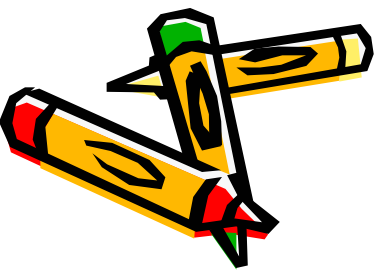
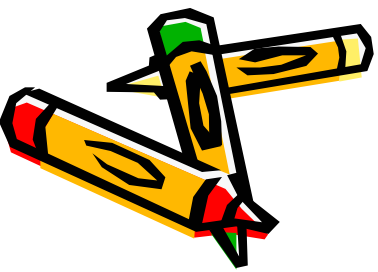


Table1: Latency Assurance: *This table contain examples from the formula presented showing how long you can be 99% sure that the network will run without incurring the specified delay (Tmax) under different loading conditions. Most applications can run comfortably on a fast 100Mbit net. Many will work on a 10Mbit net if a delay of 5ms or so is acceptable.*

Bandwidth (Mbits/sec)	Packet Size (bytes)	Message Rate	Tmax (ms)	Time	
100	128	1000	2	293K yrs	⇐
100	128	1000	1	1140 yrs	
100	128	1000	0.5	9 yrs	
100	1024	1000	2	604 yrs	
100	1024	1000	1	2 yrs	
100	128	5000	1.5	483 yrs	
10	64	1000	7	9 yrs	
10	64	1000	2	10 hrs	
10	128	250	4	2 yrs	
10	128	1000	7	1 yr	
10	128	1000	2	1 hr	⇐
10	128	500	3.5	53 days	
10	1024	100	8	23 yrs	



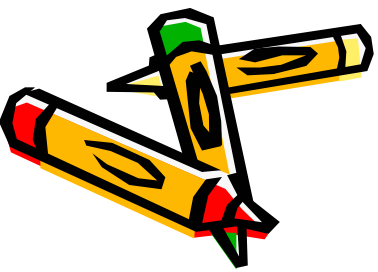
ref: http://www.rti.com/products/ndds/literature.html

Example:
using the model it shows for 100Mbps Ethernet network sending 1000 messages of 128bytes payload generated every second and a message deadline of 1ms, indicates that there is a 99% certainty that there will not be a delay of more then 1 ms caused by collisions in about 1140 years. However the same load with 2ms deadlines, in 10Mbps network has an only an interval of one hour.

Keeping the bus utilisation factor low is important even though it appears to be a waste of resources but given the high bandwidth of Ethernet relative to the requirements of many applications makes this possibility a practical one.
This approach has been adopted in:

- Network Data Delivery Service (NDDS) from RTI
  - middleware for traffic management and managed applications.
- OCERA Real-Time Ethernet (ORTE) – open source

For higher bus utilisation need traffic shaping to avoid bursts.



Modify CSMA/CD MAC layer to improve temporal behavior

- **reduce probability of collisions**

  Virtual Time CSMA

  implements a kind of CA that delay message transmissions according to a temporal parameter.

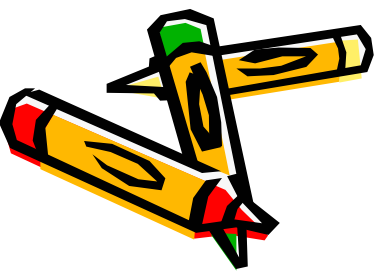
- **sort out collisions in deterministic way**

  Windows

  CSMA/DCR

  EQuB

  } modify the back-off and retry mechanism so that the network access delay can be bounded.



Other approaches to improving Ethernet's behavior:

- **Token Passing**

  used in FDDI and PROFIBUS

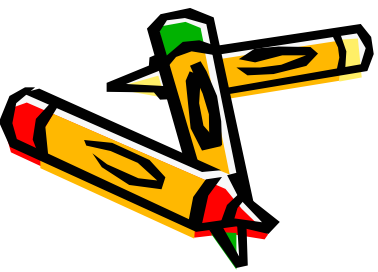
- **Time Division Multiple Access (TDMA)**

  used in TTP/C, TT-CAN, SAFEBus and SWIFTNET

- **Master/Slave techniques**

  used in ETHERNET Powerlink and FTT-Ethernet

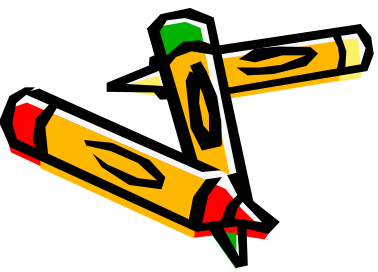
- **Switched Ethernet**



Current Research

Switched Ethernet

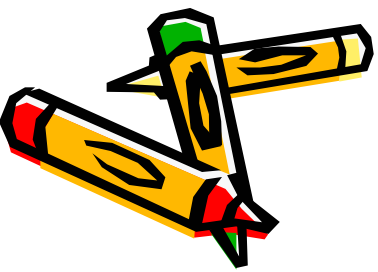
- improved throughput
- reduce impact on CSMA/CD
- bursts can lead to loss of packets in buffer overflow
- multicast traffic treated as broadcasts – flooding
- can use VLANs to limit effects of multicasting
- switch latency
- low number of priority levels insufficient to support priority based scheduling



Protocols that operate over switched Ethernet support real-time communications are:

- Earliest Deadline First (EDF) scheduled switch
  - supports both real-time and non-RT traffic
  - RT traffic scheduled according to EDF algorithm
  - need real-time layer on network components, both end nodes and switch
  - real-time layer is responsible for traffic management

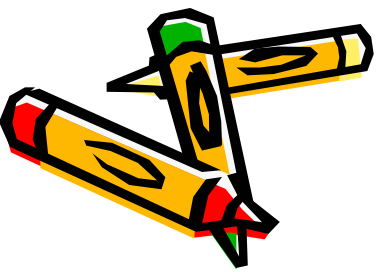
- EtheReal
  - end nodes and operating systems untouched
  - protocol is supported by services on switch only
  - services are accessible by end nodes using user-level libraries
    - supports both real-time and non-RT traffic
    - reserve bandwidth for RT traffic



Conclusions

- The popularity of Ethernet has made it attractive for use in areas like real-time traffic, where it was not originally designed.

- Through manipulation of the bus arbitration, addition of transmission control layers and/or use of switching, some real-time applications can take advantage of Ethernet for real-time communication.



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