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**Performance of TCP over ABR with
Long-Range Dependent VBR
Background Traffic Over Terrestrial
and Satellite ATM Networks**

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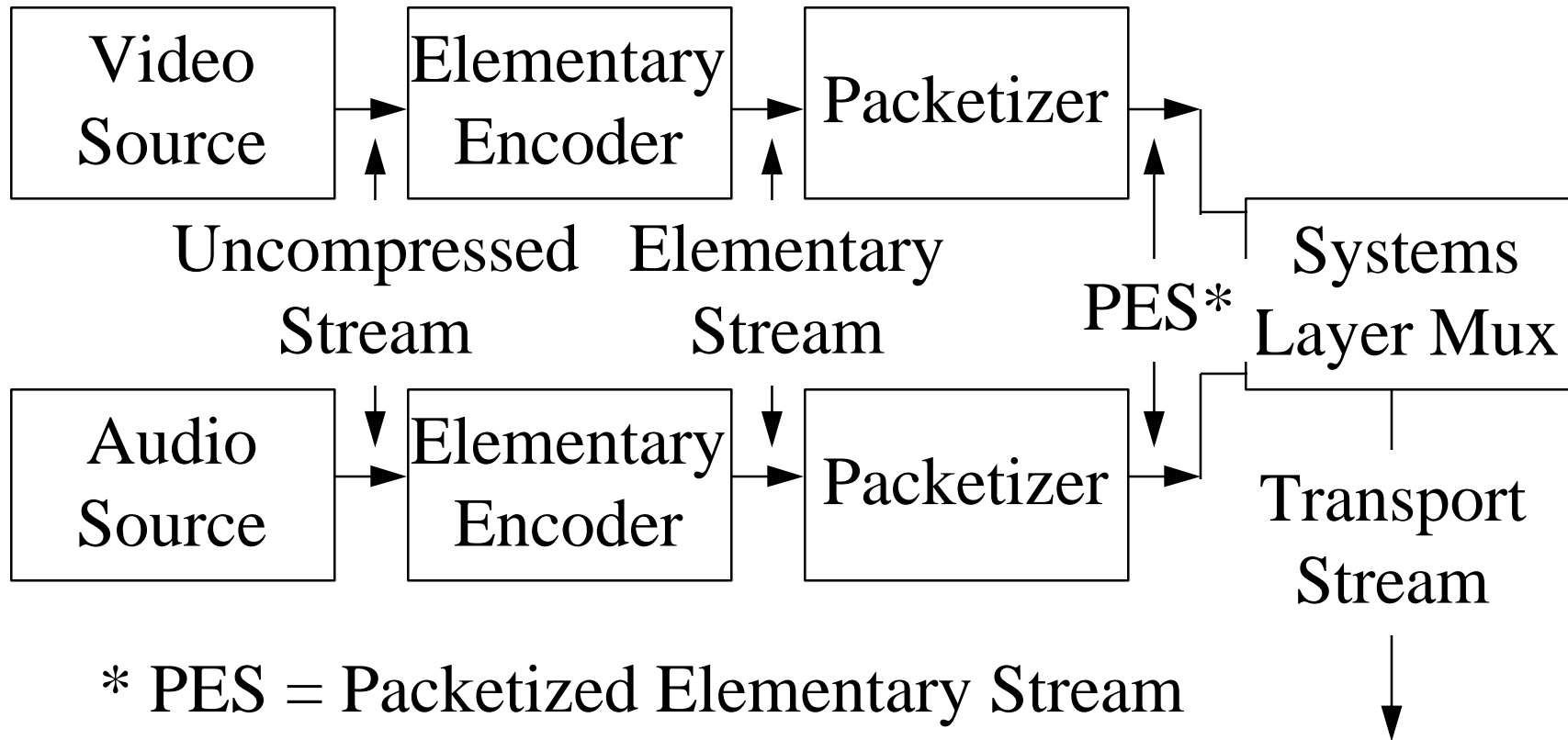
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- ❑ MPEG2 over ATM Overview
- ❑ Modeling MPEG2 Transport Streams over VBR
- ❑ Simulation Results for Terrestrial Networks
- ❑ Simulation Results for Satellite Networks

