96-1294
Performance of TCP over ABR on ATM Backbone and with Various VBR Traffic Patterns

Shivkumar Kalyanaraman, Raj Jain, Sonia Fahmy, Rohit Goyal and Jianping Jiang

Raj Jain is now at Washington University in Saint Louis, jain@cse.wustl.edu http://www.cse.wustl.edu/~jain/

Seong-Cheol Kim

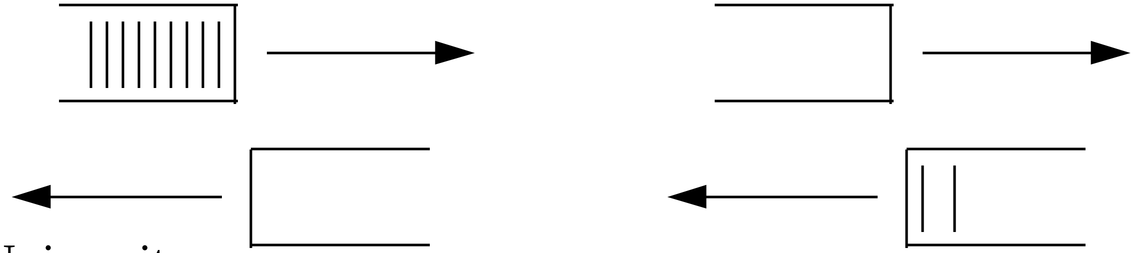
Samsung Electronics Co. Ltd.

http://www.cis.ohio-state.edu/~jain/

- TCP over ABR on ATM backbone
- TCP over ABR with VBR background
  $\Rightarrow$ High variance in demand and capacity
- Effect of VBR on-off times, feedback delay, switch scheme

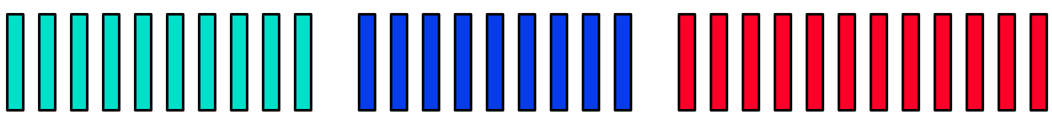
Out-Of Phase Effect

- Bursty load and backward RM 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



Flocking Effect

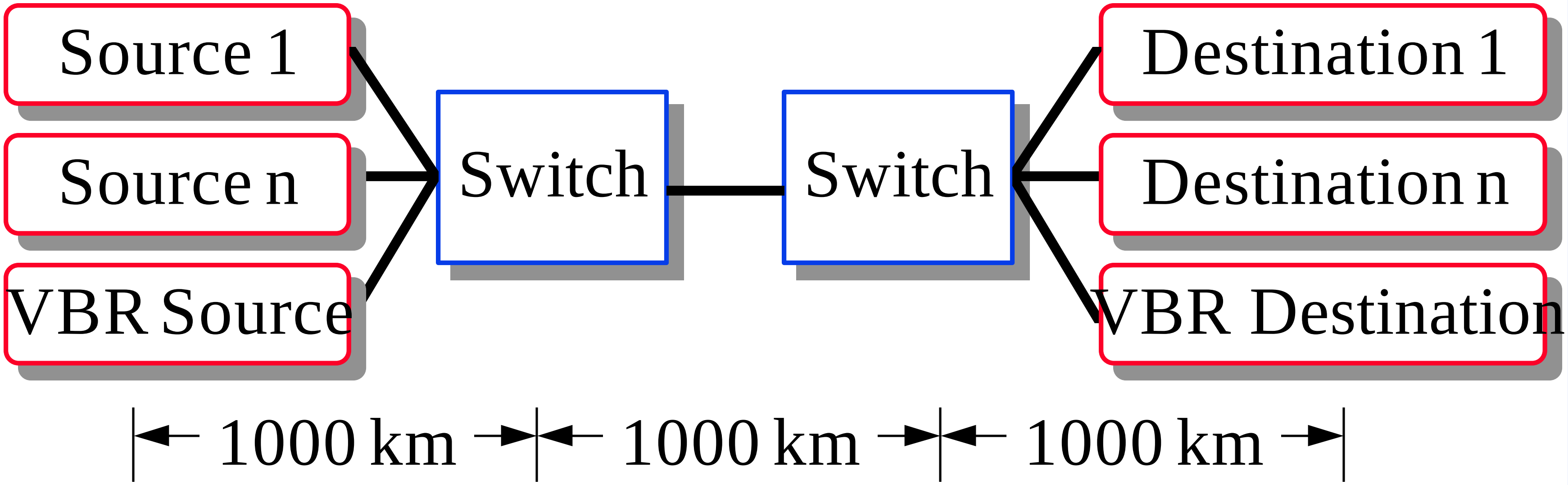
- All cells of a VC are often seen together.
- There is clustering of sources.
- Not all sources are seen all the time.
- TCP traffic is an example of "variable demand" ABR traffic.



