# Ethernet in Automation: Technological Advances towards Real-time Communication

*Overview and Current Research Trends*

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## Short Biography

- **M.Sc. Degree in Electronic Engineering** from the University of Catania, Italy (1994)
- **Ph.D. in Computer Engineering (1998)**

  Thesis: "Open Issues in time-critical distributed systems for process control"
- **Lecturer at the University of Catania** since A.Y.1997-98
- **Awarded a 4-year research scholarship (1999)**

  Project: "Advanced Systems and Technologies for Distributed Information Management in Real-Time Environments"
- **Post-doctoral position** as a Visiting Researcher at the College of Engineering of Seoul National University, Seoul, South Korea (Aug. 2000 - Feb. 2001)
- **Assistant Professor with tenure** at the Department of Computer Engineering and Telecommunications, University of Catania, Italy (since June 2001)

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## My Research Interests

- **Real-Time Systems**
- **Computer Networks**
- **Distributed Operating Systems**

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## My Research on Real-Time Systems

**Main Application Areas:**
- Process Control Systems
- Embedded Systems
- Multimedia Systems
- Wireless Systems

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## My Research on Real-Time Systems

- **Task Allocation and Scheduling**
  - to ensure that timing requirements of real-time applications are met
- **Real-Time Communication**
  - Fieldbus Protocols
  - Transmission Scheduling Algorithms
  - Network Interconnection Architectures
- **Real-Time Databases**
  - Architectures and Algorithms for Transaction Management and Scheduling

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## Presentation Overview

- Traffic requirements and network infrastructures in Distributed Process Control Systems (DPCSs)
- The need for harmonisation
- Motivation for using Ethernet in DPCSs
- Advances in Ethernet technology
- Switched Ethernet and Shared Ethernet in DPCSs
- Approaches to improve the r-t performance of a Shared Ethernet
- Statistical real-time communication over Shared Ethernet
- Conclusions and open issues

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## Functional Levels in DPCSs

- Modern DPCSs organise plant activities hierarchically into 3 functional levels:
  - **Factory** level
  - **Cell** level
  - **Field** level

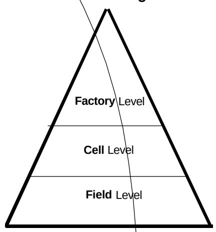
- These levels feature **applications** with different **requirements** in terms of **temporal constraints and bandwidth**

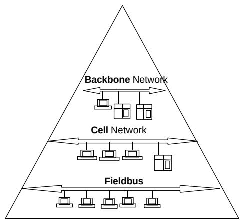
  - Passing down to the lower levels in the automation hierarchy, temporal constraints become more stringent.



## Network Levels in DPCSs

To take different traffic requirements into account, communication architectures are also organised as **levels of networks** using different communication protocols



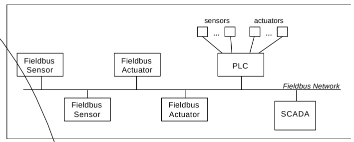



## Network Levels in DPCSs

- **Backbone level networks**:
  - high bandwidth, fault-tolerance
  - ATM and FDDI are generally used
- **Cell–level networks**:
  - both soft real-time and non real-time traffic
  - Ethernet or token-passing based protocols
- **Fieldbuses**:
  - real-time with more or less critical **deadlines**
  - Deadlines depend on the dynamics of each control sequence
    data acquisition → processing → corrective action



## Fieldbuses




- Fieldbuses replace the previously used point-to-point connections based on the 4-20 mA current-loop standard
- Fieldbus protocols can be
  - **distributed**: e.g. Profibus, P-Net, CAN
  - **centralised**: e.g. WorldFIP, IEC/ISA Fieldbus



## The Need for Communication Harmonization in DPCSs

- **Heterogeneity** between the various levels of the communication hierarchy
  - causes problems of **incompatibility**
  - complicate the exchange of information between different levels.

- At the Field level, when different Fieldbus protocols are used, inter-communication and interoperability problems also arise.

- Thus manufacturers and users are currently showing great interest in **harmonising** the whole communication infrastructure of the plant.

- The use of a **single network** could overcome the limits of current systems.