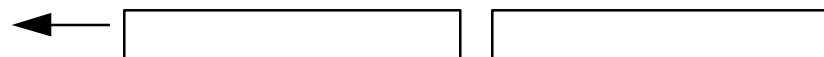
MPEG-2 Over ATM



* PES = Packetized Elementary Stream

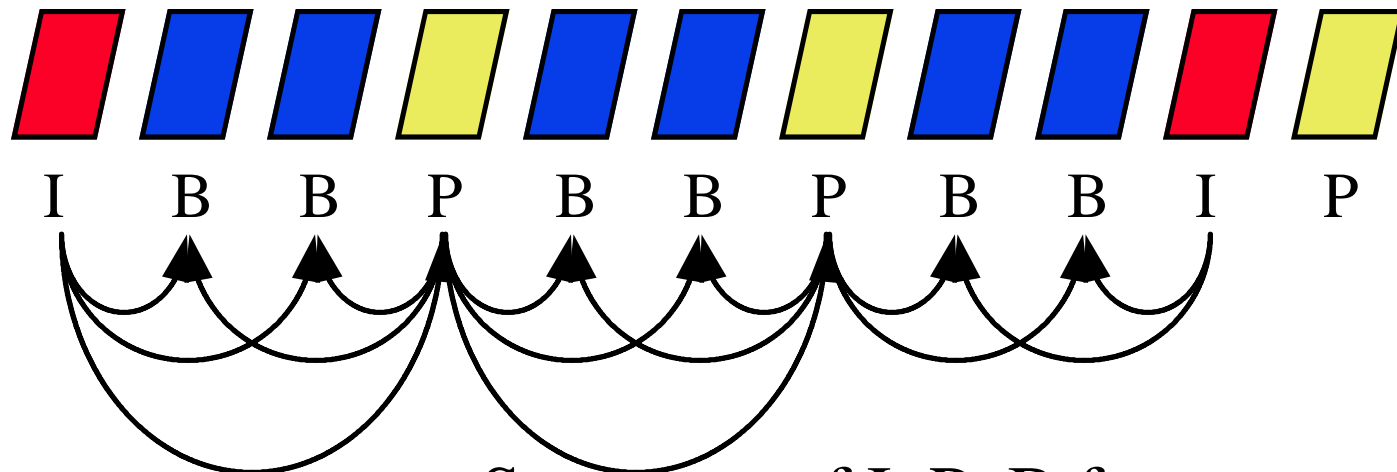


ATM cells



188-byte packets

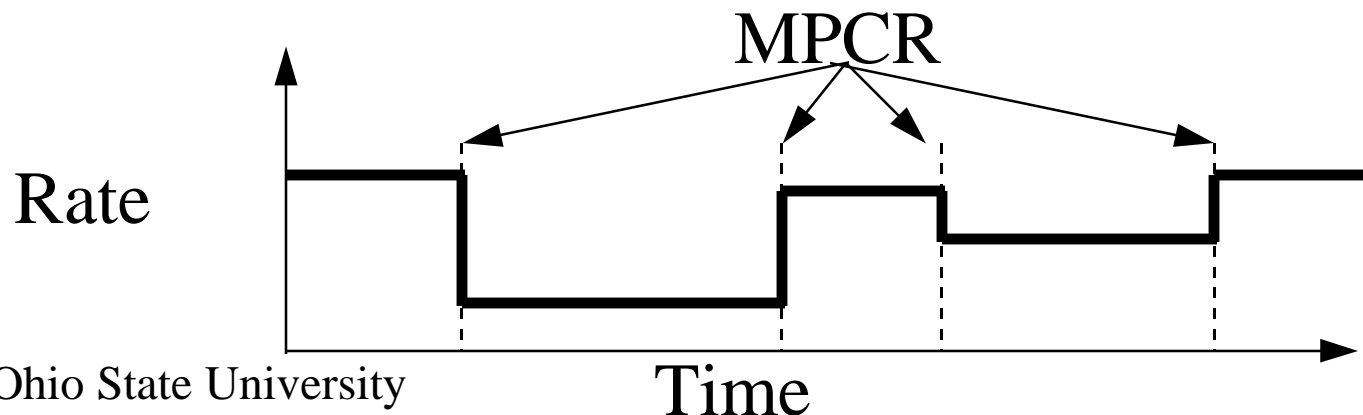
Elementary Stream



- Elementary stream: Sequence of I, P, B frames
 - Individually coded **I** frames - Large
Transmission time = 4 to 5 frame display time
 - Predictively coded **P** frames - Medium
Transmission time = 0.5-1 frame display time
 - Bidirectionally coded **B** frames - Small
Transmission time = 0.2 frame display time

