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Switch Algorithm Testing: A Case Study with ERICA

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Overview

- Objectives of ATM traffic management
- The ERICA algorithm
- Extensions of ERICA
- Performance evaluation of ERICA and ERICA+
Objectives of Traffic Mgmt

- Efficiency and minimal delay
- Fairness: Max-min allocation and fairness index
- Good steady state: Minimal oscillations.
- Fast transient response
- Adaptation to the presence of multiple traffic classes ⇒ ABR capacity is not fixed
- Scalability to various speeds, distances, number of switches and number of VCs
- Need to adapt to high variance in demand and different traffic models
Source Models

Increasing complexity:
- Persistent cell traffic
- Bursty cell traffic
- Source bottleneck
- Persistent TCP sources
- Bursty TCP sources
ERICA Scheme: Basic

- **Explicit Rate Indication for Congestion Avoidance**
- Set target rate, say, at 95% of link bandwidth
  \[ \text{ABR Capacity} = \text{Target Utilization} \times \text{Link Bandwidth} \]
- Monitor input rate and number of active VCs
  \[ \text{Overload} = \frac{\text{ABR Input rate}}{\text{ABR Capacity}} \]
- This VC’s Share = VC’s Current Cell Rate/Overload
- Fair share = Target rate/ Number of Active VCs
- \[ \text{ER} = \max(\text{Fair share}, \text{This VC’s share}) \]
- \[ \text{ER} = \min\{\text{ER}, \text{ABR Capacity}\} \]
- \[ \text{ER in Cell} = \min(\text{ER in Cell}, \text{ER}) \]
ERICA Features

- Uses measured overload
  ⇒ If sources use less than allocated capacity, all unused capacity is reallocated to others.
- Two parameters: Target utilization, Averaging interval
- Simple Order (1) computation
- Fast response due to optimistic design
- Fairness is improved at each step. Even under overload.
- Converges to efficient operation in most cases
- Max-min fair in most cases
ERICA Extensions

1. Forward CCR
2. Same feedback in one Interval
3. Fair share first
4. per-VC CCR measurement
5. Time + count based averaging
6. ERICA with VBR
7. Bi-directional Counting
8. Max-min Fairness
9. Averaging of number of sources
10. Boundary cases
11. Averaging of load factor
12. ERICA+ (ERICA with queue control)
1. **Innovation: Use forward CCR**

- **Problem:** CCR in backward direction is too old
- **Solution:** Read CCR in forward RM cells. Give feedback in backward RM cells.
- **Effect:** Shorter control loop for active VCs
  ⇒ Faster convergence

![Diagram showing the control loop and RM cells](image)
2. Same Feedback in One Interval

- **Problem**: Oscillations for high-rate sources
- **Reason**: Mismatched control and monitoring intervals
  - Control Interval = Inter-RM cell time
  - Monitoring Interval = Averaging interval
- **Solution**: Do not change feedback in one averaging interval.

```
Source      Switch      Dest.
```

```
Load Measurement Interval
```
3. Innovation: Fair Share First

- **Problem**: Transient overloads at state changes
- **Solution**: Source below Fair Share go only up to fair share first.
  
  IF $\text{CCR} < \text{Fair Share}$ and $\text{ER}_{\text{Calculated}} \geq \text{Fair Share}$
  
  THEN $\text{ER}_{\text{Calculated}} = \text{Fair Share}$

- **Example**: Two sources $\{10, 10\}$, $\{50,10\}$, $\{90,50\}$...

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4. Per-VC Rate Measurement

- **Problem**: Some VCs are bottlenecked at the source. CCR does not reflect source rate.

- **Solution**:
  - Count number of cells in each VC
  - Source Rate = Number of Cells Seen/Averaging Interval
  - This VC's Share = Source Rate/Overload

- **Advantage**:
  - Also handles sources not using their allocation. ⇒ Switch based “use it or lose it”
5. Time + Count Based Averaging

- **Problem**: Averaging over a fixed interval
  ⇒ Sudden overload can cause queue build up
- **Solution**: Average over $t$ ms or $n$ cells whichever happens first.
6. Innovation: ERICA with VBR

- Monitor VBR usage
- ABR capacity = Target Rate - VBR input rate
- **NOTE:** Target utilization applies to total link load
  ABR capacity = Target Utilization × Link Rate
  - VBR output rate
  and not
  ABR capacity = Target Utilization ×(Link Rate
  - VBR output rate)
  ⇒ VBR Output rate < Target utilization
Out-Of Phase Effect

- Bursty load and backward RM (BRM) cells are often out of phase.
- When there is load in the forward direction, there are no BRMs.
- By the time the switch sees BRMs, there is no load in the forward direction.
- The above effect disappears when the bursts become larger than RTT.
7. Innovation: Bi-directional Counting

- **Problem**: Data cells or RM cells may not be seen in one direction. Resulting in undercount and overallocation.

