Design and Performance Evaluation of a New Spatial Reuse FireWire Protocol

Master's thesis defense
by
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VC001 (vijay.ppt - 09/18/03)

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Topics

- Motivation
- Contributions
- Background
- Design of Spatial Reuse FireWire Protocol (SFP)
- Performance evaluation of SFP
- Conclusion

VC003

Motivation

- Video surveillance systems with *thousands* of cameras are needed
  - For monitoring of stadiums, airports, runways, etc.
- Existing dedicated medium networks are too costly
  - The wire cost can exceed the camera cost!
- Wireless is not a solution
  - Not enough bandwidth
  - Need wiring in any case for power to cameras
- What is needed are new *shared-medium* protocols
  - Daisy-chained networks
  - High speed
  - Suitable for variable bit-rate video traffic

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Contributions

1) Review of networking technologies for video surveillance

2) Performance evaluation of FireWire for video transport

3) Design and performance evaluation of SFP
– SFP = new Spatial reuse FireWire Protocol

Attributes of SFP are:

- Increases throughput of a FireWire
- Adds QoS support for video

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Background

• Existing video surveillance systems are human monitored
  – Places a limit on the number of cameras

• Future video surveillance will be image processing driven
  - Large number of cameras
  - Cameras are very low cost
  - Image processing in the camera

• There are three generations of video surveillance systems…
  – Generation 1 – *Existing*
  – Generation 2 – *Emerging*
  – Generation 3 – *Future*

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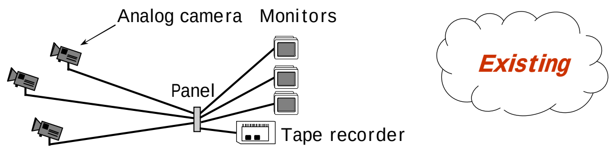
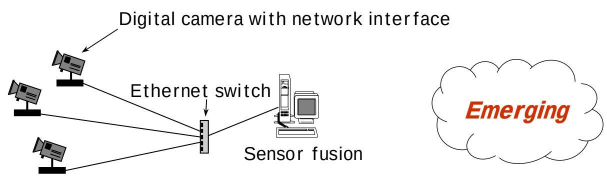
Background continued



Dedicated coax cables, analog transmission. No processor in cameras.



Dedicated twisted-pair cables, encoder in cameras (processor possible).

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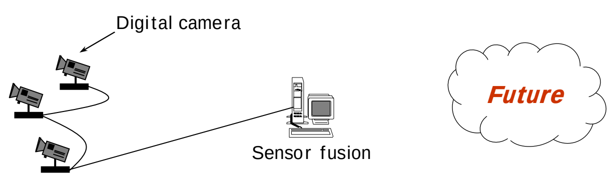
Background continued



Shared-bandwidth, twisted-pair or fiber cables. Processor in cameras.

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Background **continued**

Overview of FireWire

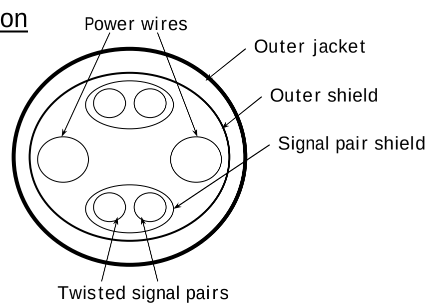
- Serial bus technology, Apple (1987)
- Shared-medium daisy-chained topology (tree), built-in power
- 63 nodes in a bus (repeat path),
- Up to 1024 buses can be bridged

	IEEE 1394	**IEEE 1394a**	**IEEE 1394b**
Internode distance	4.5 meters (max)	4.5 meters (max)	100 meters (max)
Maximum hops	16	63	63
Physical medium	STP	STP	STP, POF, MMF
Cable bandwidth	100, 200, 400 Mbps	100, 200, 400 Mbps	Up to 1.6 Gbps
Loop prevention	No	No	Yes
Arbitration	Large idle gaps	Small idle gaps	No idle gaps