## Why Ethernet in Automation?

Ethernet technology seems to be the most natural candidate for **several reasons**:

- **Low Cost**
  Thanks to the great availability of manufacturers, Ethernet boards and devices (e.g. switches, hubs) are cheaper than other technologies.
- **Enhanced Performance**
  Recent advances in Ethernet technology have improved its performance greatly (Fast Ethernet, Gigabit Ethernet, Switched Ethernet, etc.)
- **Maturity and Stability**
  Achieved through its wide deployment and acceptance
- **Low Overhead for technicians or network administrators**
  The change from 10 Mbps Ethernet to Fast Ethernet or Gigabit Ethernet only entails an increase in know-how as compared with the greater effort required to acquire expertise in other technologies.

## Ethernet in Automation

**Even at the Field level the possibility of using Ethernet is attractive**

▪the use of a single network makes it possible to overcome the inter-communication and interoperability problems due to the use of different Fieldbus systems.

▪the bandwidth offered by an Ethernet is typically higher than that offered by Fieldbus systems.

However, as field devices mainly exchange small-size data, due to the overhead introduced by the Ethernet frame size, the data throughput obtained is significantly less than the available bandwidth.



## Ethernet in Automation

Some of the Organizations involved in the effort:

▪ **IAONA (Industrial Automation Networking Alliance)**,

founded in the USA with the aim of establishing Ethernet as the standard in the industrial environment

*http://www.iaona.com*

▪ **IAONA Europe,**

founded in Europe with the aim of promoting the use of open networking in industrial and embedded applications *http://www.iaona-eu.com*

▪ **IEA (Industrial Ethernet Association)**,

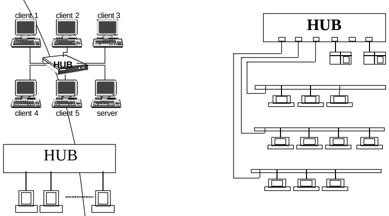
founded to establish standards for the use of Ethernet products in the industrial marketplace

*http://www.industrialethernet.com*



## Shared Ethernet

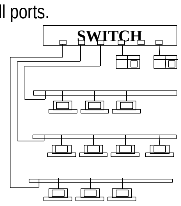
**Shared Ethernet:** the physical medium is either a bus or a hub, so all the generated traffic is broadcast to every station in the network and collisions may occur.






## Switched Ethernet

**Switches:** "intelligent" hubs which examine the destination address of each incoming frame and send it only to the required ports, rather than simply broadcasting it to all ports.






## Switched Ethernet

**Switches regenerate packets and possess filtering and forwarding functionalities**

**Filtering:** ability to determine whether a frame should be forwarded or dropped

**Forwarding**: ability to determine the port(s) to which a frame should be sent

Switches examine destination and source addresses of the incoming frame and compare them to a **table** of network segments and addresses.

If the segments are the same, the packet is dropped (**filtered**).

Otherwise the packet is **forwarded** to the proper segment.



## Switched Ethernet

**Switches vs. Bridges**

▪ Bridges possess filtering and forwarding functionalities, but lack of some additional features provided by switches

▪Switches have a larger number of ports

**Switches vs. Routers**

Routers

▪forward packets using network-layer addresses

▪before forwarding the packet, make change in it

▪introduce more processing overhead, as they have to process frames up through Layer 3

## Advantages of Switches

**Switches**

- prevent bad packets from spreading by not forwarding them
- are "**self-learning**"
- use a **Spanning Tree Protocol**

to prevent cycling and multiplying of frames in the presence of multiple redundant paths between LAN segments

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## Advantages of Switches

**Switches**

- are easy to install (**plug-and-play** devices)
  - no configuration is needed at installation time or when a host is removed from a LAN segment
- can connect **different LAN technologies** (e.g. 10 Mbps and 100 Mbps Ethernets, 100 Mbps and 1 Gbps)
- offer **high-speed links**
  - to link the switches together (creating a "collapsed backbone" network) or
  - to give added bandwidth to important servers getting a lot of traffic

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## Advantages of Switches

- Switches make each network segment an **indipendent collision domain (segmentation)**
- As switches have a large number of ports, **dedicated access** can be provided by direct connection of a host to the switch

**micro-segmentation**: i.e. a separate switch port for each host

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## Advantages of Switches

- Some switches can operate in **full duplex mode**

They can send and receive frames at the same time over the same port

- **micro-segmentation + full-duplex operation**: a way of improving real-time performance

In this case contention and collisions are removed, so there is no need for CSMA/CD and Binary Exponential Back-off

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## Ethernet in Automation

Typically, manufacturers of communication systems for process control recommend an **extensive use of switches** (even **micro-segmentation**)

Pros.

- the designer can cluster stations into **separate collision domains**

Cons.

- **expensive**
- no optimal usage of the **bandwidth**

when only a small portion of the bandwidth offered by each switch channel is actually used by a single connected host.

