# Uncompressed HD Video Streaming with Congestion Control

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http://www.east.isi.edu/~ladan/APAN.pdf

# Outline

- Goals
- The UltraGrid system
  - Approach
  - Architectural overview
  - AccessGrid integration
- Experiences with transport of HDTV content
  - Experimental setup
  - Performance measurements
- Media aware congestion control
- Conclusion

# Goals

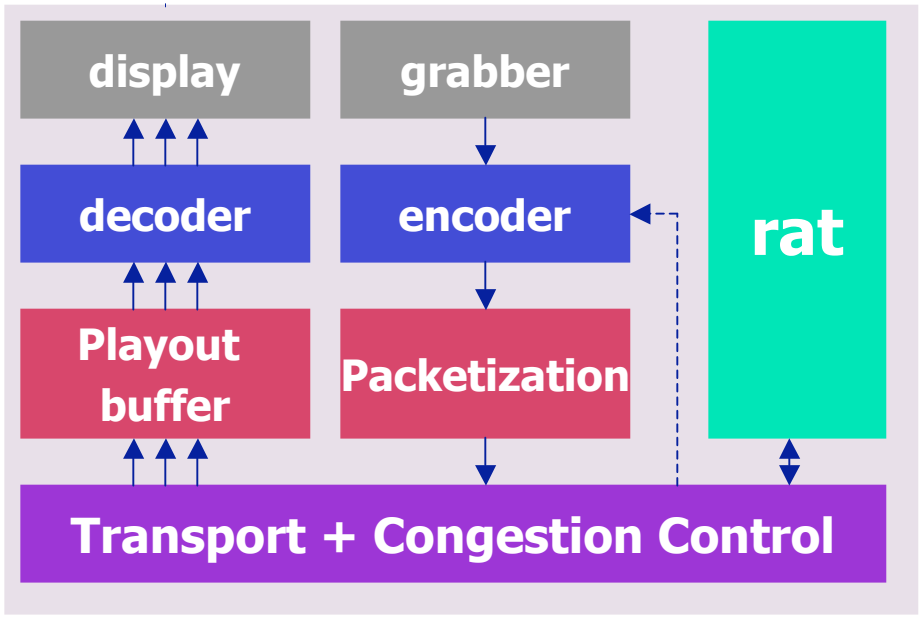
- Raise the bar beyond the limits of currently available video conferencing tools:
  - Develop next generation ultra-high quality video conferencing tool:
    - Using commercial off-the-shelf hardware
    - Best effort IP networks

- Capitalize on increases in end-system capabilities and network capacity to further enable and enhance virtual collaborations

# Approach

- Integrate recent advances and research in:
  - Codecs and media formats: DV, FireWire, and High Definition TV
  - Error correction and concealment
  - Fine grained scheduling
  - Adaptive media playout
  - Congestion control
- Use standard protocols:
  - Real-time Transport Protocol (RTP)
  - Custom payload formats and profiles where necessary
- Develop systems that can be safely deployed on the public Internet, yet can scale with network capacity

# Architectural Overview



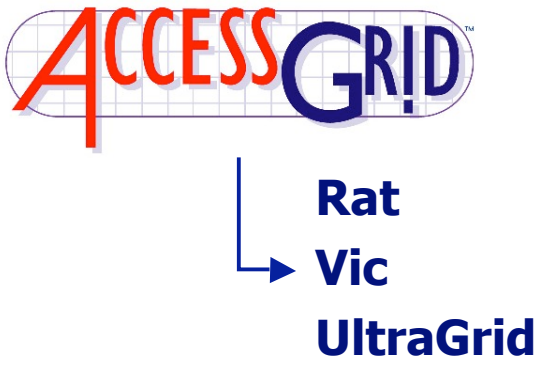

**UltraGrid Node**

- Transport protocols:
  - RTP/RTCP
  - RFC 3550
- Congestion Control:
  - TCP Friendly Rate Control (TFRC)
  - RFC 3448
- Leverage other open source projects:
  - Rat
  - Libdv
  - vic