VC009

Background **continued**

FireWire cable cross-section



FireWire transactions

Asynchronous – Guaranteed in delivery
Isochronous – Guaranteed in time (reserved bandwidth)
Asynchronous streaming – Guaranteed neither in time nor delivery

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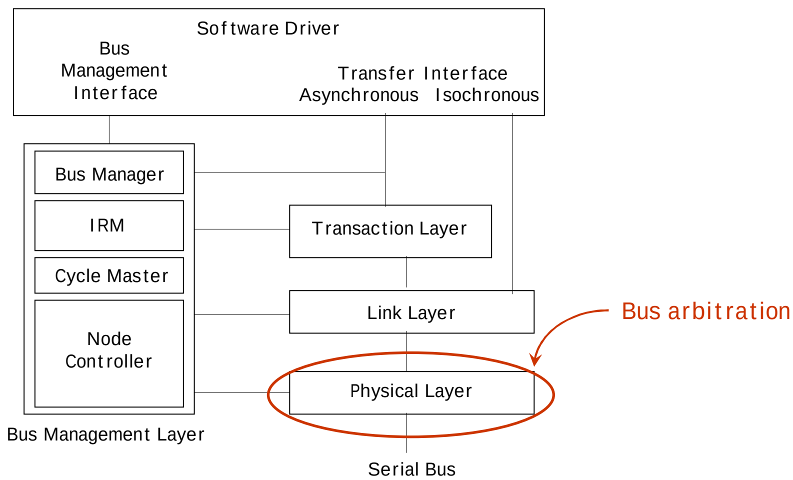
VC010

Background continued

FireWire protocol stack



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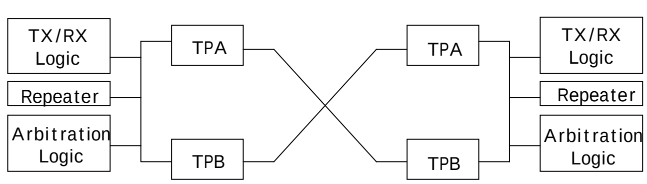
Background continued

FireWire data transmission interface



- Two twisted pairs cross wired between nodes

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Background continued

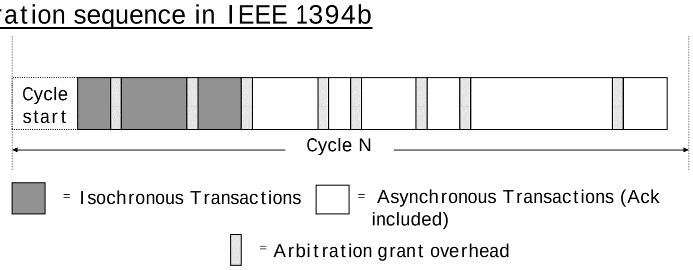
Bus arbitration in FireWire

- Nodes request the *bus owner* for access
- *Bus owner* makes the arbitration decision
  - *Bus owner* selects a best request and issues a grant
- Granted node can transmit data
  - Other nodes continue to request and wait for a grant
- Arbitration different in IEEE 1394, IEEE 1394a & IEEE 1394b
  - IEEE 1394b is full-duplex

VC013

Background continued

Arbitration sequence in IEEE 1394b



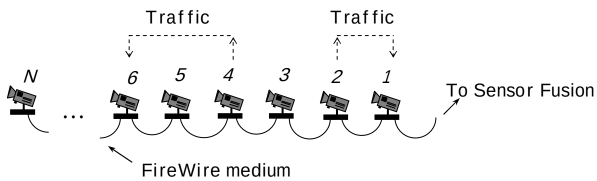
- The *bus owner* is the last node to complete data transmission
- The *bus owner* has "limited" knowledge about requesting nodes
- Arbitrations are overlapped with data transmission (full-duplex)
- Arbitrations are based upon a 125 microsecond cycle
- Arbitration requests and grants are 10-bit tokens