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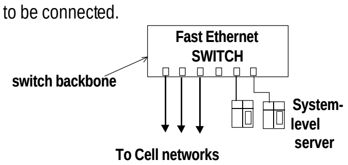
## Ethernet in Automation

**Backbone level**: the main performance parameter is **throughput**

A Fast Ethernet switch can be used, with a number of ports equal to the number of Cell networks to be connected.

**A collapsed backbone through a Fast Ethernet switch**




The large bandwidth offered by the switch can easily support the typically high traffic flows at this level (e.g., company database backup operations, file transfers to download applications, etc.).

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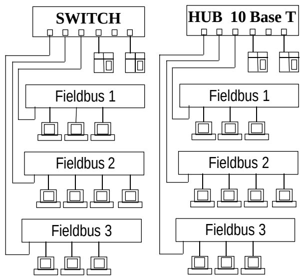
## Ethernet in Automation

**Cell level**: the main performance parameters are **throughput** and **timeliness**

Cell networks have to support communications between devices (typically workstations) and between Fieldbuses which may have real-time constraints.

Also
- **cost** of network devices
- **simplicity** of **configuration** can be considered




**Switch–based Cell Network** **Hub-based Cell Network**



## Ethernet in Automation

- **Hub-based Cell network:** the Cell network and all the Fieldbuses will constitute a single collision domain

  As the total traffic volume (i.e. Cell + Fieldbus traffic) increases, there may be a performance degradation for both the system as a whole and the single Fieldbuses.
- **Switch-based Cell network:** creates separate collision domains thus reducing the interference between the various Fieldbuses

  Also, switches allow full-duplex operation.

**The use of a switch at the Cell level appears to be preferable to that of a hub**

The higher cost of switch than a hub is not of great significance here, due to the low number of switches required for networks at the Cell level.



## Switched Ethernet in Automation: Backbone and Cell level

At the **Backbone** and/or **Cell level**, the use of switches enables to exploit some features that recent advances in switching technology offer

- **micro-segmentation**
- **the capability to build Virtual LAN** (VLANs)
- **traffic prioritisation**
- **flow control**



## Switched Ethernet in Automation: Backbone and Cell level

- **VLANs**
  - allow stations on multiple physical LAN segments to communicate as if they were on a common LAN without being constrained by their physical location
  - give a chance for flexibility and mobility of stations across multiple LAN segments

  - VLANs can be really appealing at both the Backbone and the Cell level, where
    - the various network compartments do not operate in total isolation (as nodes belonging to different compartments or manufacturing cells can need to exchange data)
    - it may happen that stations move across network segments.



## Switched Ethernet in Automation: Backbone and Cell level

- **traffic prioritisation:** according to IEEE 802.1p specification, Layer 2 switches are given the ability to support different traffic classes using **priorities** (priority fields have been defined by the IEEE 802.1Q specification)

Pros. This allows to handle data according to its temporal constraints

Cons.
- a **multiple-queue hardware is required** to handle traffic priorities as switches should employ multiple buffer queues for each output port
- in full-duplex switches **congestion** on a given port remains a problem



## Switched Ethernet in Automation: Backbone and Cell level

- **flow control capabilities** throttle devices which send traffic when a switch is overloaded, thus reducing potential frame loss due to congestion
  - **Link-to-link**
  - **End-to-end**

- Pros. : better throughput
- Cons.
  - latency (and traffic because of the "pause frames") added to a potentially congested segment or to an uncongested one
  - the need for buffers is reduced, but not eliminated

  Related problems, such as switch buffers sizing and full buffers handling, have to be dealt with in the network design (back-pressure flow control or packet dropping to handle full buffers)

## Switched Ethernet in Automation: Field level

**Field level**: both real-time (with more or less critical time constraints) and non-real-time traffic is exchanged

**Pros and Cons of micro-segmentation at the field level**

- Pros. It can guarantee deterministic and reduced access times
- Cons.
  - **it is quite expensive** due to the high number of switches needed at this level
  - **its use is not fully justified**
    as some of the attractive features of Switched Ethernet become less significant in the context of field devices interconnection
  - **it wastes a large amount of bandwidth**
    as in general a field device actually requires only a small portion of the bandwidth offered by each switch channel

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## Ethernet in Automation: Field level

To better utilise the bandwidth, **hubs** could be used instead of switches at the Field level

**Shared Ethernet** is a candidate

In order to obtain the required performance levels (in terms of timeliness in data delivery)