# Codec Support

| Codec | Max Data Rate | RTP Payload | Minimum Hardware Support Sender | receiver |
|---|---|---|---|---|
| **HDTV** | ~1 Gbps | **draft-ietf-avt-uncomp-video** | HDTV capture card + HDTV camera | HDTV capture card -or- X11+hardware acceleration |
| **DV** | 50 Mbps | RFC 3189 | FireWire + DV camera | - |
| **M-JPEG** | - | RFC 2435 | - | - |
| **H.261** | - | RFC 2032 | - | - |

# Integration with the AccessGrid




- Add UltraGrid capabilities as a "plug-in" service in AccessGrid:
  - AccessGrid community benefits from UltraGrid video formats and codecs
  - UltraGrid benefits from AccessGrid infrastructure

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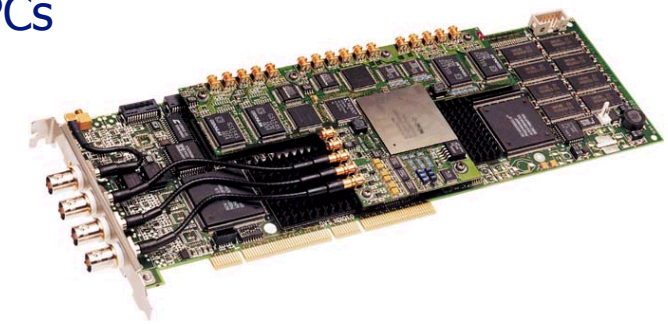
# Uncompressed Video Transport Hardware Support

- Current instantiation:
  - DVS HDstation capture card
  - Transmitter and receiver hosted on separate PCs
    - Dell PowerEdge 2500 servers
    - 1.2GHz PIII Xeon/Dual 64 bit PCI
    - Linux 2.4
  - Gigabit Ethernet
    - must down-sample video < 1G



- The combination makes HDTV grabbing and transport feasible on commodity hardware
  - PC + HDTV grabber

- Alternative HDTV capture cards now available:
  - Kona Card: http://**aja**.com/products_**kona**.html
  - Centaurus: http://www.**dvs**.de/english/products/oem/**centaurus**.html