VC014

Background continued

Performance limitations in FireWire

1) Lack of spatial reuse or concurrent packet transmissions



- Entire network envisioned as a logical serial bus
- Throughput limited to single link capacity
- No destination stripping of packets

2) Lack of support for priority traffic
- Isochronous service lacks flexibility to support VBR video

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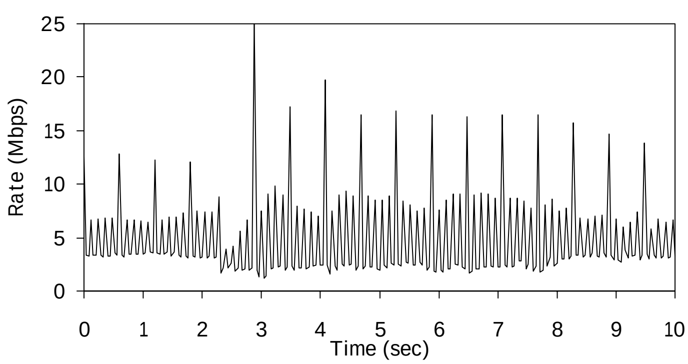
Background continued

Rate plot of an MPEG-2 video (mean data rate – 5 Mbps)



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Design of SFP

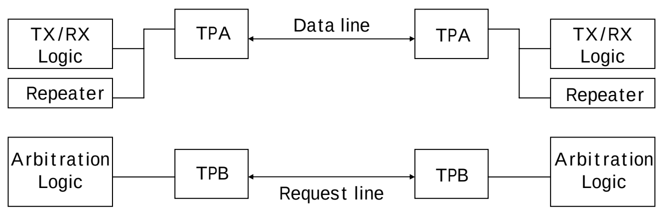
Overview of Spatial reuse FireWire Protocol (SFP)

- SFP is a **new** extension of the IEEE 1394b architecture
- SFP offers
  - spatial reuse of bandwidth (for improved throughput)
  - support for priority traffic (for real-time apps)
- SFP adds to IEEE 1394b
  - New data transmission interface that uses existing cable
  - Informative request packets
  - Caching of requests
  - Destination stripping of data packets

VC017

Design of SFP continued

SFP data transmission interface



- Twisted pairs TPA and TPB operate as independent half-duplex lines
- TPA carries data traffic.
  - TPA can operate in *blocking mode* or *repeat mode*
- TPB exclusively carries arbitration requests

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Design of SFP continued

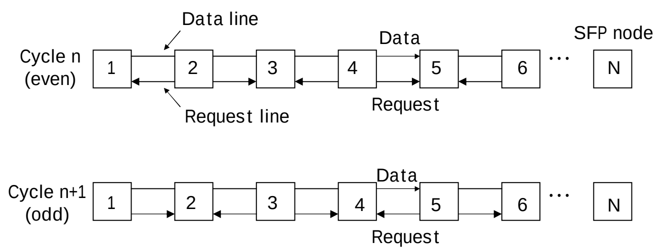
Overview of arbitration in SFP

- Nodes broadcast a request packet that is cached by every node
- *Bus owner* "selects" a group of requests from the cache
  - Selected requests (corresponding nodes) are granted
- A grant packet with information about granted nodes is broadcast
  - Granted nodes can transmit data

VC019

Design of SFP continued

Synchronous request transfer between nodes



- Each node caches incoming requests and retransmits
- Arbitration is continuous and independent of data traffic

VC020

Design of SFP continued

Each request packet contains the following fields of information:

- Source address of the arbitrating node
- Destination address of the data packet
- Arbitration phase, alternates between *Current* and *Next*
  - Arbitration phase ensures fairness among like priority nodes
- Size (in bytes) of the data packet
- Priority of the data packet, can be *High*, *Medium* or *Low*

VC021

Design of SFP continued

Arbitration schedule

- Arbitration is always done for head-of-line packet
  - In the highest non-empty priority queue
- *High* priority arbitrations are never preempted
- *Low* and *Medium* priority arbitrations may be preempted
  - If a higher priority packet is enqueued

