Congestion Manager

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6.829 Computer Networks

October 24, 2001

Outline

- Motivation (problem CM solves?)
  - Sharing info on concurrent flows
  - Enable application adaptation
- CM Architecture
- The CM API (and tradeoffs)
- More about the CM Framwork...
- Implementation
- Limitations

Motivation

- End-systems supply much functionality
  - Reliability
  - In-order delivery
  - Demultiplexing
  - Message boundaries
  - Connection abstraction
  - Congestion control

Of these, congestion control is the only functionality required by all communications applications!

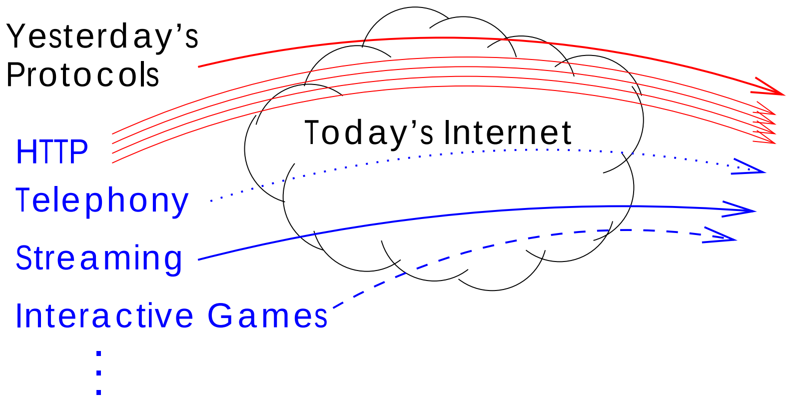
Problem...

"Multimedia Transmissions Drive Net Toward Gridlock"

- *Sara Robinson, NYT, 8/23/99*

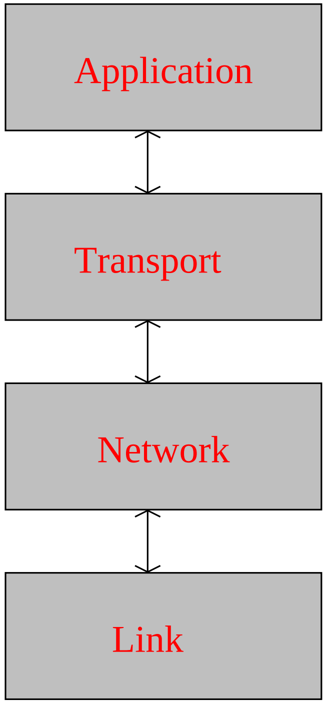
Today's End-System Architecture

TCP's AIMD solves the problem, right?



- Doesn't enable application adaptation
  - Streaming (e.g., audio, video, etc.)
- Doesn't handle concurrent flows
  - e.g., WWW
  - any application that would benefit from shared information

Adaptation



- Little information is transferred across layers to applications
- Increasing number of non-TCP applications