# Uncompressed Video Transport RTP payload format

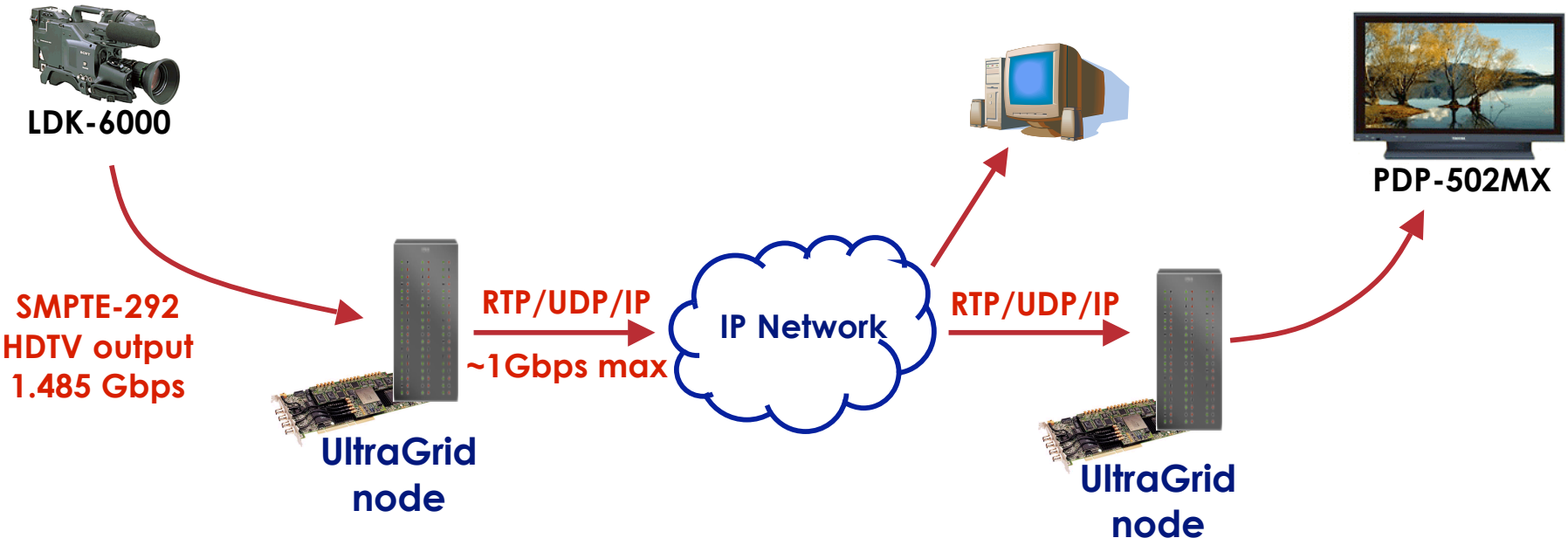
- "RTP Payload Format for Uncompressed Video"
  - Open standard for uncompressed video transport on IP networks
    - draft-ietf-avt-uncomp-video-06.txt (cleared AVT Last Call)
  - Supports range of formats including standard & high definition video
  - Interlaced and progressive
  - RGB, RGBA, BGR, BGRA, YUV
  - Various color sub-sampling: 4:4:4, 4:2:2, 4:2:0, 4:1:1

- Pixel group, "pgroup":
  - Samples related to the same pixel are not split across different packets

- Standard RTP header fields used in the usual manner
  - Marker indicates end of frame
  - 90kHz timestamp indicates the frame capture time

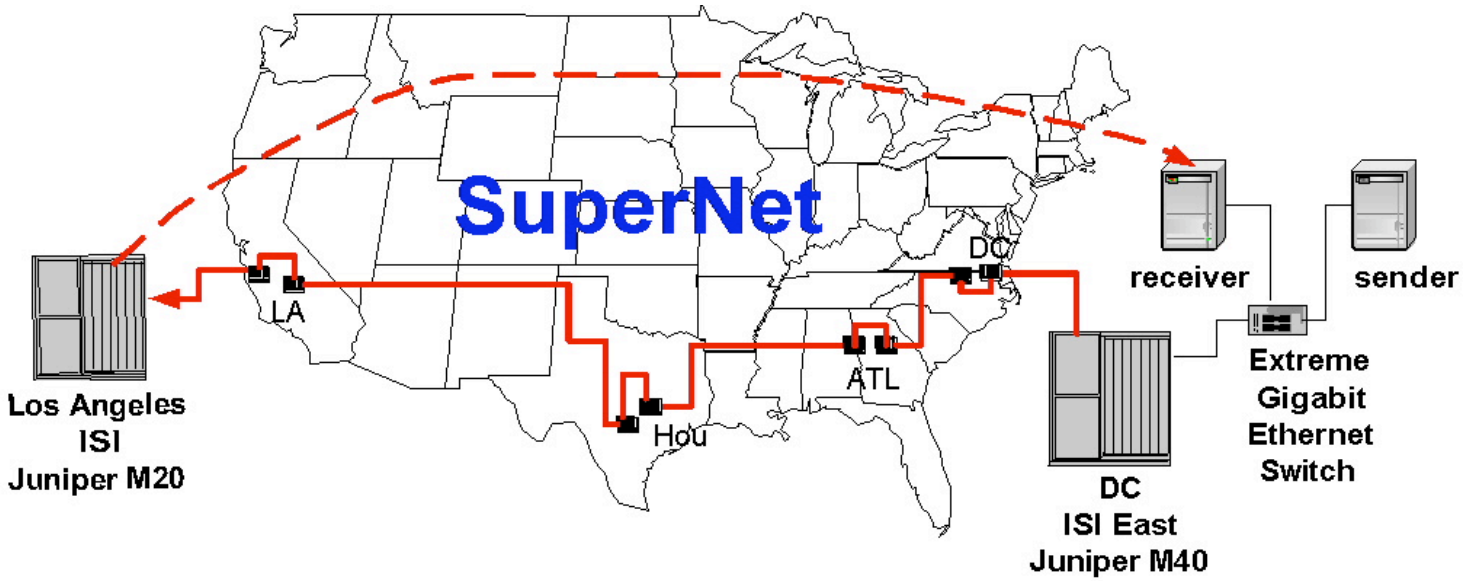
- RTP payload header
  - Extended RTP sequence number -> 32bit sequence