- **Solution**: A VC is active if any of the following holds:
  - Data cells seen in the forward direction in the last averaging interval
  - Data cells seen in the forward direction in this averaging interval
  - BRMs seen in the reverse direction
Unfairness in ERICA

- \( \text{ER}_{\text{Calculated}} = \text{Max}\{\text{Fair Share, CCR/overload}\} \)
- ERICA becomes unfair if ALL of the following conditions hold true:
  - Overload = 1
  - Some VCs are bottlenecked at other switches
  - All VCs that are not bottlenecked at other switches have a CCR greater than the fair share
- Under the above condition, the CCRs do not change at all. The allocation stabilizes. But the stable operating point may not be max-min fair.
Max-Min Alloc of 150 Mbps : \{10, 10, ..., 10, 70, 70\}

With \{10, 10, ..., 10, 60, 80\}, Link 2 Fair Share = 50, Load = 1, Max\{Fair share, CCR/load\} = 60 and 80 for VC16 and VC17.
8. Innovation: Fairness Fix

- **Solution:**
- All VCs that are bottlenecked at this switch must get the same allocation = maximum allocation
- Remember maximum ER in the previous interval
- IF overload $\leq 1+\delta$
  - THEN $\text{ER}_{\text{Calculated}} = \text{Max}\{\text{Fair Share, CCR/Overload, Max}_\text{ER}\}$
  - ELSE $\text{ER}_{\text{Calculated}} = \text{Max}\{\text{Fair Share, CCR/Overload}\}$
Example: On Link 2, Fair Share = 50

- \{10, 10, ..., 10, 60, 80\}, Load = 1, ER=10,80,80
- \{10, 10, ..., 10, 80, 80\}, Load = 17/15, ER=10, 70.6, 70.6
- \{10, 10, ..., 10, 70.6, 70.6\}, Load = 1.008, ER=10, 70.03, 70.03
9. Averaging of Number of Sources

- Not all active sources seen in every interval
  - $\Rightarrow$ Fair share overestimated
  - $\Rightarrow$ High Allocation

- Solution:
  - Source activity lies between 0 and 1
  - Activity $= 1$ if the source is seen
  - Activity decays by a factor $\alpha$, every interval the source is not seen

\[
\begin{array}{cccccc}
1 & 0.9 & 0.81 & 0.72 & 0.65 & 1
\end{array}
\]
## 10. Boundary Cases

<table>
<thead>
<tr>
<th>ABR Capacity</th>
<th>Input Rate</th>
<th>Overload</th>
<th>Fair share</th>
<th>CCR/Overload</th>
<th>Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero</td>
<td>Non-zero</td>
<td>$\infty$</td>
<td>Zero</td>
<td>Zero</td>
<td>Zero</td>
</tr>
<tr>
<td>Non-zero</td>
<td>Zero</td>
<td>$\infty$</td>
<td>C/N</td>
<td>Zero</td>
<td>C/N</td>
</tr>
<tr>
<td>Non-zero</td>
<td>Non-zero</td>
<td>I/C</td>
<td>C/N</td>
<td>CCR*C/I</td>
<td>Max(CCR*C/I, C/N)</td>
</tr>
<tr>
<td>Zero</td>
<td>Zero</td>
<td>$\infty$</td>
<td>Zero</td>
<td>Zero</td>
<td>Zero</td>
</tr>
</tbody>
</table>

- If N ≤ 1 then N = 1
- Here, I = input rate, C = Capacity, N = # of Srs

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11. Averaging of Load Factor

- Load Factor = Input Rate / ABR Capacity
- Load factor is a ratio
  - Both numerator and denominator are variable
    - Average numerator and denominator separately
- Input rate itself is a ratio
  - Add number of cells seen and time separately
- Similarly, for ABR Capacity
Is Low Queue Length Good?

- Queue length is close to 1. Not good if bandwidth becomes available suddenly
  You can’t use BECN to ask sources to increase
  Low rate sources may have long inter-RM cell times

- Link utilization is 90% or below
  May not be acceptable for high-cost WAN links.

- Very high queue length is also bad.
12. Innovation: ERICA with Queue Control

- Target utilization is dynamically changed.
- During steady state: Target utilization = 100%
- During overload the target may be low, e.g., 80%
- During underload the target may be high, e.g., 110%
- Available Bandwidth = fn(Unused bandwidth, Queue length, queue length goal)
- Unused bandwidth = Link Rate - VBR output rate
- Rest is similar to ERICA
**Innovation:**

**Use Queue Delay Threshold**

- Since available bandwidth (AB) varies dynamically, a queue of 30 may be too big when AB is 1 Mbps but too little when AB is 100 Mbps.
- Use queue delay instead of queue length
  \[ \text{Queue Delay} = \frac{\text{Queue length}}{\text{Available bandwidth}} \]
- Available Bandwidth = fn(Unused bandwidth, Queue length, queue delay goal)
The function should be monotonically non-increasing and have a lower bound.