- the network has to be accurately sized
- suitable channel access mechanisms to bound packets delay are needed

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## About non-determinism in Shared Ethernet

- **In the absence of collisions, a packet will have a bounded access time**
  i.e. the max lenght of an Ethernet packet + the interframe gap
- **Collisions cause unpredictable delays due to the Binary Exponential Back-off algorithm**
  the delay which a packet experiences depends on the number of trials it undergoes until it is successfully transmitted

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## The Binary Exponential Backoff collision resolution protocol

- When a packet collides with another packet, BEB sets the **backoff time** for the packet indicating when to try its retransmission
- The backoff time is **randomly** chosen from **$\{0, 1, \ldots 2^{m-1}\}$*slot_time**
  - **m := min {10, n}**
  - **n** is the **number of times the packet has collided** with other packets
  - **slot_time** is **512 bit times** (in Ethernet 51.2 μs, in Fast Ethernet 5.12 μs)

The **range** of **backoff time increases** with **the number of times a packet collided** with other packets

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## About non-determinism in Shared Ethernet

As a result:

- **Non-determinism**
  Packet delivery deadlines cannot be deterministically guaranteed
- **Unfairness**
  Packets which have already experienced collisions may experience more collisions during their retransmissions

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## Shared Ethernet

**Consequences of unfairness**:

**- Capture Effect**

Under a high load, a station may hold the channel for consecutive transmissions, even if the contending stations have even more critical packets to transmit

The station winning the contention resets to zero the value of n

**- Packet Starvation**

High delays at offered loads of 40%

Complete starvation of some packets at offered loads as low as 60%

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## Shared Ethernet

To enforce a predictable timing behaviour in Ethernet networks

- **collision avoidance techniques**
- **methods to modify the Ethernet collision resolution protocol**
- **solutions to enforce fairness**
- **approaches to provide a statistical bound on the channel access time of Ethernet**

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## Collision avoidance techniques for Shared Ethernet

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

**Pros**: by reserving each station a time interval to transmit its packets a collision-free Ethernet is realised

**Cons**: non-flexibility, possible bandwidth waste

- **Virtual token-passing mechanisms (RETHER, TEMPRA)**

Non R-T mode: CSMA/CD

R-T mode: (virtual) token passing (RETHER) or timed-packet release access mechanism (TEMPRA)

**Cons:**

- inefficiency due to mode switching overhead
- the use of special hw-sw platforms, not Ethernet-compatible, is required

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## Collision avoidance techniques for Shared Ethernet

- **Predictable CSMA (PCSMA)**

Requires an off-line message-oriented traffic scheduling, assuming that

- all the r-t traffic is periodic
- each station has a global knowledge about all the generated messages (period, length, etc)

**Pros**: a collision-free Ethernet is realised if there is no NRT traffic

**Cons**: limited applicability, overhead due to the off-line scheduling

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## Methods to modify the Ethernet collision resolution protocol

- **CSMA with Deterministic Collision resolution (CSMA/DCR)**

The BEB is replaced by a deterministic binary tree search algorithm

- after a collision, instead of using BEB, messages are scheduled according to a station address-based policy

Cons: it cannot schedule messages according to their r-t constraints

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## Methods to enforce fairness in the Ethernet MAC

For soft-real-time applications

- **Approaches to avoid the capture effect**

CABEB, BLAM: manage the collision counter differently from BEB - BLAM also implements a channel holding time

- **Prioritised -CSMA: TDMA-like with message priorities**

The channel time is divided into n slots (n is the number of priority levels)

No collisions between different priorities may occur

A random delay is used to solve collisions between messages having the same priority

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## Methods to enforce fairness in the Ethernet MAC

- **Virtual Time Protocols**

Use a packet release delay mechanism: the delay time depends on a message parameter (i.e. laxity or priority)

- **Window Protocols**

If a station has a message within some time/priority window, it is allowed to transmit (for example, on a FCFS basis). The window size dynamically changes depending on the channel state.

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## Methods to statistically bound the channel access time

▪**Traffic Smoothing techniques** realise a **statistical r-t channel** over an Ethernet

A statistical bound on the channel access time is obtained by limiting the packet arrival rate at the MAC layer.



## Deterministic vs Statistical r-t communication

For **general-packet switching networks** we define

- **deterministic real-time channel:** a unidirectional virtual connection between two end-points that provides *a priori* deterministic guarantees for the timely delivery of packets
- **statistical real-time channel:** a unidirectional virtual circuit that guarantees the timely delivery of packets in statistical terms,

i.e. that the probability that a packet is lost during its transmission or misses its deadline is less than a certain **loss tolerance Z**.