# Uncompressed Video Transport Schematic view




- Video is down sampled at the sender:
  - RGB -> YUV
  - Color is down sampled from 10bits to 8bits
  - Auxiliary data removed
- Regenerate SMPTE-292M signal at receiver
  - Software-based processing and display is also possible
- RTP packetization based on draft-ietf-avt-uncomp-video-06.txt

# Experimental Setup




- Path characteristics:

  10 hops between ISI-east → ISI-west

  data returns via a tunnel

  132ms RTT

- Tests were conducted over SuperNet:
  - → research wide area network which overlays on a commercial ISP network
  - → OC-48 shared with commercial IP traffic; no QoS support

# Performance Measurements (w/o Congestion control)

- Sustained data rate: ~1Gbps
- Nominal loss

| Event duration | Frequency | Percentage |
|---|---|---|
| No loss | 24697400 | 99.65 |
| Single packet loss | 85797 | 00.34 |
| Two consecutive packets loss | 587 | 00.002 |
| Three consecutive packets loss | 7 | 00.00003 |
| Four or more packets loss | 0 | 00.0 |

Total packets: 24784392

# Performance Measurements (w/o Congestion control)

- Network typically did not interfere with the operation of our system
- When the path is adequately provisioned, loss is rare
  - (Data is worst-case)
- Most of the limiting factors are due to the host
  - Per-packet processing at the host
  - Memory and I/O bus bandwidth
- We believe this is typical for major ISP backbone networks
  - Problems due to access networks/interconnects/hosts