Timestamps in MPEG2

- ❑ Frames may contain a presentation timestamp.
 - ❑ To synchronize the clocks, a sample of system clock is sent every 80 μ s to 100 ms
- MPEG2 Program Clock Reference (MPCR)
We use MPCR instead of PCR (Peak Cell Rate)
- ❑ MPCR is used by a phase lock loop
 \Rightarrow Rate between MPCR is constant



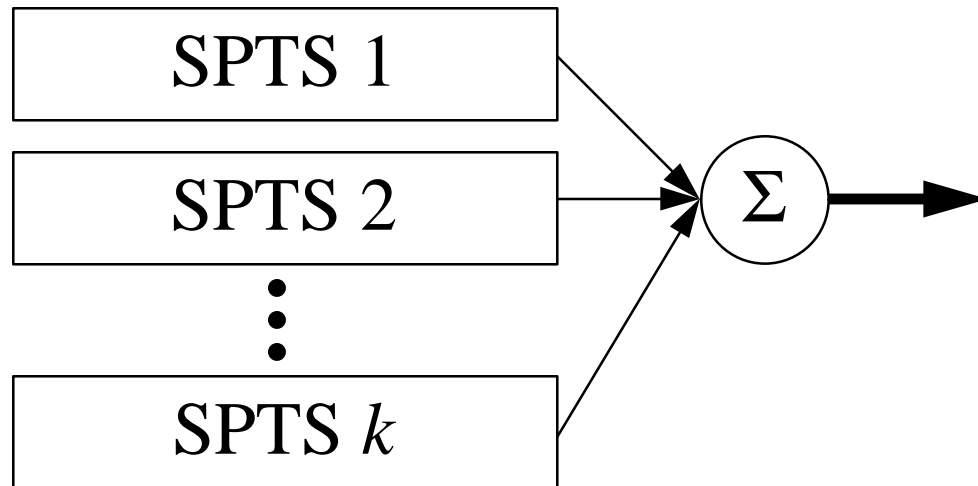
Program vs Transport Streams

- ❑ Program stream = One program, e.g., one movie.
Designed for MPEG1 compatibility.
Mostly for local video.
- ❑ Transport stream = Multiple programs, e.g., a cable.
Designed for remote video.
- ❑ For networking applications, only transport streams are of interest.
- ❑ We model each video source as a “Single Program Transport Stream (SPTS)”

MPEG2 Traffic Characteristics

- ❑ Single Program Transport Stream
- ❑ Piecewise CBR
- ❑ Rate changes only at MPCRs
- ❑ Inter-MPCR interval is random
 - Standard allows 80 μ s to 100 ms interval
 - Most implementations change only 20 to 100 ms
- ❑ Rate values have a long-range dependence

