Efficient Transport of Isochronous Streams in Residential Ethernet:

With A Generalized Admission Control Approach

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Background

Terminology

❑Subscription

- End-to-end procedure of setting up an isochronous stream. It will employ the Simple Reservation Protocol (SRP) which is the signaling for conveying resource reservation information.

❑Admission control

- Local operation in each bridge, which assesses whether there are enough resources locally in this bridge to support corresponding triggering reservation signaling.

❑Pacing

- By holding each isochronous frame until its corresponding issuing time, pacing mechanism maintains the traffic pattern along the stream path to guarantee a low jitter bound and evenly distributed buffer space requirement inside the network. More specifically with current ResE approach [1,2]:
  - "The classA frames are gated to prevent their early departure. Gating involves blocking classA frames that arrived with sourceCycle=n, until the start of cycle n+p. After the start of cycle n+p, the transmitter waits for the completion of preceding non-classA frames (or residual cycle n+p-1 classA frames), then transmits these arrived-in-cycle-n frames with sourceCycle=n+p."
  - Delay, jitter and buffer requirement in each bridge is bound to pacing parameter p

Traffic Distortion

- A switch can provide local performance guarantees to a stream only when its traffic pattern satisfies certain specifications.
- But Interactions between different isochronous streams and asynchronous frames may distort the traffic pattern of a stream.
- The distortion may cause violation of the specification even the stream satisfies the specification at the entrance to the network.

Rate-controlled Static Priority Queuing [1]

- A rate controlled server has two components: a rate controller and a scheduler
  - Rate controller shapes input stream traffic to desired traffic pattern by assigning an eligibility firing time to each frame
  - Scheduler orders the transmission of eligible frames