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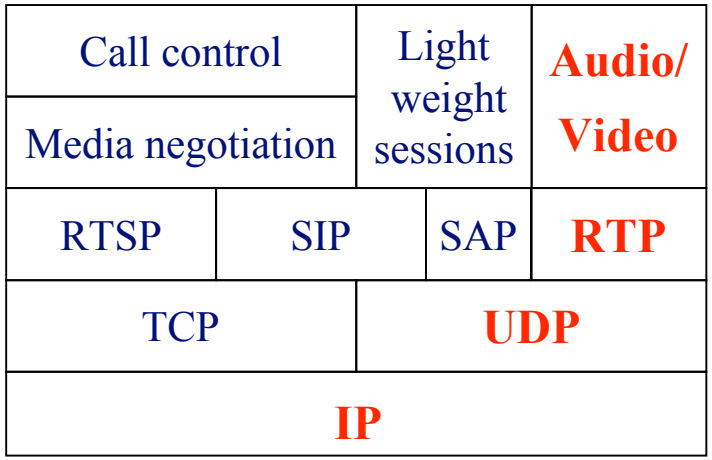
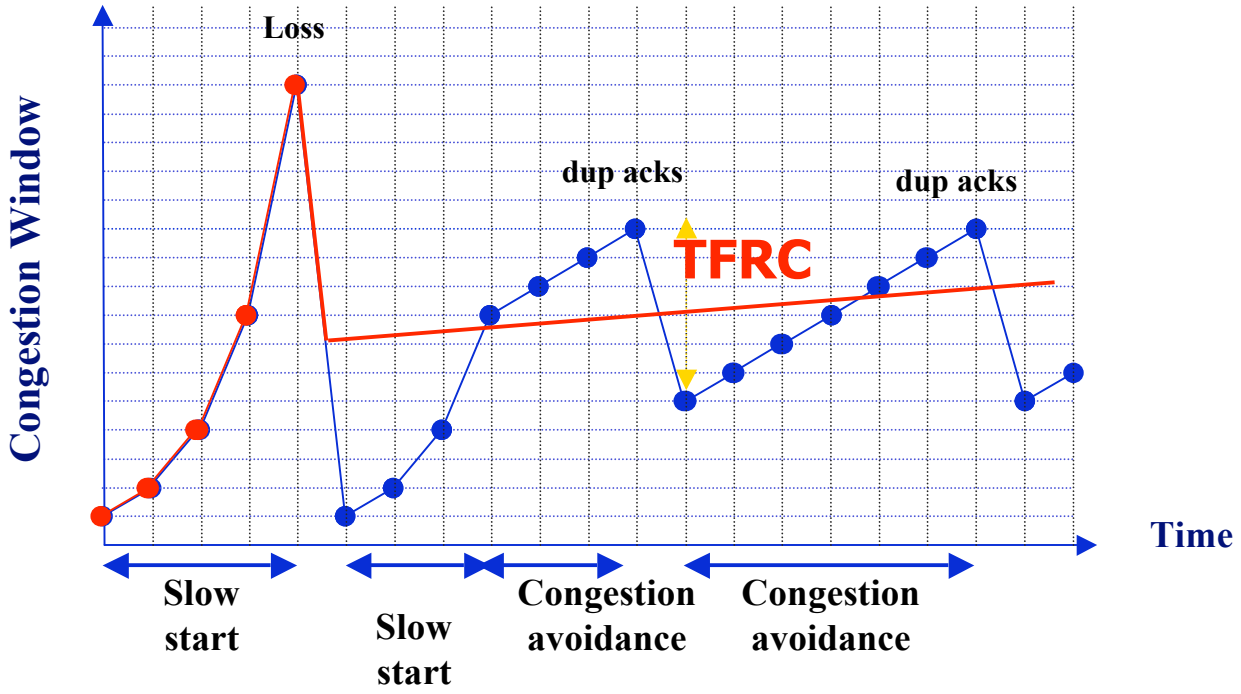
# Congestion Control and IP Networks

- An IP network provides a best-effort packet-switched service: no admission control, packets are discarded at intermediate routers.
- Congestion control is the responsibility of the transport protocol.
- UDP: no congestion control
- TCP does congestion control:
  - ➔ Continuously seeks additional bandwidth
  - ➔ Cuts back on transport when congestion is detected




**Multimedia Protocol Stack**

# TCP Congestion Control




- TFRC provides a smoothly changing sending rate suitable for streaming media applications.
- Is fair to TCP on average