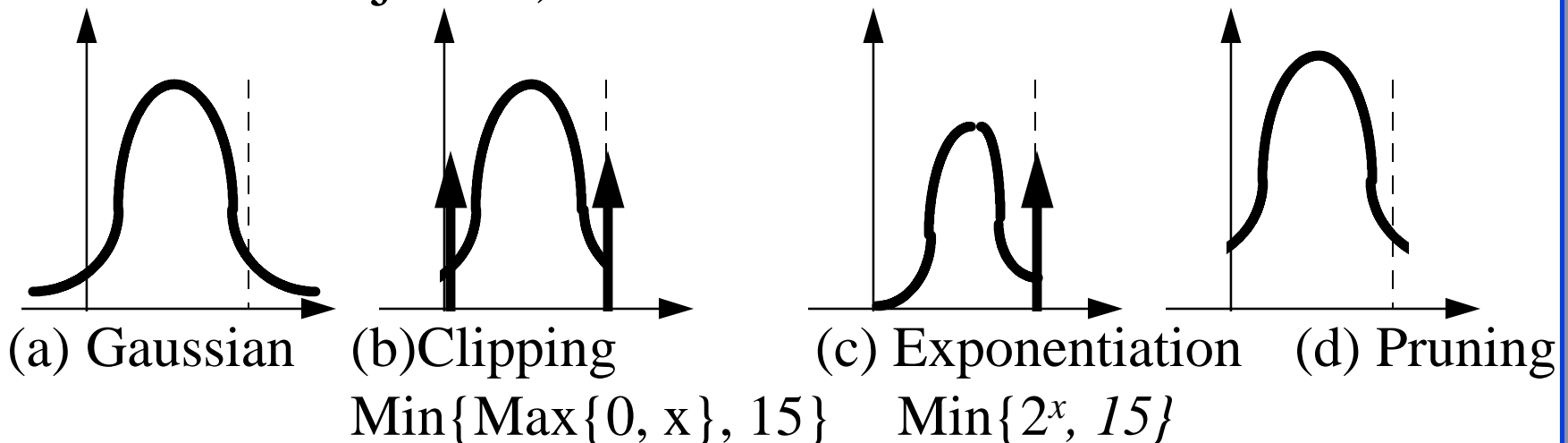
VBR Traffic Model



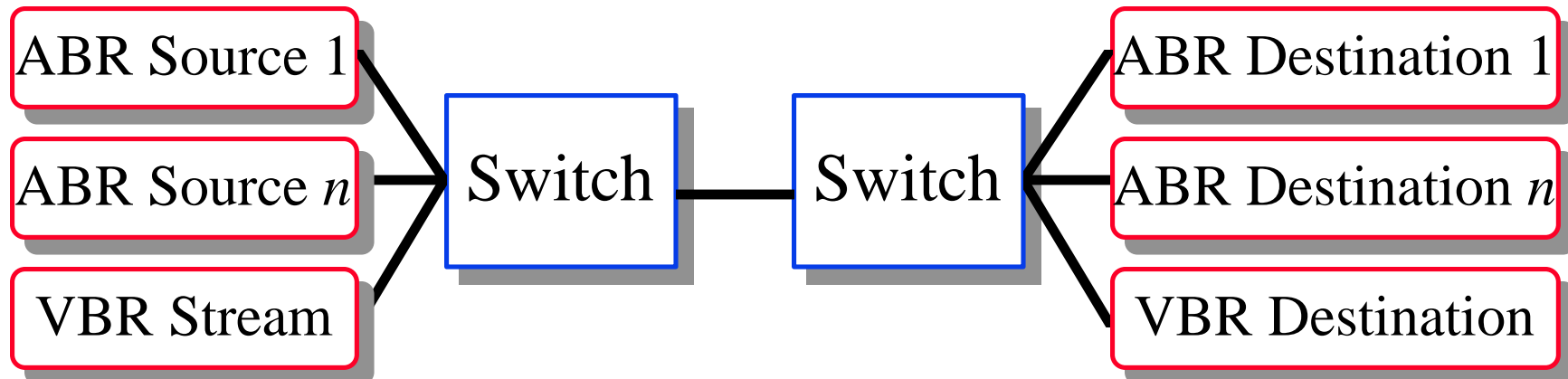
- ❑ VBR background = Sum of k transport streams
- ❑ Each transport stream has
 - ❑ a random inter-MPCR interval = Uniform(20,100)
 - ❑ a random long-range dependent rates
(Fractional Gaussian Noise)

VBR Model (Cont)

- Maximum bandwidth demand = 15 Mbps
Minimum bandwidth demand = 0 Mbps
⇒ Random numbers below 0 or above 15 are ignored (Pruning)
(Alternative choices: clipping or exponentiation were rejected).



n Source + VBR WAN Configuration



← 1000 km → ← 1000 km → ← 1000 km →

- ❑ All links 155 Mbps
- ❑ If VBR background, sum of k independent SPTSs
Various mean and variances, $H=0.8$
- ❑ All traffic unidirectional; Large file transfer application
- ❑ 15 ABR sources, RTT = 30 ms, Feedback Delay = 10 ms

TCP over ABR

- 512 Bytes of data:
 - = 512 B (data) + 20 B (TCP header)
 - + 20 B (IP header) + 8 B (LLC/SNAP)
 - + 8 B (AAL5 trailer)
 - = 568 B = 12 Cells
 - = $53 \times 12 \text{ B} \times (32/31) = 656.5 \text{ B}$ on wire
- Maximum TCP data throughput on 155.52 Mbps
 - = $(512/656.5) \times 155.52 \text{ Mbps} = 121.3 \text{ Mbps} = 78\%$