VC022

Design of SFP continued

Arbitration scheduler algorithm

```
While (TRUE) do
    If (High priority transmit buffer has packets) then
        Send request packet with priority field = High
        WAIT (until a grant for request is received)
        Trigger packet transmit
    Else if (Medium priority transmit buffer has packets) then
        Send request packet with priority field = Medium
        WAIT (until a grant for request is received or a High priority packet is enqueued)
        If (grant for the request is received) then
            Trigger packet transmit
    Else if (Low priority transmit buffer has packets) then
        Send request packet with priority field = Low
        WAIT (until a grant for request is received or a High/Med priority packet is enqueued)
        If (grant for the request is received) then
            Trigger packet transmit
```

VC023

Design of SFP continued

Bus owner

- *Bus owner* makes the arbitration decision
  - Arbitrating decision is selecting a group of nodes for access
- *Bus owner* "identifies" its successor among granted nodes
  - Last node to complete packet transmission is next *bus owner*
- *Bus owner* broadcasts a grant packet
  - Each grant packet contains the following fields of information:
    1) Granted address list: addresses of all granted nodes
    2) Destination address list: addresses of destination nodes
    3) Arbitration reset status: TRUE or FALSE
    4) Address of the next *bus owner*

VC024

Design of SFP continued

Bus owner arbitration decision

- Group the requests in the cache into minimum number of sets
- Select a set containing at least one highest priority level request
- Issue grant to all requests (corresponding nodes) in the selected set

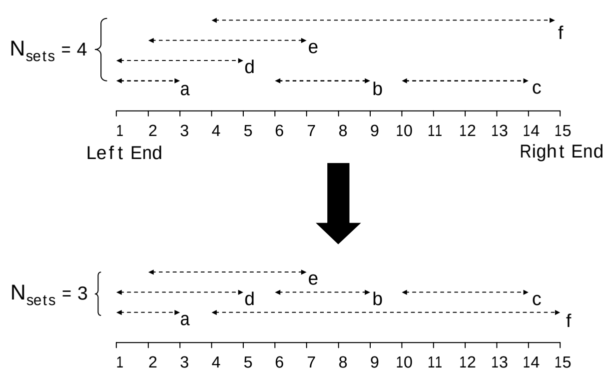
Priority levels in SFP

Priority class	Arbitration phase	Priority level
High	*Current*	1 (highest)
	Next	2
Medium	*Current*	3
	Next	4
Low	*Current*	5
	Next	6 (lowest)

VC025

Design of SFP continued

Grouping compatible requests into minimum number of sets



VC026

Design of SFP continued

Grouping compatible requests into minimum number of sets

- Each request has a *left address* and a *right address*
  - Each request has a unique "signature"
- Two requests can be placed in the same set
  - If *left address* of one is >= *right address* of the other

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Design of SFP continued

Algorithm for grouping requests

- Scan the requests in sorted order (based on *left* & *right* addresses)
  - Request cache ensures sorted ordering of requests
- A stack data structure is used, from Zhang and Dai [28]
  - To identify the request whose *right address* is recently seen
- If left address of a request is seen

  If stack is empty then

  place the request in a new set

  Else

  place the request in the same set as the one in stack top

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Design of SFP continued

Algorithm for grouping requests

For (each slot of the request cache) do
    For (i = 1 to number of requests for this slot) do
        If (R_i has associated flag set to 1) then
            Push R_i on the stack
    For (i = 1 to number of requests for this slot) do
        If (R_i has associated flag set to 0) then
            If (stack is empty) then
                index = index + 1
                Assign R_i to the set S_{index}
            Else
                Pop R from stack
                Assign R_i to the same set as R