TCP over ABR: Buffering

- Buffering depends heavily upon switch scheme.
- For the ERICA scheme and the traffic loads considered:
  - W/o VBR, 3×RTT buffers will do for any number of TCP sources
  - In general, Qmax = a×RTT + b×Averaging Interval + c×Feedback delay + d×fn(VBR)
- After TCP sources are rate-limited:
  Switch queues become zero, source queues build up

n Source + VBR Configuration



- All links 155 Mbps
- If VBR background , y ms on, y ms off, start at t = 2ms
  All traffic unidirectional; Large file transfer application
- # sources = 15, FRTT =30 ms, Feedback Delay = 10 ms
- Source buffer size = 100, 1000, 10000, 100000, ∞ cells.

Simulation Parameters

- Source: Parameters selected to maximize ACR
  TBE = 512
  CDF = 0.5
  ICR = 10 Mbps
  ADTF = 0.5 sec
  PCR = 155.52 Mbps, MCR= 0, RIF (AIR) = 1,
  Nrm = 32, Mrm = 2, RDF = 1/512
  Traffic: TCP/IP with Infinite source application
- Switch: ERICA+
  Averaging interval = min{100 cells, 1000μs} and other values

TCP/IP Parameters

- Maximum Segment Size = 512 bytes
- Timer granularity = 100 ms
- No TCP processing time
- Max window = 16 × 64 kB = 24576 cells
  One-way delay = 15 ms = 291 kB
- No delay ack timer
- Fast retransmit/recovery or Early packet drop (EPD) have no impact when there is no loss.

TCP over ABR on ATM Backbone with no VBR

Source Buffer (cells/VC)	Max Source Q (cells/VC)	Max Switch Q (total cells)	Total Throughput (Mbps)
100 (< Win)	> 100 (overflow)	8624 (0.78*RTT)	73.27
1000 (< Win)	> 1000 (overflow)	17171 (1.56*RTT)	83.79
10000 (< Win)	> 10000 (overflow)	17171 (1.56*RTT)	95.48
100000 (> Win)	23901 (0.97*Win)	17171 (1.56*RTT)	110.90

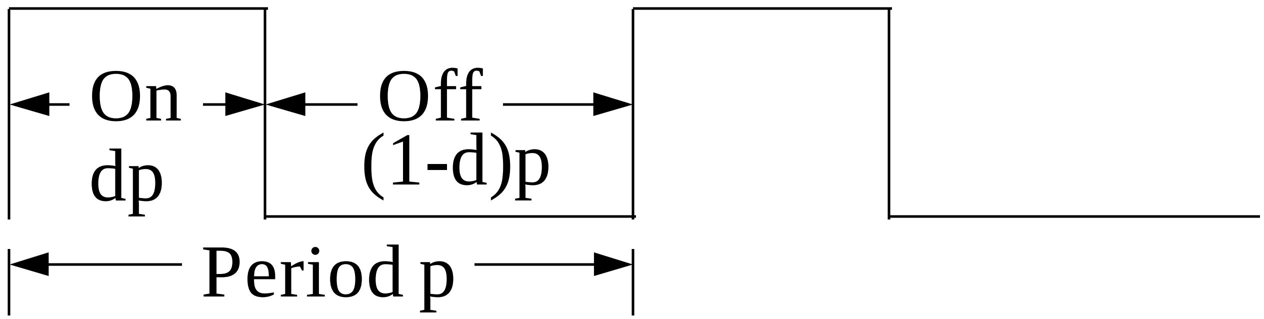
ATM Backbone (Cont)

- Source buffering = Receiver window per VC
  - VC's data in network
- Total source buffering
  = Edge router buffering
  = Sum of receiver windows
  = UBR switch buffering
- Switches reach maximum queue given minimum source buffering.