CM exports a simple adaptation API

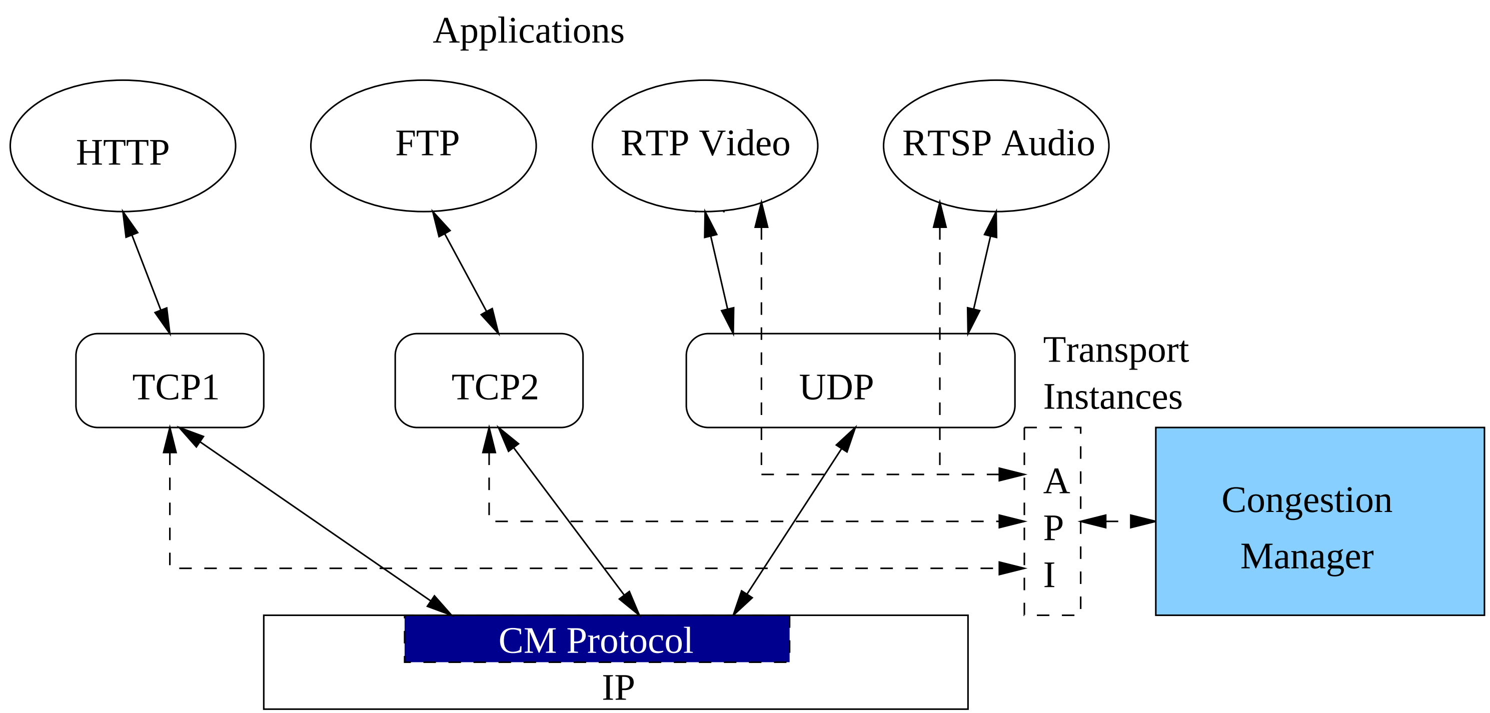
Concurrent Flows: Web of Troubles

- Web browsers perform concurrent downloads
  - Simultaneous dowloading for embedded images
  - Proxies can multiplex requests
  - Aggressive downloading => Higher Throughput
- But...
  - Why slow start each connection?
  - Loss information is not shared between flows
  - More connections = More bandwidth! (fair?)
  - Concurrent streams are competing, should be cooperating!

What can we do to ensure fair behavior and yet gain some of the benefits of concurrent downloads?

CM abstracts all congestion-related information into one place.