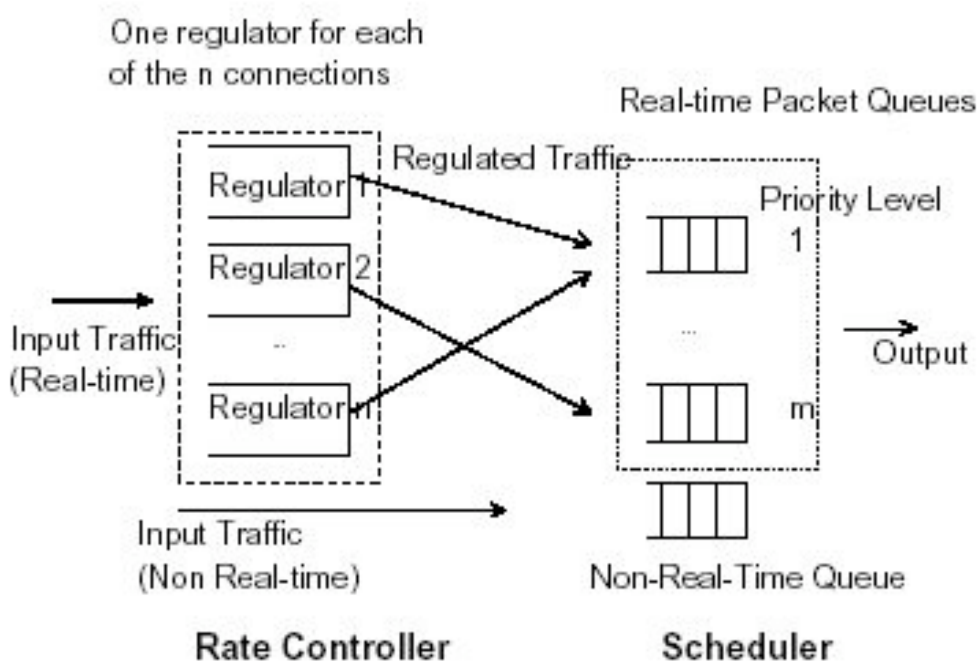


Figure 1: Rate-Controlled Static-Priority Queueing

Application of RCSP to ResE

- We can use the delay-jitter controlling regulator model
  - The scheduler define the maximum possible delay experienced by a isochronous frame
    - Delay bound is derived from traffic profile and admission control criteria
  - For each incoming isochronous frame, the regulator will compensate the difference between the maximum possible delay and the frame's actually experienced delay in the upstream node
    - Jitter will not be accumulated.
    - Maximum buffer requirement can be fixed.
- We defined a base cycle for all isochronous streams in ResE, then the rate-controller (regulator) can be simplified:
  - Relative eligibility time can be used instead of absolute eligibility time
    - "The classA frames are gated to prevent their early departure. Gating involves blocking classA frames that arrived with sourceCycle=n, until the start of cycle n+p. After the start of cycle n+p, the transmitter waits for the completion of preceding non-classA frames (or residual cycle n+p-1 classA frames), then transmits these arrived-in-cycle-n frames with sourceCycle=n+p."
  - Since all streams use a same cycle, there is no need for per-connection regulation

Efficient Transport of Isochronous Streams

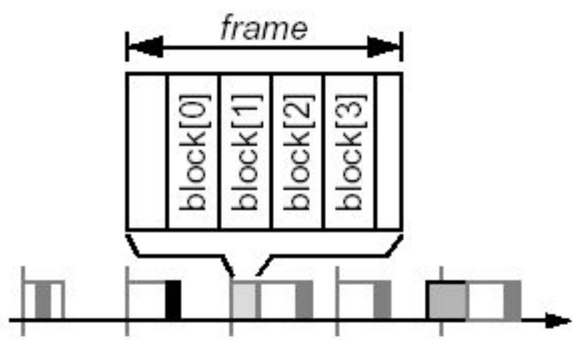
Problem Statement: Low Bandwidth Streams

- In 100M Ethernet a prevalence choice of cycle size is 125us, and the pacing parameter *p* is set to 2. [2,3]
  - Since all streams reserve identical bandwidth in each 125us cycle, for low bandwidth streams it causes the problem of high overhead.
    - The overhead of transmit a payload data unit in Ethernet includes IPG (12bytes), Preamble(8bytes), DA(6bytes), SA(6bytes), Length/Type(2bytes), FCS(4bytes), Pad(0~46bytes, depend on PDU size)
    - For example, for a 2Mbps CD audio stream
      - With a 125us cycle, The utilization is ~38% (32bytes payload per cycle, 32/(32+38+14)=~38%)
    - But by using a large cycle size, the utilization can be obviously improved
      - With a 250us cycle, the utilization is ~62% (63bytes payload per cycle, 63/(63+38))
      - With a 500us cycle, the utilization is ~77% (125bytes payload per cycle, 125/(125+38))
  - We need a solution to improve the utilization efficiency for low bandwidth streams while keeping same low delay/jitter performance and implementation simplicity as previous approach.

Existing Solution

❑Encapsulate several low bandwidth content into blocks [2]

- However, the application of this scheme is limited:
  - Only content streams with same source-destination nodes pair can be multiplexed
  - Source node and destination node need additional processing power for encapsulation and de-encapsulation.



c) Groups of blocks

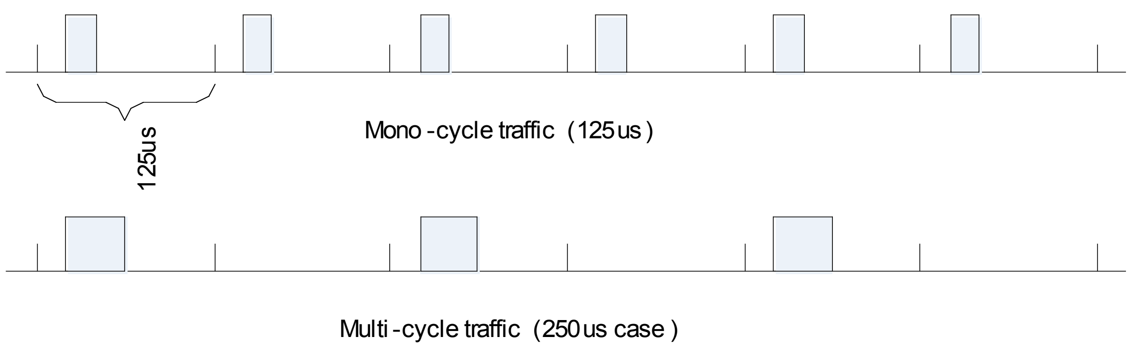
Proposed Solution

❑Sub-rate allocation

- This concept was defined in IEEE802.15.3 as "A channel time allocation that occurs only once every n superframes (n>1)".