**Pr(end-to-end packet loss)** £ **Z**

or

**Pr(packet delay>delay bound)** £ **Z**



## Statistical r-t communication over Ethernet

In Ethernet networks the delay which a packet experiences depends on the number **n** of trials it undergoes until it is successfully transmitted

New def. of **statistical real-time channel** over an **Ethernet:**

*a packet of a statistical real-time channel over an Ethernet must satisfy the following condition:*

***Pr(n £ K) > 1-Z*** ***(a)***

The number of trials can be related to the delay as follows:

**$D_K^*$ : worst case delay** of a packet when its transmission has succeeded at its $K^{th}$ trial,

from (a) the following condition holds

**Pr (D £ $D_K^*$) > 1-Z** **(b)**



## Statistical r-t communication over Ethernet

To provide a **statistical bound** on the channel access time of Ethernet, a **sufficient condition is:**

**limiting** the total arrival rate of newly generated packets from the stations under a threshold called the ***network-wide input limit***

In the literature:

- ▪an analysis to derive the threshold for CSMA-CD 1-persistent with the Binary Exponential Back-off collision resolution protocol
- ▪the relationship between **packet delay** distribution and network **utilization**



## Statistical r-t communication over Ethernet

As the Ethernet MAC protocol is **fully distributed**, each station

- cannot know the current instantaneous network-wide packet arrival rate
- can only regulate its own packet arrival rate

In order to keep the network utilization (total arrival rate) below the threshold, a ***station input limit*** is assigned to each station



## Statistical r-t communication over Ethernet

The network-wide input limit can be distributed among stations according to their needs

In each station, a local **traffic smoother**

regulates the packet stream arriving from the application programs so that the packet arrival rate at the MAC layer is kept below the given **station input limit**

## Traffic smoothing

**Only non-R-T traffic is affected by smoothing**

Only non-RT packets are delayed to keep the station traffic arrival rate (which includes both RT and non-RT traffic) under the station input limit.

Within a node, RT packets are distinguished from non-RT packets using the TOS (Type Of Service) field of IP header

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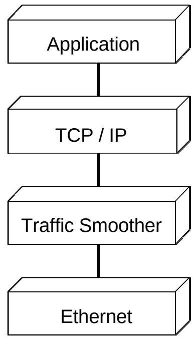
## Traffic smoothing

The traffic smoother is a software layer which

- is **inserted** between the TCP/IP and the Data Link layer
- buffers any non real-time packets arriving in a burst and sends them in such a way that their arrival at the MAC layer is staggered, thus keeping the arrival rate below the *station input limit.*
- requires only a **minimal change** in the OS kernel
- does not require changes to the current standard of Ethernet MAC protocol or TCP/IP stack

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## Traffic smoothing

The traffic smoother is implemented by using a **leaky bucket-based** algorithm

- *A* **credit bucket depth** (CBD), which indicates the capacity of the credit bucket, and a **Refresh Period** (RP) are defined.
- Every RP seconds, up to CBD credits are replenished.

If the number of credits exceeds the value of the CBD, any excess credits are discarded.

A real-time packet is not affected by smoothing, but its transmission does consume credits.

Non r-t traffic in a station is transmitted using any credits that are left over after the transmission of the real-time traffic for that station.

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## Leaky bucket-based algorithm

When a non-real-time packet arrives from the IP layer,

- if there is at least one credit in the bucket, the packet is sent

the traffic smoother removes a number of credits equal to the size in bytes of the packet;
if there are too few credits in the bucket for the size of the packet, they are “borrowed”, so the number drops to a negative value.

- if the number of credits in the bucket is less than or equal to zero,

the packet is not transmitted to the Ethernet NIC Ethernet until at least one credit becomes available following a replenishment.

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## Traffic smoothing

- Traffic smoothing is needed especially when packets arrive in a burst

Packets are more likely to collide when they arrive in a burst than arriving sporadically

- The CBD/RP ratio is the *station input limit* and determines the average throughput available for a station

By varying the values of RP and CBD it is possible to control the bursty nature of a flow of packets and thus of the traffic generated by the single stations

- Smoothing bursty packet streams will enable the packet arrival process to be modelled as a Poisson process

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## Static Traffic Smoothing

- The **network-wide input limit is fixed**

It depends on packet deadlines and tolerable packet-loss (or deadline miss ratios)

- the **smoothing** is said to be **static** when also the **station input limit** is **fixed**