Simulation Parameters

- Source: Parameters selected to maximize ACR
TBE = 512
CDF = 0 (Rule 6 disabled)
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 = $\min\{500 \text{ cells}, 5000 \mu\text{s}\}$
Target queueing delay $T_0 = 0.5 \text{ ms}$, QDLF = 0.5
ERICA+ curves: Hyperbolic with $a=1.15$, $b=1.00$

TCP/IP Parameters

- ❑ Maximum Segment Size = 512 bytes
- ❑ Timer granularity = 100 ms
- ❑ No TCP processing time
- ❑ Max window on WAN = $16 \times 65,536 \text{ B}$
= 10,485,760 B > 30 ms at 121.3 Mbps = 454,875 B
- ❑ Max window on Satellites = $256 \times 34,000 \text{ B}$
= 8,704,000 B > 550 ms at 121.3 Mbps = 8,339,375 B
- ❑ No delay ack timer
- ❑ Fast retransmit/recovery or Early packet drop (EPD)
have no impact when there is no loss.

Performance Metrics

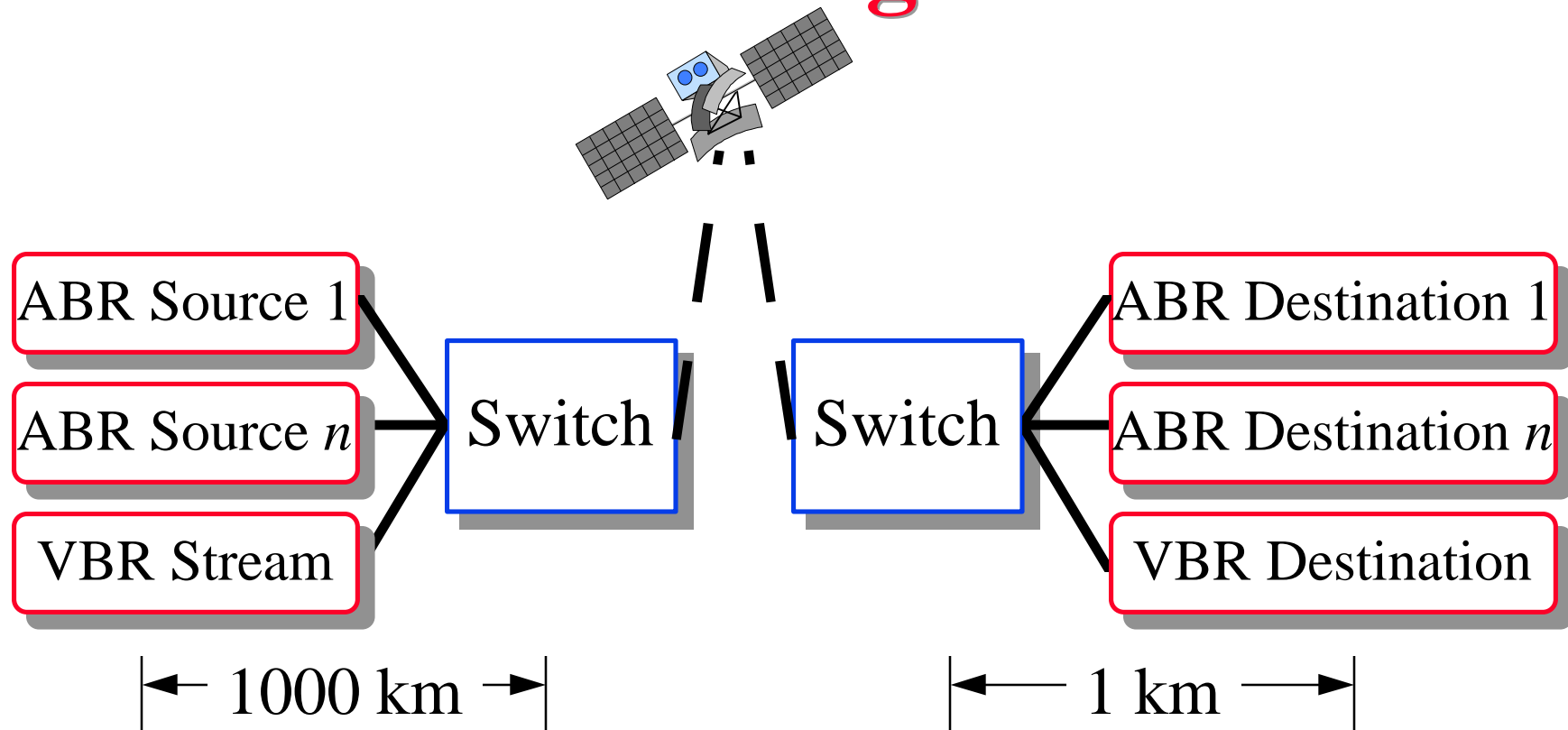
- ❑ ABR Capacity
 - = Link Bandwidth - VBR mean rate
 - Note 100% link bandwidth can be used in ERICA+.
 - Not 90% as in ERICA.
- ❑ Max Possible TCP Throughput
 - = $0.78 \times$ ABR Capacity
- ❑ Efficiency
 - = TCP Throughput / Max Possible TCP Throughput
- ❑ Maximum queue length