❑Sub-rate traffic model in ResE

- A base-cycle of P_{base} is defined for ResE system
- Isochronous streams can use a value which is the multiple of base-cycle (P_{base}) as their stream data traffic period.
  - Those streams send out frames periodically based on their individual cycle.
    - Low bandwidth streams can then fit into the sub-rate traffic model to keep its utilization ratio above a reasonable threshold.
  - For the implementation feasibility, the maximum number of cycle classes in ResE system should be limited. For example, 2~4 classes would be effective and operational.



Proposed Solution (cont.)

- For the sub-rate traffic model scenarios, a more generalized admission control criteria should be used to guarantee the same delay/jitter performance for isochronous stream packets as fixed rate scenarios in previous approach while using the same isochronous packets pacing scheme.
  - Notations:
    - N, the maximum allowable number of traffic classes in system
    - Bn (n=1…N), the maximum cumulative bandwidth (bit/s) that is allowed to be assign to class-n traffic. The bandwidth should include all possible overhead.
    - Cn (n=1…N), the ratio of class-n traffic's period to the basic-cycle.
    - r, the ratio of total link capacity that can be assigned to isochronous streams.
    - l, link capacity
    - k, the transmit time (include all overhead) for a largest asynchronous packet. (For example, in 100M Ethernet, k~123us; in GbE, k~12.3us)
    - p, pacing parameter. Isochronous frames that arrived cycle m will be paced to be forwarded utile cycle m+p.

Proposed Solution (cont.)

- The generalized admission control condition is as follows [1]:
  - Maximum accumulative allocated bandwidth constraint:

$$\sum_{n=1}^{N} B_n \le r \times l \qquad (1)$$

  - Worst case local delay should be less than the pacing holding time ():

$$\sum_{n=1}^{N} \frac{B_n \times C_n \times P_{base}}{l} + k \le p \times P_{base} \qquad (2)$$

or be rewritten as:

$$\sum_{n=1}^{N} C_n B_n \le (p - \frac{k}{P_{base}}) \times l \qquad (3)$$

(For expression simplicity, we assume here the link transmission delay can be ignored. This delay can be easily taken into account by adding its worst-case value to the right side of equation(2))

- By substituting system parameters into above equations, admission control parameters Bn can be calculated.

Proposed Solution (cont.)

- The admission control condition can also be easily written in other forms:
  - In the form of cumulative allocated time-slice (T_n, including all overhead) per sub-rate cycle:

$$\begin{cases} \sum_{n=1}^{N} \frac{T_n}{C_n} \le r \times P_{base} \\ \sum_{n=1}^{N} T_n \le p \times P_{base} - k \end{cases}$$

  - Similarly, it can be written in the form of cumulative allocated bits (b_n, including all overhead) per sub-rate cycle:

$$\begin{cases} \sum_{n=1}^{N} \frac{b_n}{C_n} \le r \times l \times P_{base} \\ \sum_{n=1}^{N} b_n \le (p \times P_{base} - k) \times l \end{cases}$$

Proposed Solution (cont.)

❑Extension of information carried in subscription signaling

6	*mcastID*	— Multicast destination label
6	*talkerID*	— Multicast talker identifier
2	*plugID*	— Resource within the talker
2	*maxCycles*	— Delay from the talker
4	*maxBw*	— Maximum required bandwidth
4	*reserved*	— Reserved

Subscription information

- To support sub-rate traffic model, a new field Traffic_Rate_Factor should be added to existing subscription information
  - Traffic_Rate_Factor is an integer that equals to the ratio of the traffic frames' period to the base-cycle, which is notated as Cn in the admission control conditions.