Available Bandwidth = Unused Bandwidth $\times$ Factor

Factor = $F_{\text{min}}$
Sample Queue Control Function 1

Capacity Multiplication Factor

\[ \text{Factor} = \frac{b T_0}{(b-1)T + T_0} \]

\[ \text{Factor} = \frac{a T_0}{(a-1)T + T_0} \]

\[ \text{Factor} = F_{\text{min}} \]

Queue Delay $T$

Parameters: \( \{a, b, T_0, F_{\text{min}}\} = \{1.15, 1.05, 5 \text{ ms}, 0.5\} \)

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Advantage of Q-Control

- Can tolerate errors in measurements:
  - Number of active sources
  - VBR load
  - ABR input rate
- Allows n-VC TCP operation with buffers $\approx 1 \times$ RTT
- 100% Utilization
Simulation Parameters

- All links have a bandwidth of 155.52 Mbps
- All LAN links are 1 Km long and all WAN links are 1000 Km long
- All VCs are bi-directional
- RIF = 1
- TBE = Large ⇒ Disable rule 6
- Target utilization = 95% (LAN), 90% (WAN)
- All sources, including VBR are deterministic
- Averaging interval = Min{50 cells, 1 ms} for LANs and Min{100 cells, 1 ms} for WANs
ERICA+: Parameters

Parameters: \{a, b, F_{\text{min}}\} = \{1.15, 1.05, 0.5\}

\[ T_0 = 100 \, \mu s \text{ (LAN)}, \ 500 \, \mu s \text{ (WAN)} \]
Efficiency Test

- Single source configuration: Filters out many non-working schemes
- ERICA achieves efficiency
- No rate oscillations in the steady state
- Utilization is at the target (95%)
- With ERICA+, utilization is 100% with no oscillations and minimal queues
Two source configuration

For ERICA, convergence is fast, the queue lengths (delays) are small

For ERICA+, convergence is fast, the queue length reaches target, no rate oscillations, and 100% link utilization
Parking lot configuration

Max-min allocation = $1/n$ for all VCs

ERICA and ERICA+ allocate the max-min share

Parking lot configuration is not sufficient to demonstrate max-min fairness

Original ERICA unfair in certain situations, e.g., some VCs bottlenecked at low rates
Fairness (Cont)

- Modified ERICA is fair
- Curves of number of cells received at the destination vs time have the same slope
- Transient response is slightly worse but the steady state performance is still good
- Modified 2-source configuration,
- Source 2 is active from 10 ms to 20 ms only
- Also illustrates the effect of the "fair share first" algorithm
- ERICA exhibits good transient response
Adaptation to Variable Capacity

- VBR source with peak rate of 124.42 Mbps (80%)
- VBR source is on/off for 1 ms/1 ms (high frequency)
- on/off for 20 ms/20 ms (low frequency)
- Fast response to VBR load
- Utilization drops reflect feedback delay
- Spikes in the queue lengths also reflect the feedback delay, but the queues are rapidly drained
- ERICA+ adapts rapidly to changing background
- Target queue goal is not reached due to the high variance
Bursty Traffic

- One persistent + One bursty (request-response) VC
- Request Size = 16 cells
- Response Size = 128 (small), 1024 (medium), and 6144 (large) cells
- Performance of the reverse (response) shown
- ERICA can adapt to small and medium bursts of data, and the queue lengths are constrained
- With a target utilization of 90%, not enough capacity to drain large bursts of data from the switch queues before the next burst is received
Bursty Traffic (Cont)

- Solution 1: Smaller target utilization
- Solution 2: Bi-directional counting limits the queue sizes for large bursts (out-of-phase effect)
- Solution 3: Averaging the number of active sources
- Solution 4: ERICA+ can adapt to bursty traffic better than ERICA

- With ERICA+ and small burst sizes, the queue delay is below the target
- Even with large burst sizes, averaging not required for ERICA+
ACR Retention

- ACR Retention = Sources cannot use their ACR
- If they suddenly use ACR ⇒ Overload
- Larger number of such VCs ⇒ Sudden overload
- 10 Sources limited to 10 Mbps for first 100 ms only
- ERICA rapidly detects the overload and gives the appropriate feedback
- Per-VC CCR measurement option can mitigate the overload situation
Summary

- Efficiency and delay requirements
- Fairness
- Transient and steady state performance
- Scalability
- Adaptation to variable capacity and various source traffic models