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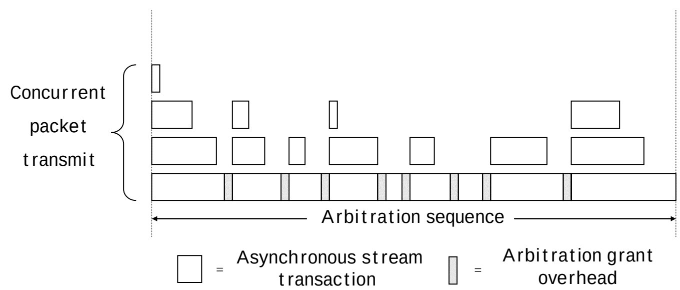
Design of SFP continued

Arbitration sequence in SFP



No isochronous service in SFP

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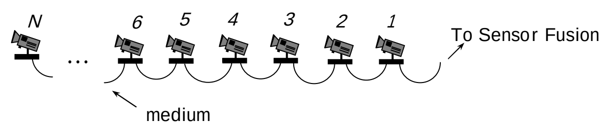
Performance evaluation of SFP

Evaluation done with CSIM-18 simulation models



Traffic models
- MPEG-2 traces [18], (mean bit-rate 5 Mbps)
- Poisson arrivals of fixed length packets

Traffic distribution between nodes
- Spatial_min (No spatial reuse, all packets to head end)
- Spatial_average (uniform distribution)
- Spatial_video (90% to neighbors 10% to head end)
- Spatial_max (all packets to right neighbor)

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Performance evaluation of SFP **continued**

Experiments on the performance of SFP and IEEE 1394b

- Experiment #1: IEEE 1394b, async stream vs. isochronous
  - Response variable is queuing delay
  - Control variable is number of nodes
  - MPEG-2 sources, 100 Mbps link bandwidth
- Experiment #2: SFP, IEEE 1394b, different traffic distributions
  - Response variable is queuing delay
  - Control variable is offered load
  - Poisson sources, 60 nodes, 400 Mbps link bandwidth
- Experiment #3: SFP, different traffic distributions
  - Response variable is queuing delay
  - Control variable is number of nodes
  - Poisson sources of 5 Mbps data rate, 100 Mbps link

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Performance evaluation of SFP continued

- Experiment #4: SFP, different fixed packet sizes
  - Response variable is maximum throughput
  - Control variable is packet size
  - Poisson sources, 100 nodes, 400 Mbps link bandwidth

- Experiment #5: SFP, priority traffic
  - Response variable is queuing delay
  - Control variable is offered load
  - 20% packets are *High*, 30% are *Medium*, and 50% are *Low*
  - MPEG-2 sources, 60 nodes

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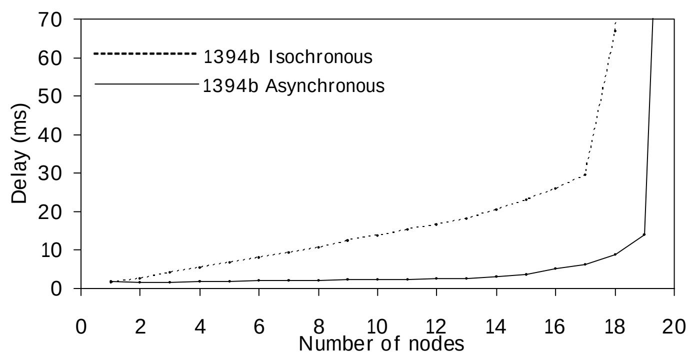
Performance evaluation of SFP continued

Experiment # 1 results



➡ Asynchronous streaming better than isochronous

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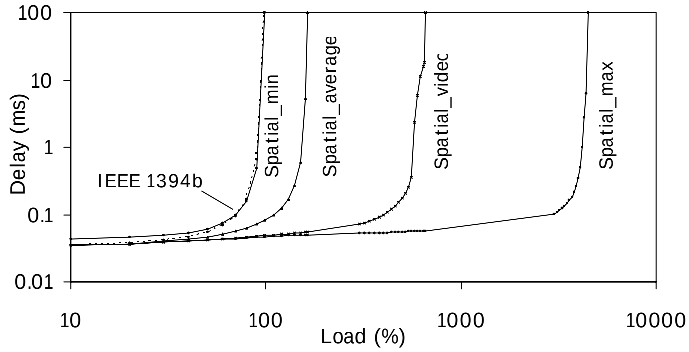
Performance evaluation of SFP continued