→Totally two input parameters are used in admission control: sub-rate class and bandwidth requirement (C_n and B_n)

Proposed Solution (cont.)

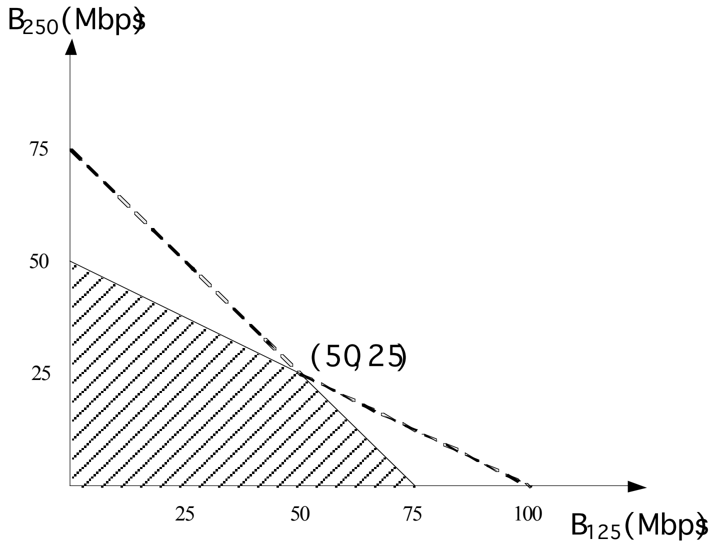
❑System operation

- Based on the application requirements, system parameters N, Cn, r and p are predefined for the ResE network. Then corresponding admission control parameters Bn are determined and configured.
  - Bn may even be adaptively adjusted in a ResE network
- When an application needs to set up a new class-n isochronous stream, it indicates its traffic class n and its bandwidth requirement Bq in the subscription protocol signaling.
- Each relevant ResE switch makes admission control decisions by comparing if the accumulative bandwidth for class-n traffic will exceed the corresponding admission control parameter Bn.
  - If not, the admission control is successful on this switch
  - Otherwise, the admission control is failed on this switch

Design Examples: Fast Ethernet

- Assumptions:
  - 100Mbps Ethernet
  - Two kinds of CBR streams. Base cycle P_{base} is set to 125us. One of the stream uses 125us cycle; the other one uses 250us cycle.
  - At most 75% link capacity can be allocated to those streams.
  - Pacing parameter p is set to 2.
  - Note the maximum bandwidth can be allocated to the two kinds of streams as B_{125} and B_{250},resepecatively.
- Then the admission control conditions are:

$$\begin{cases} B_{125} + B_{250} \le 75Mbps \\ B_{125} + 2 \times B_{250} \le 100Mbps \end{cases}$$

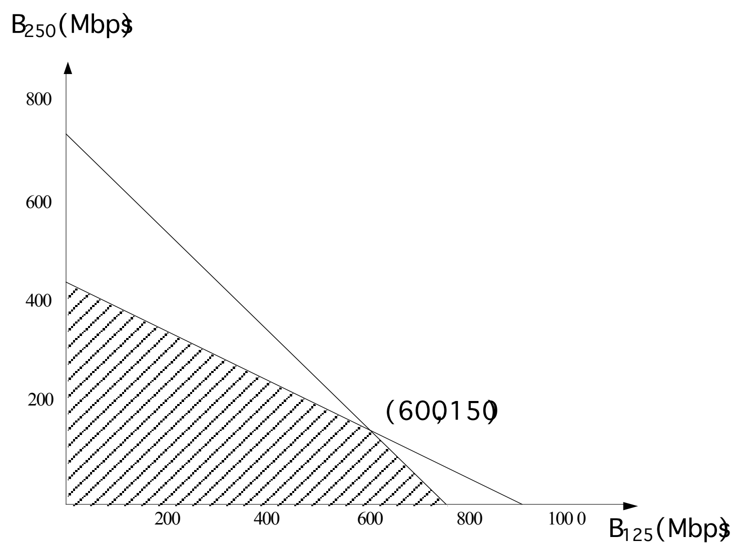


- By using a 250us cycle, a 2Mbps CD audio can increase its utilization ratio from 38% to 62% compared with conventional 125us cycle model.