- **Static smoothing** assigns each station a fixed maximum transmission rate **irrespectively** of the **actual load** currently on the network

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## Static Smoothing: Pros and Cons

**Pros:** no need for each station of monitoring the traffic produced by all the other stations

**Cons:**

- **unflexibility,** possible bandwidth **under-exploitation**

The *station input limit* assigned to each station

- is based on a worst-case assumption, i.e. all the burst stations transmitting at the same time
- does not change even if the actual load currently on the network is significantly below the *network-wide input limit*

- **unscalability when the number of stations is high**

as the station input limit depends on the **max** number of nodes which may generate non-r-t traffic

In large-scale LANs, non-real-time traffic, like ftp traffic, may experience a **large delay** because of a **small** station input limit

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## Dynamic Traffic Smoothing

**Dynamic (adaptive) smoothing:**

dynamically modifies the *station input limit* a station is assigned according to changes in the network load**,** while keeping the arrival rate below the network-wide input limit

In this way the traffic generation rate of each station is no longer fixed, but adapts itself to the underlying network load condition

This improves bandwidth exploitation as well as scalability and offers a better throughput for non-RT packets

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## Dynamic Traffic Smoothing

**How to acquire knowledge of the current network workload?**

A suitable **user process** in each machine (called a sniffer process) can monitor the global traffic trends

Different approaches can be used, such as

- the measurement of **throughput**
- the **number of collisions**

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## Dynamic Traffic Smoothing

In Ethernet-based networks any transmitted frame is listened to by all the other stations

Normally only the destination station processes the frame, but it possible to modify Ethernet boards so as to make them function in a *promiscuous* mode

**Promiscuous mode**:

the network interface processes each frame transiting through the network and passes it to the kernel of the operating system

To avoid overloading the operating system kernel, it is necessary to prevent the kernel from processing the frames in their entirety, thus consuming a large amount of CPU time

The problem can be solved:

1. reading not the entire frame, but only the IP packet header or a part of it.
2. reading only frames from stations which can transmit non real-time traffic

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## Dynamic Traffic Smoothing

Different approaches have been proposed in the literature to evaluate the network load for dynamic smoothing purposes

- the **Harmonic-Increase and Multiplicative-Decrease** (HIMD) adaptation algorithm to react to the detection of a single collision over a given interval

The RP is doubled when a packet collision is detected, while in absence of collisions it is periodically increased by a constant

Drawback: reacting to a single collision increases the responsiveness of the smoother, but can cause instability problems

- **a feedback-based mechanism** using the measurement of either throughput or the number of collisions in a certain time interval

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## Dynamic Traffic Smoothing

Example: **adaptive smoothing based on throughput control**

The adaptation is realised by changing the refresh period, RP, according to the throughput measured over an interval $\tau$, while keeping the CBD value fixed.

If the throughput value exceeds the pre-established threshold,

the RP is increased by the maximum between twice its current value and a given $RP_{max}$ value.

If the throughput does not exceed the threshold,

the RP is decreased by a quantity $\Delta$ (equal to 50% of the initial RP) down to a value of $RP_{min}$.

The adaptive smoothing based on the number of collisions works in the same way, but what is counted is the number of collisions a station is affected by in the interval $\tau$.

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## Performance Evaluation of Traffic Smoothing

**Network and simulation parameters**

- Data Rate:10 Mbit/s
- Interframe Gap:9.6 µs
- Min Frame Length:512 bits
- Max Bus Length:2500 m
- Number of Repeaters:4
- Repeater Delay:3.2 µs
- Simulation Time:600 s



## Performance Evaluation of Traffic Smoothing

**First simulation: no bursts, no traffic smoothing**

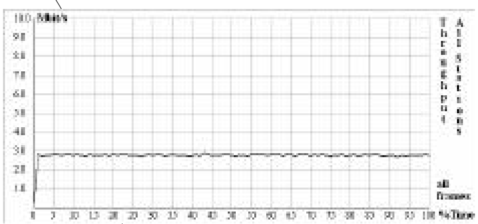
- 10 stations generating the same amount of real-time cyclic and acyclic traffic
  - Cyclic (periodic) Workload: 329 frames/s, Cyclic Frame Length: 512 bits
  - Acyclic (sporadic) Workload: 35 frames/s, Average Acyclic Frame Length: 6000 bits
  - Traffic Function:Exponential
- The overall bandwidth consumed by data field is
- 1 Mbit/s for cyclic traffic
- 2 Mbit/s for acyclic traffic.