The Big Picture

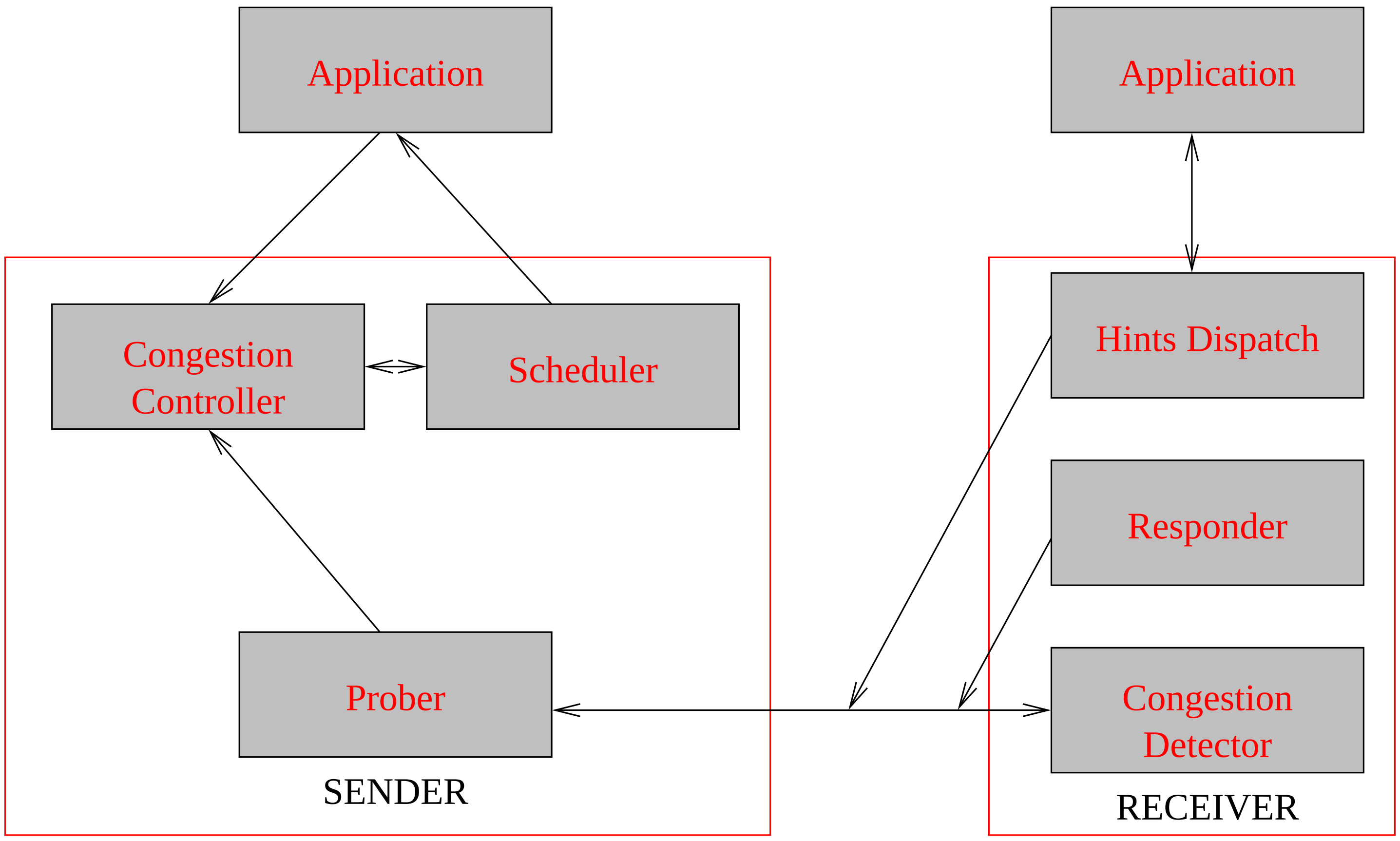


- CM performs all congestion related tasks for macroflow.
- Applications adapt using the CM-exported API.
- Frees transport/app protocols from reimplementing CC.