Design Examples: GB Ethernet

- Assumptions:
  - 1000Mbps Ethernet
  - Two kinds of CBR streams. Base cycle P_{base} is set to 125us. One of the stream uses 125us cycle; the other one uses 250us cycle.
  - At most 75% link capacity can be allocated to those streams.
  - Pacing parameter p is set to 1.
  - Note the maximum bandwidth can be allocated to the two kinds of streams as B_{125} and B_{250},resepecatively.
- Then the admission control conditions are:

$$\begin{cases} B_{125} + B_{250} \le 750Mbps \\ B_{125} + 2 \times B_{250} \le 900Mbps \end{cases}$$



- By using a 250us cycle, a 2Mbps CD audio can increase its utilization ratio from 38% to 62% compared with conventional 125us cycle model.

Further Extension: VBR Stream Scenario

- Problem statement:
  - Some applications in ResE will use VBR traffic model
  - Current solution reserves resources only based on the peak rate
    - It may decrease the acceptance ratio of admission control

Proposed Solution

- Each admission control request includes both its average bandwidth requirement and its peak bandwidth requirement.
  - Cumulative allocated average bandwidth should be less than a fixed ratio to protect the performance of asynchronous data
  - Cumulative allocated peak bandwidth should be less than the line rate and guarantee the delay bound

Proposed Solution (cont.)

- We can derive the admission control conditions (in the form of allocated bits per sub-rate cycle) [1]:

$$\begin{cases} \sum_{n=1}^{N} \frac{ba_n}{C_n} \le r \times l \times P_{base} \\ \sum_{n=1}^{N} bp_n \le (p \times P_{base} - k) \times l \\ \sum_{n=1}^{N} \frac{bp_n}{C_n} \le l \times P_{base} \\ ba_n \le bp_n \quad (n = 1 \ldots N) \end{cases}$$

ba_n (n=1…N): the maximum cumulative bits in terms of average that is allowed to be assign to class-n traffic, including all possible overhead.
bp_n (n=1…N): the maximum cumulative bits in terms of peak that is allowed to be assign to class-n traffic, including all possible overhead.

→Totally three input parameters are used in admission control: sub-rate class, average bandwidth requirement, and peak bandwidth requirement (C_n, ba_n and bp_n)

Design Examples

- 100Mbps; P_{base} =125us; No sub-rate streams; p=2; 75% for Iso.

$$\begin{cases} ba_{125} \le 9375(bits) \\ bp_{125} \le 12696 \approx 12500(bits) \\ bp_{125} \le 12500(bits) \\ ba_{125} \le bp_{125} \end{cases}$$

$$\begin{cases} ba_{125} = 9375(bits) \\ bp_{125} = 12500(bits) \end{cases}$$

- 100Mbps; Pbase=125us; Two kinds of streams; p=2; 75% for Iso.

$$\begin{cases} ba_{125} + \frac{ba_{250}}{2} \le 9375(bits) \\ bp_{125} + bp_{250} \le 12696 \approx 12500(bits) \\ bp_{125} + \frac{bp_{250}}{2} \le 12500(bits) \\ ba_{125} \le bp_{125}; ba_{250} \le bp_{250} \end{cases}$$

$$\begin{cases} ba_{125} = 9000(bits) \\ ba_{250} = 750(bits) \\ bp_{125} = 10000(bits) \\ bp_{250} = 2500(bits) \end{cases}$$

Design Examples (cont.)