The maximum throughput will be 3 Mbit/s.

- This simulation is useful to see the original performance of the network without burst traffic.

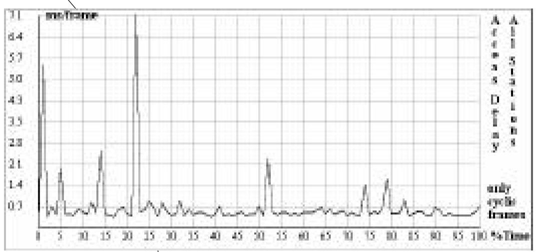


## Throughput without bursts





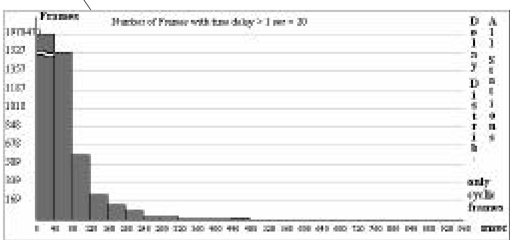

## Average Access delay without bursts






## Average Access delay without bursts

Almost all the cyclic frames access the channel within 40 ms.



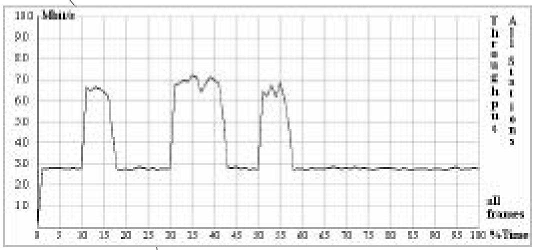



## Dynamic Traffic Smoothing

- 5 stations were added to the previous scenario, transmitting bursts of non real-time traffic.
- the performance of the network was observed without smoothing as well as using both dynamic and static smoothing.

| | Workload | Frame Length | Start Burst | End Burst |
|---|---|---|---|---|
| **Station 11** | 1000 frames/s | 12208 bits | 10% | 12% |
| **Station 12** | 1000 frames/s | 12208 bits | 30% | 32% |
| **Station 13** | 1000 frames/s | 12208 bits | 31% | 33% |
| **Station 14** | 500 frames/s | 12208 bits | 50% | 52% |
| **Station 15** | 500 frames/s | 12208 bits | 53% | 55% |

## Throughput with bursts - no smoothing

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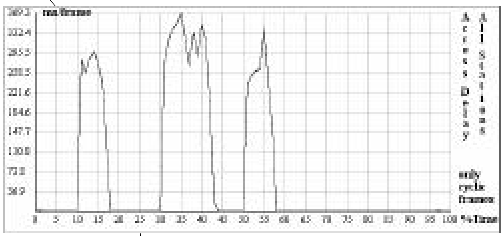
## Average Access delay with bursts - no smoothing

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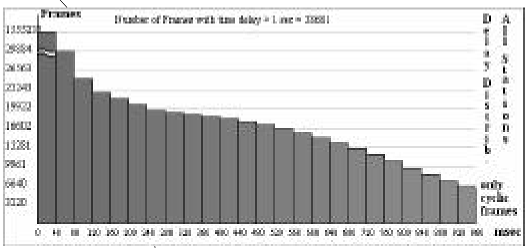
## Delay distribution with bursts - no smoothing

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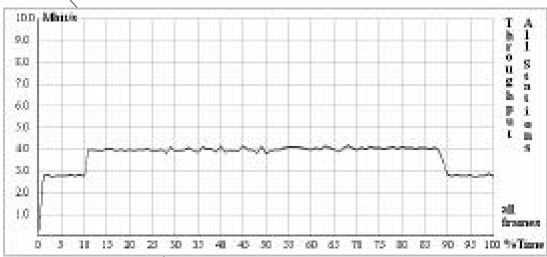
## Throughput with Dynamic Smoothing

The network-wide input limit was fixed equal to 4 Mbit/s.