WAN Simulation Results

Per-video Source		ABR Performance		
Mean Rate (Mbps)	Standard Deviation (Mbps)	Max Switch Queue (Cells)	TCP Throughput (Mbps)	Efficiency
5	5	$11634 = 3.18 \times F/b \text{ delay}$	76.77	95.2%
7.5	7	$8175 = 2.22 \times F/b \text{ delay}$	66.30	93.8%
10	5	$3884 = 1.05 \times F/b \text{ delay}$	56.52	91.8%

- Efficiency $> 90\%$ = Very close to maximum possible
- Maximum switch queue = $3 \times$ Feedback delay or $1 \times$ RTT
- Lower VBR Usage \Rightarrow Higher ABR capacity
 \Rightarrow ABR errors \Rightarrow Higher ABR queues

n Source + VBR Satellite Configuration 1



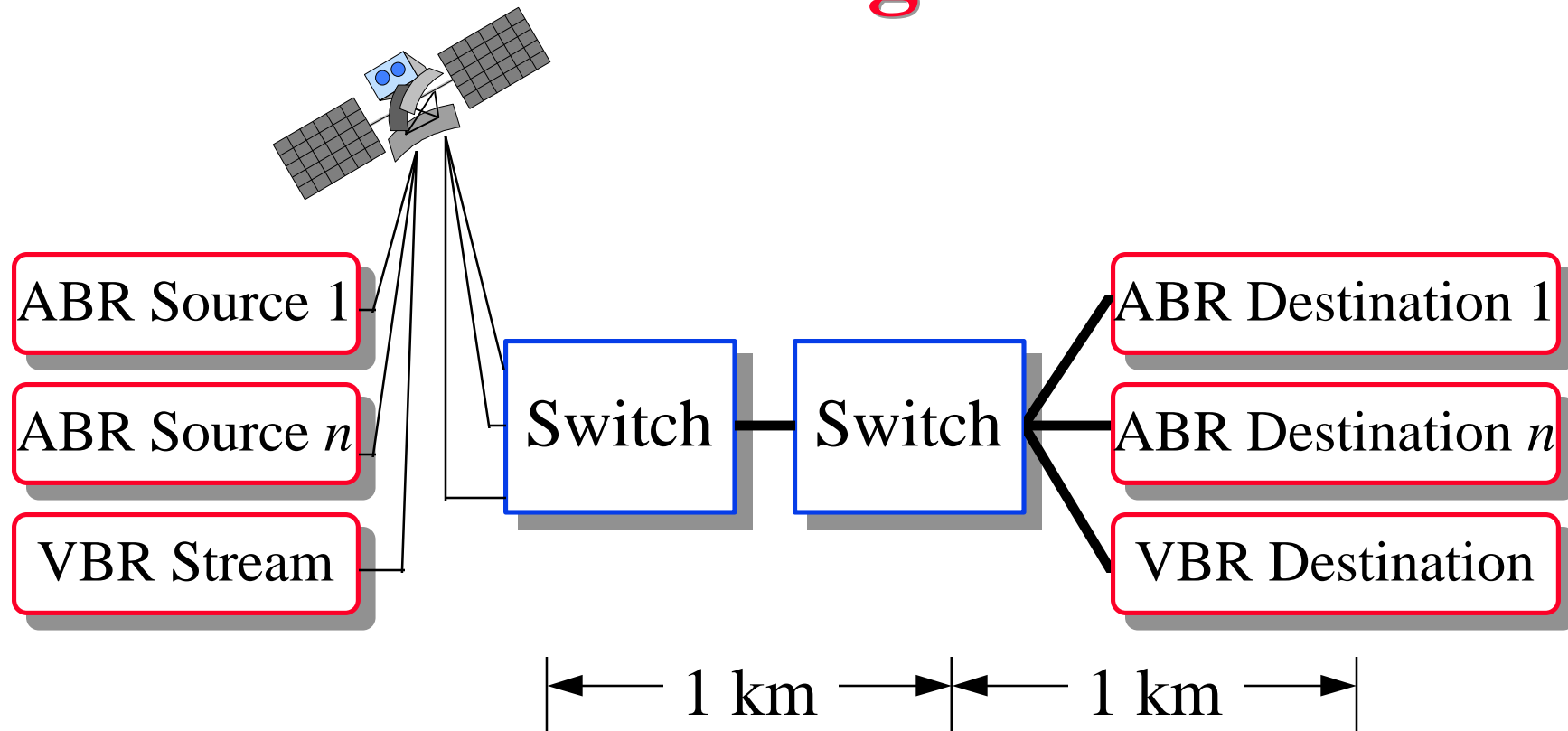
- 15 ABR sources, $RTT = 550$ ms,
Feedback Delay = 10 ms