- 1000Mbps; P_{base} =125us; No sub-rate streams; p=2; 75% for Iso.

$$\begin{cases} ba_{125} \le 93750(bits) \\ bp_{125} \le 237696(bits) \\ bp_{125} \le 125000(bits) \\ ba_{125} \le bp_{125} \end{cases}$$

$$\begin{cases} ba_{125} = 93750(bits) \\ bp_{125} = 125000(bits) \end{cases}$$

- 1000Mbps; Pbase=125us; Two kinds of streams; p=2; 75% for Iso.

$$\begin{cases} ba_{125} + \dfrac{ba_{250}}{2} \le 93750(bits) \\ bp_{125} + bp_{250} \le 237696(bits) \\ bp_{125} + \dfrac{bp_{250}}{2} \le 125000(bits) \\ ba_{125} \le bp_{125};\ ba_{250} \le bp_{250} \end{cases}$$

$$\begin{cases} ba_{125} = 75000(bits) \\ ba_{250} = 37500(bits) \\ bp_{125} = 100000(bits) \\ bp_{250} = 50000(bits) \end{cases}$$

Further Extension: Multi-Priority Iso. Streams

- In previous solutions, all isochronous streams belongs to a same priority class, which means all streams share the same per-hop delay and jitter performance
  - Per-hop Delay = $p*P_{base}$
  - End-to-end Jitter = $p*P_{base}$
- ResE applications may need differentiated performance between streams.
  - Isochronous streams may be classed with different priorities. Each priority class provides its specific per-hop delay and end-to-end jitter performance value.

Current Solutions

- A rate-monotonic scheduling based method [2]
  - “Rate-based scheduling involves associating a priority with frame transmissions, where the priority is a monotonic function of the frame transmission frequency”
- Disadvantage:
  - The performance of isochronous streams is bound with their transmission frequency. But real applications’ requirement can be more general. There is not necessarily relationship between the delay/jitter performance and the transmission frequency.

Proposed Solutions

- Isochronous streams are assigned with priority classes.
  - Assume there are Q priority classes. Subscript q (q = 1…Q) is used to indicate the priority classes.
  - For each priority class q , a specific pacing parameter p^q is used.
    - Frames of priority class q with arrival-cycle n will be gated to prevent their early departure. They aren't eligible for departure until the start of cycle $n+p^q$.
    - $p^1<p^2<\ldots<p^Q$
    - Therefore specific per-hop delay (p^q*P_{base}) and end-to-end jitter (p^q*P_{base}) performance is provided for this class
  - Non-preemptive strict priority queues are used for the forwarding of eligible frames
    - Class 1 has the highest priority; Class Q has the lowest priority
- In each priority class, the isochronous streams can still use different transmission frequency (sub-rate streams) and VBR traffic model.

Proposed Solutions

❑Corresponding admission control conditions can be derived as [1]:

$$\begin{cases} \sum_{q=1}^{Q}\sum_{n=1}^{N^q}\frac{ba_n^q}{C_n} \le r \times l \times P_{base} \\ \sum_{q=1}^{m}\sum_{n=1}^{N^q} bp_n^q + p^m \times \sum_{q=1}^{m-1}\sum_{n=1}^{N^q}\frac{bp_n^q}{C_n^q} \le (p^m \times P_{base} - k) \times l \quad (m = 1 \ldots Q) \\ \sum_{q=1}^{Q}\sum_{n=1}^{N}\frac{bp_n^q}{C_n^q} \le l \times P_{base} \\ ba_n^q \le bp_n^q \quad (n = 1 \ldots N;\ q = 1 \ldots Q) \end{cases}$$

→Totally four input parameters are used in admission control: priority class, sub-rate class, average bandwidth requirement and peak bandwidth requirement (p^q, C_n^q, ba_n^q and bp_n^q)

Conclusion

❑ This extended traffic model and corresponding generalized admission control criteria provide us a ResE approach which can:

- use the same simple pacing mechanism as previous approach.
- keep the same low delay/jitter performance as previous approach
- improve the utilization efficiency for low bandwidth streams
- improve the acceptance ratio for VBR streams
- provide priority differentiation for isochronous streams. And there is no limitation on the relationship between the delay/jitter performance and transmission frequency.

Reference

- [1] H. Zhang et. al in: *Rate-controlled static priority queuing*, Infocom93
- [2] Residential Ethernet (RE) (a DVJ working paper), http://grouper.ieee.org/groups/802/3/re_study/material/index.html
- [3] Residential Ethernet Tutorial, http://grouper.ieee.org/groups/802/3/tutorial/mar05/tutorial_1_0305.pdf

Thanks