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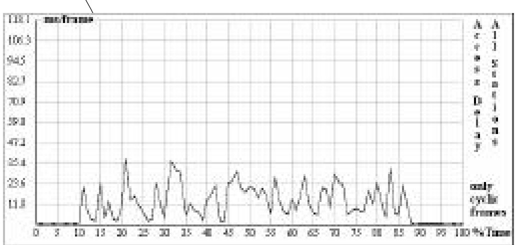
## Average Access delay with Dynamic Smoothing

The average access delay is considerably lower than that obtained without smoothing

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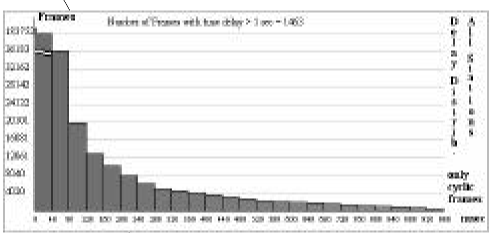
## Delay distribution with Dynamic Smoothing

The number of cyclic frames that take more than a second to access the channel is 1463 as compared with 38681 when no smoothing is used

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## Static Traffic Smoothing

For the sake of simplicity the available bandwidth was assumed to be equally shared between the five stations transmitting non-real-time traffic

Each burst station was assigned 200 Kbit/s.

- The parameters for the leaky bucket algorithm were :

CBD = 2 kbit, RP = 10 ms.

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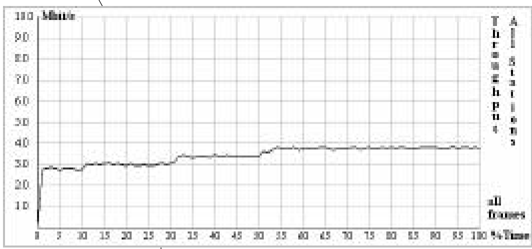
## Throughput with Static Smoothing

Each burst station only used the available bandwidth and the bursts continued beyond the end of the observation period

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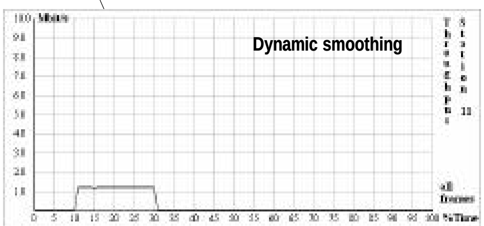
## Dynamic vs. Static Smoothing

Let us compare the time taken by station 11 to transmit its burst with dynamic smoothing and with static smoothing.

Dynamic smoothing allows stations transmitting non real-time traffic to be served as fast as possible, without exceeding the network-wide input limit

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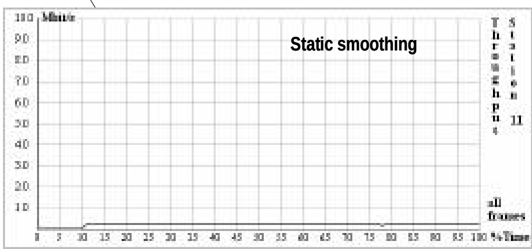
## Dynamic vs. Static Smoothing

Using static smoothing it takes a considerable time to complete transmission

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## Dynamic vs. Static Smoothing

- The access times for cyclic frames in both cases are comparable.
- Static smoothing cannot cause worse delays for r-t traffic as it is more restrictive than dynamic smoothing.
- The same holds for the delay distribution for cyclic frames.

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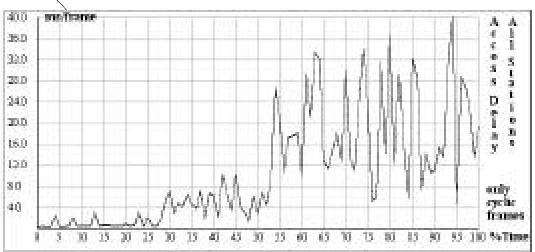
## Average Access Delay - Static Smoothing

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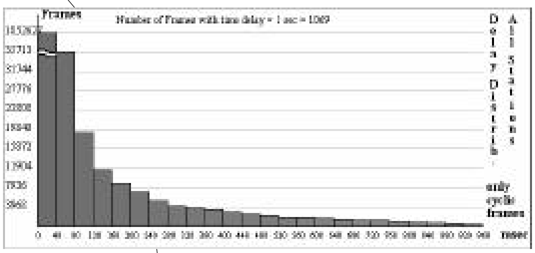
## Delay Distribution- Static Smoothing






## Static vs. Dynamic Smoothing

Dynamic Smoothing

- uses the available bandwidth more efficiently than static smoothing
- tries to meet the requirements of burst stations as much as possible
- keeps the total arrival rate of new packets below the network-wide input limit.



## Conclusions

- Dynamic smoothing improves both the real-time features of a Shared Ethernet and its performance in general.
- It greatly reduced the amount of bandwidth wasted, thus providing shorter transmission times for the non real-time stations
- The satisfactory results obtained with dynamic traffic smoothing can be further improved by partitioning the network into separate collision domains through use of a full-duplex switch.



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**The End**