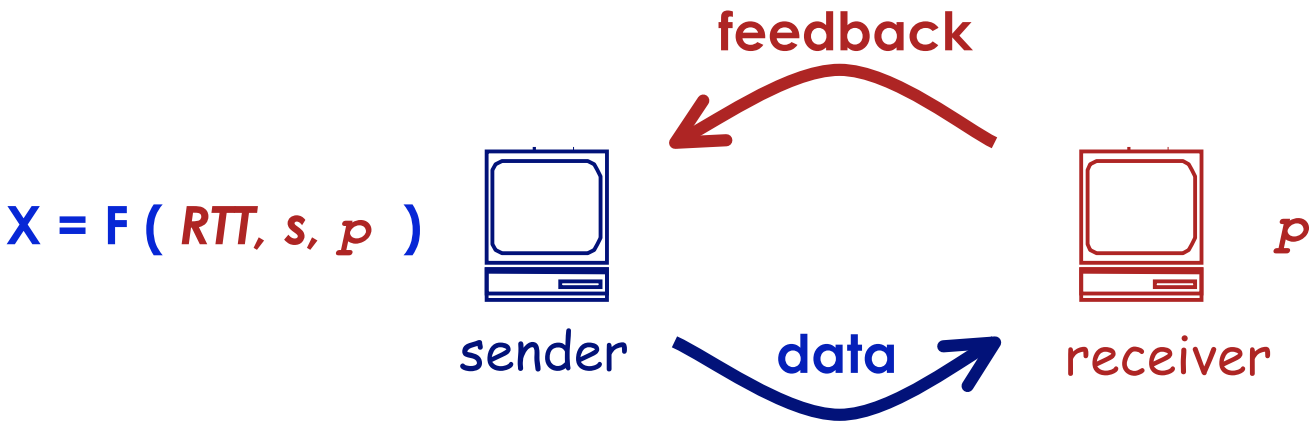
# TCP Friendly Rate Control

- TFRC is a equation based congestion control scheme:
  - Fair to TCP on average
  - Any equation that computes TCP throughput as a function of:
    - Loss event rate: ***p***
    - Round trip time: **RTT**
  - RFC 3448

$$X = \frac{s}{RTT\sqrt{\frac{2p}{3}} + \left(4RTT\left(3\sqrt{\frac{3p}{8}}\right)p\left(1+32p^2\right)\right)}$$

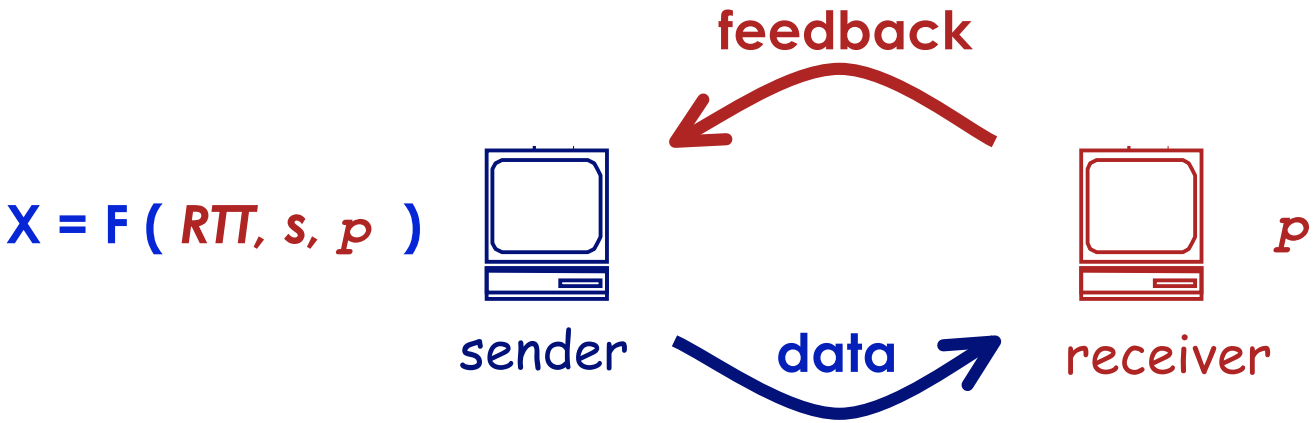
# TCP Friendly Rate Control

- Loss event rate, ***p***, is computed by the receiver:
  - Feedback is sent to sender at least once per RTT --or--
  - Once per data packet for data flows that send less than once per RTT
- Sender, computes TCP friendly rate based on feedback received from the receiver.