Experiment # 2 results



SFP throughput better than IEEE 1394b

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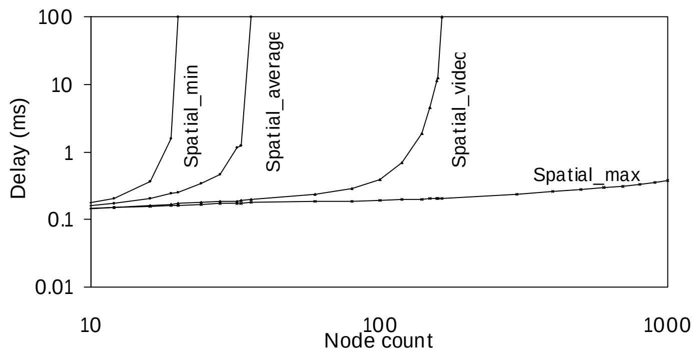
Performance evaluation of SFP continued

Experiment # 3 results



Spatial reuse results in higher node count

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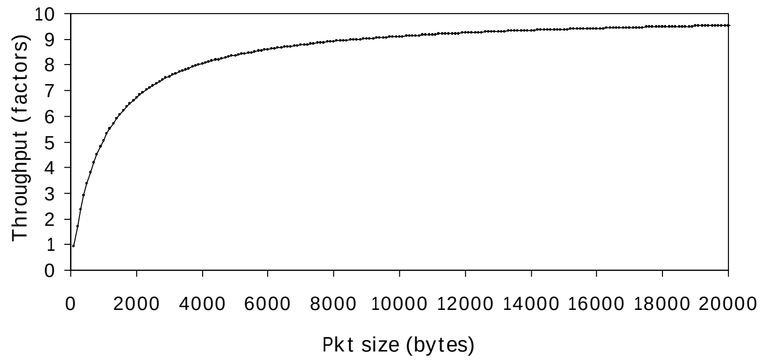
Performance evaluation of SFP continued

Experiment # 4 results



➡ Throughput increases with packet size

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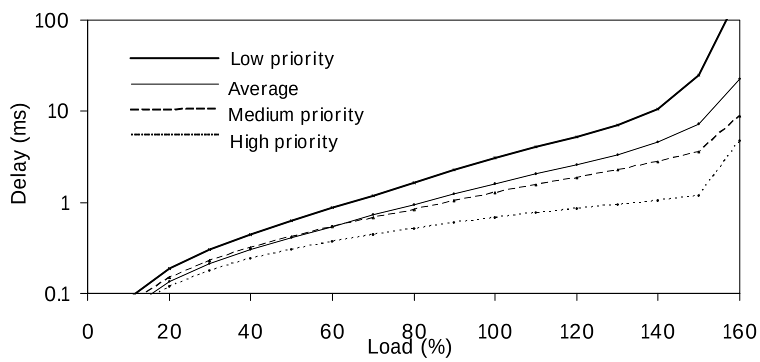
Performance evaluation of SFP continued

Experiment # 5 results



➡ Priority traffic have distinct delays

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Conclusion

Major contribution is

New low-cost SFP bus arbitration protocol for video surveillance networks that builds on the existing FireWire protocol

1) SFP improves the throughput of IEEE 1394b FireWire
2) SFP supports three classes of priority
3) SFP asynchronous stream packets offer better delay for packet video than isochronous service
4) SFP ensures fairness among like priority nodes and supports variable size packets

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Publication

V. Chandramohan and K. Christensen, "A First Look at Wired Sensor Networks for Video Surveillance Systems," *Proceedings of the High Speed Local Networks Workshop at the 27th IEEE Conference on Local Computer Networks*, pp. 728-729, November 2002.

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