Implications for Edge Routers

- ABR pushes the TCP queues to the edge of the ATM network
- To avoid cell loss, edge routers need one window of buffering per TCP connection
- If limited buffers and edge routers cannot flow control TCP sources, performance degradation is same irrespective of whether the loss occurs at the ATM source or the switch
- ATM network buffering less for ABR
  $\Rightarrow$ Benefit for ABR service providers
  Low queues $\Rightarrow$ Low delay in the network

Parameters



- Number of sources = 15
- Infinite source and switch buffer size
- VBR: Duty cycle d = 0.9, 0.8, 0.7
- Period p = 1, 10, 100 ms
- On time = d*p, Off time = (1-d)*p
- All traffic unidirectional, large file transfer application

Effect of VBR On-Off Times

#	Duty Cycle(d)	Period (p) (ms)	Max Switch Q (cells)
1.	0.95	100	2588 (0.23*RTT)
2.	0.80	100	5217 (0.47*RTT)
3.	0.70	100	5688 (0.52*RTT)
4.	0.95	10	2709 (0.25*RTT)
5.	0.80	10	Diverges
6.	0.70	10	Diverges
7.	0.95	1	2589 (0.23*RTT)
8.	0.80	1	4077 (0.37*RTT)
9.	0.70	1	2928 (0.26*RTT)

Effect of VBR On-Off Times

- Queues small for large or small on-off times.
- Queues unbounded for some medium on-off time cases.
- Off-times Effect: High rate feedback vs queue drain
- Unbounded queues if high rate feedback dominates

Effect of Feedback Delay

Feedback Delay	RTT	Duty Cycle (d)	Period (p)	Max Switch Q
1 ms	3 ms	0.8	10 ms	4176 cells (0.4*RTT)
5 ms	15 ms	0.8	10 ms	Diverges
10 ms	30 ms	0.8	10 ms	Diverges

- Queues may be bounded for small feedback delays, but unbounded for large feedback delays.
- Time to allocate high rate
  = MIN (Off Time, Feedback delay)
- Time to control overload = c*Feedback delay

Effect of Switch Scheme

- Switch scheme needs to overcome effects of variance
- TCP: variance in ABR demand
- VBR: variance in ABR capacity
- Variance $\Rightarrow$ Errors in measurement $\Rightarrow$ Errors in feedback $\Rightarrow$ Queues

Enhancements to ERICA

- ERICA+ uses queueing delay as an additional metric
- Longer averaging interval:
  Averages with less variance
  Trades off stability for responsiveness
- Averaging of number of active sources
- Averaging of overload factor
- Boundary Conditions: zero load, no sources seen

Effect of Switch Scheme: Results

Avg Interval (n cells, T ms)	Averaging of Na? (An = 0.9)	Averaging of z? (Az = 0.2)	Duty Cycle d	Period p(ms)	Switch Queue (cells)
(100, 1)	Yes	Yes	0.7	20	5223
(500, 5)	Yes	No	0.7	20	5637

- All cases, we studied, have small bounded queues.
- Averaging of number of sources required.
- Averaging of overload is approximately equivalent to using a larger interval
- Longer averaging interval $\Rightarrow$ lesser processing cost.

Summary

- ABR pushes TCP queues to the edge of the network.
- Edge routers require buffers equal to the sum of TCP receiver windows for zero loss over ABR.
- TCP and VBR produce a variable demand and variable capacity workload
  $\Rightarrow$ Unbounded queues with simple ABR schemes.
- VBR on-off time and feedback delay are important factors.
- ERICA+ enhancements help convergence of queues: Averaging of N and overload factor, longer averaging intervals, and boundary conditions