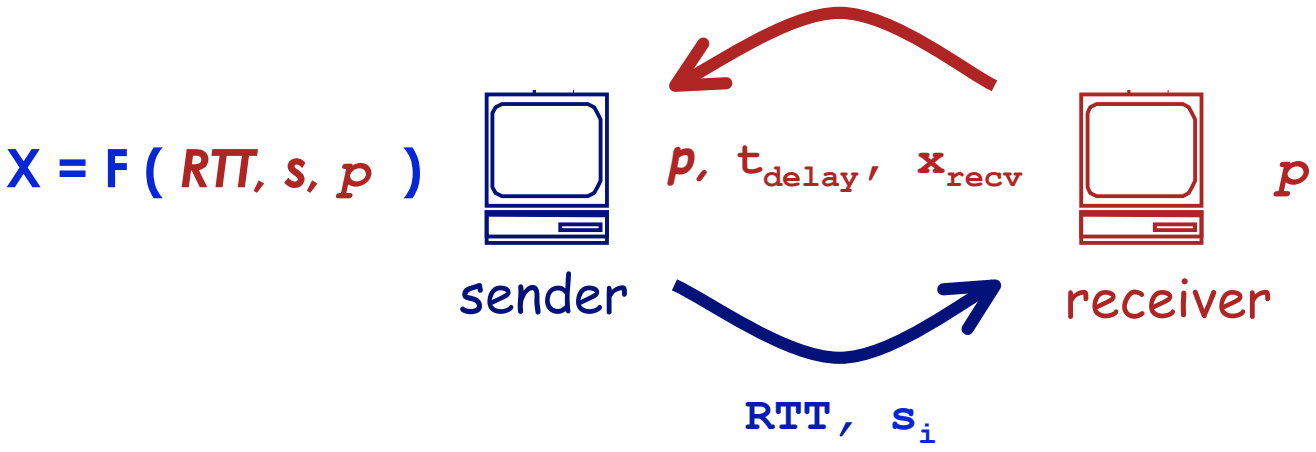
# TCP Friendly Rate Control

- RFC 3448: IETF standard document for TFRC
  - ➔ defines the mechanism of congestion control
  - ➔ does not describe how TFRC interacts with the transport layer
  - ➔ TFRC can be used with different transports:  I.e: UDP, RTP



# RTP Profile for TCP Friendly Rate Control

- The RTP Profile for TCP Friendly Rate Control detail the interactions of TFRC with RTP/RTCP: draft-ietf-avt-tfrc-profile-00.txt
  - format of data packet
  - format of RTCP feedback packets:
    - Receiver data rate: $x_{recv}$
    - Processing time for data packets: $t_{delay}$
    - Loss event rate: $p$
  - timing of RTCP packets



# TFRC and UltraGrid

- Preliminary implementation of draft-ietf-avt-tfrc-profile-00.txt in UltraGrid.

- Test TFRC's rate adaptation:

  - **? Mbps**
    - RTP/UDP
    - TFRC congestion control
    - Network is lightly loaded and loss free

  - ~1 Gbps
    - RTP/UDP
    - No congestion control
    - Careful monitoring
    - Network is lightly loaded and loss free