Results: Satellite Configuration 1

Per-video Source		ABR Performance
Mean Rate (Mbps)	Standard Dev. (Mbps)	Max Switch Queue (Cells)
5	5	6824 = $1.86 \times F/b$ delay
7.5	7	5313 = $1.45 \times F/b$ delay
10	5	6062 = $1.65 \times F/b$ delay

- ❑ Switch queues depend upon the feedback delay
- ❑ Switch queues are below 3 times the feedback delay regardless of the variance.

n Source + VBR Satellite Configuration 2



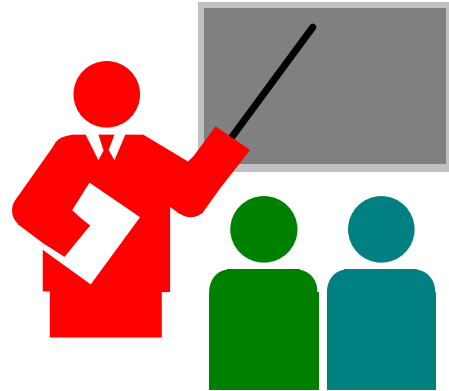
- 15 ABR sources, RTT = 550 ms,
Feedback Delay = 550 ms

Results: Satellite Configuration 2

Per-video Source		ABR Performance
Mean Rate (Mbps)	Standard Dev. (Mbps)	Max Switch Queue (Cells)
5	5	212520 = $1.05 \times F/b$ delay
7.5	7	229599 = $1.14 \times F/b$ delay
10	5	165681 = $0.82 \times F/b$ delay

- Same results as in Satellite 1:
 - Switch queues depend upon the feedback delay
 - Switch queues are below 3 times the feedback delay regardless of the variance.

Summary



- ❑ MPEG2 compressed video = piecewise CBR, long-range dependent rate, random inter-MPCR intervals
- ❑ ABR with appropriate switch algorithm can handle the randomness in ABR capacity
- ❑ With ERICA+ and Infinite TCP Traffic:
 - ❑ Queue lengths $< 3 \times$ Feedback delay
 - ❑ Efficiency close to the maximum possible.
 - ❑ Queues are similar to those with deterministic VBR

Key References

- ❑ All of our previous contributions and papers are at:
<http://www.cis.ohio-state.edu/~jain/>
- ❑ Mathew Goldman, “Variable bit rate MPEG2 over ATM: Definitions and Recommendations,” AF-TM 96-1433, October 1996.
- ❑ Vern Paxson, “Fast approximation of self-similar network traffic,” LBL report LBL-36750, April 1995.
- ❑ Christos Tryfonas, “MPEG-2 Transport over ATM Networks,” MS Thesis, UC Santa Cruz, Sept 1996.