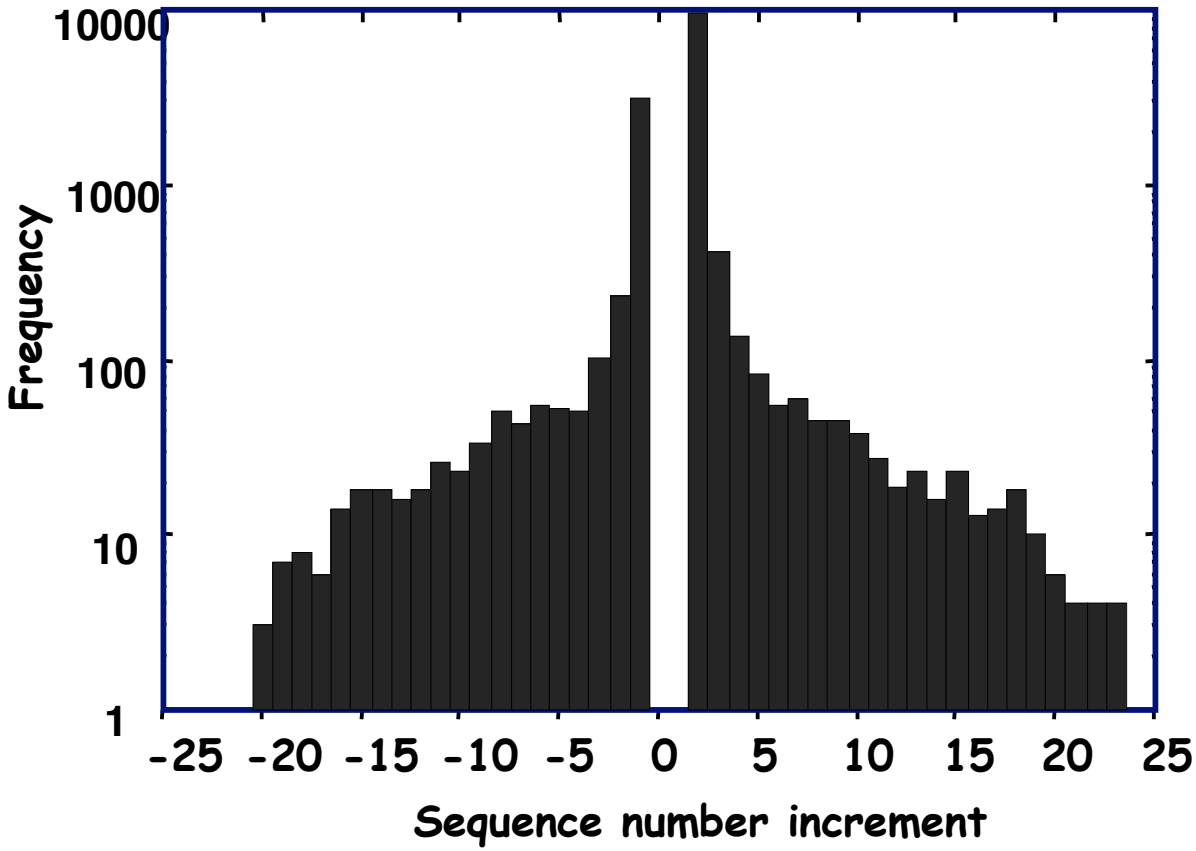
# TFRC and UltraGrid

- Preliminary implementation of draft-ietf-avt-tfrc-profile-00.txt in UltraGrid.
- Results?
  - **Much lower!**
    - RTP/UDP
    - TFRC congestion control
    - Network is lightly loaded and loss free
  - ~1 Gbps
    - RTP/UDP
    - No congestion control
    - Careful monitoring
    - Network is lightly loaded and loss free

# Reordering?

- Independent TCP tests (iperf):
  - ➔ 200Mbps
- Loss rate is very low on network path
- Could it be reordering?

Upto 1.3%reordering



# Media aware congestion control

- To be fair to TCP flows, TFRC emulates TCP's congestion signals:
  - Packet loss
  - Packet reordering
- Data trace exhibited nominal packet loss, but over 1% reordering --> reduced data rate
- Media applications tolerant of reordering
- Media aware congestion control schemes must balance fairness to TCP and media applications resilience to reordering

# Summary

- Demonstrated the ability of IP networks to support high quality, high rate, media.
  - Limitations appear to be in the end system, rather than network
- Highlighted the importance of congestion control for media applications.
- Congestion control for media applications must take into account their requirements and characteristics:
  - Resiliency to reordering
    - "TCP-derived" congestion control schemes must be adapted to media applications.
    - Decouple "packet loss" from "packet reordering".
  - Rate adaptation tailored to media content

# Further Information…

**http://www.east.isi.edu/projects/UltraGrid/**