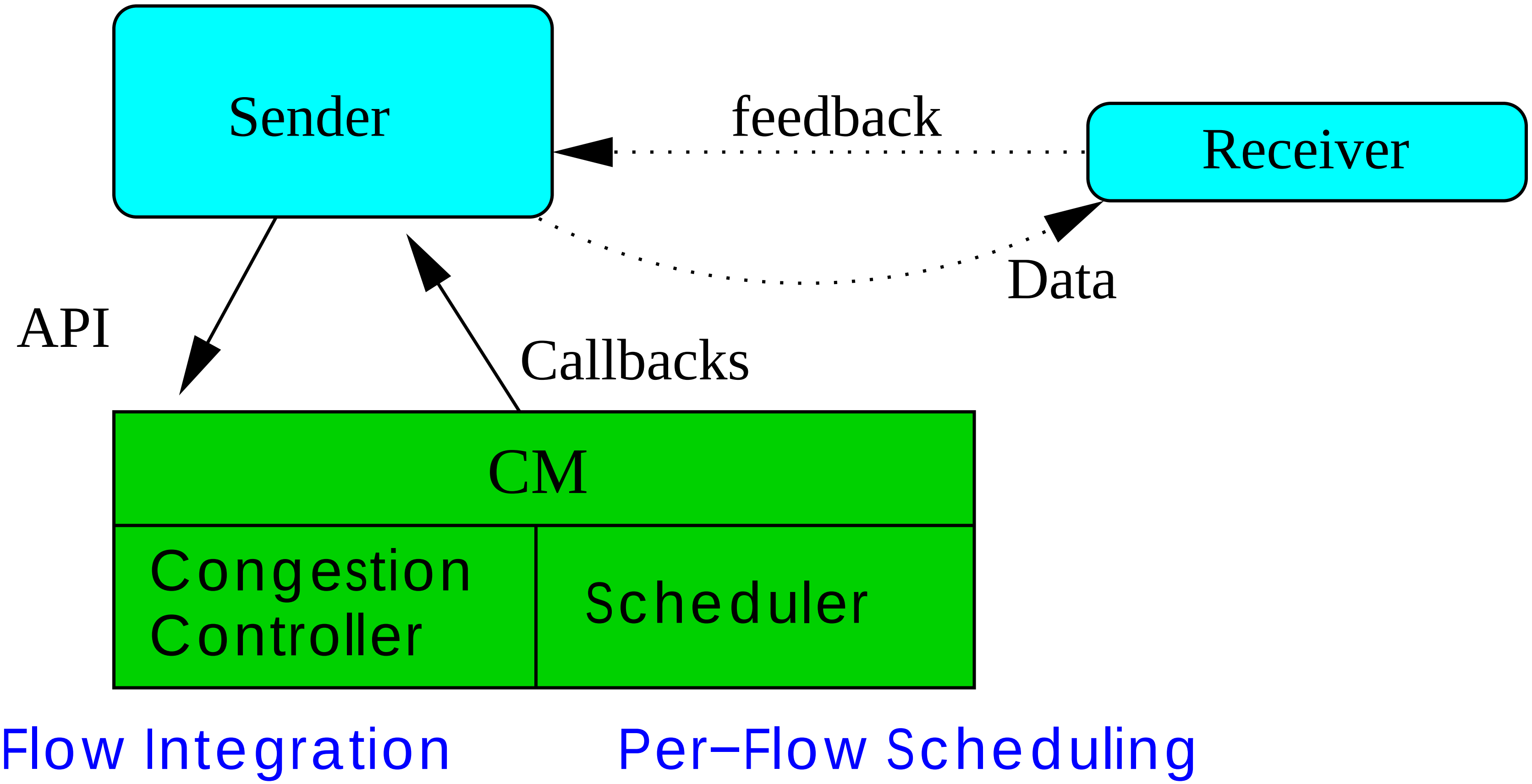
Questions

- What to send?
  - API
- When to send?
  - Congestion controller
- Who should send?
  - Scheduler
- What’s the network state?
  - Application feedback/CM Probing
  - OR...can avoid modifying receiver stack if applications provide feedback.

CM Architecture



CM Architecture



- Separate congestion management from transport.
- Multiple applications and protocols can share congestion info.
- Separate congestion control and scheduling.

Macroflows

- All streams on a "macroflow" share congestion state
- What is a "macroflow"? Streams grouped by:
  - Destination address?
  - Address and port?
  - End host application?
- Let the application group flows into macroflows that share state
- Quickly detecting good macroflows...

The CM API

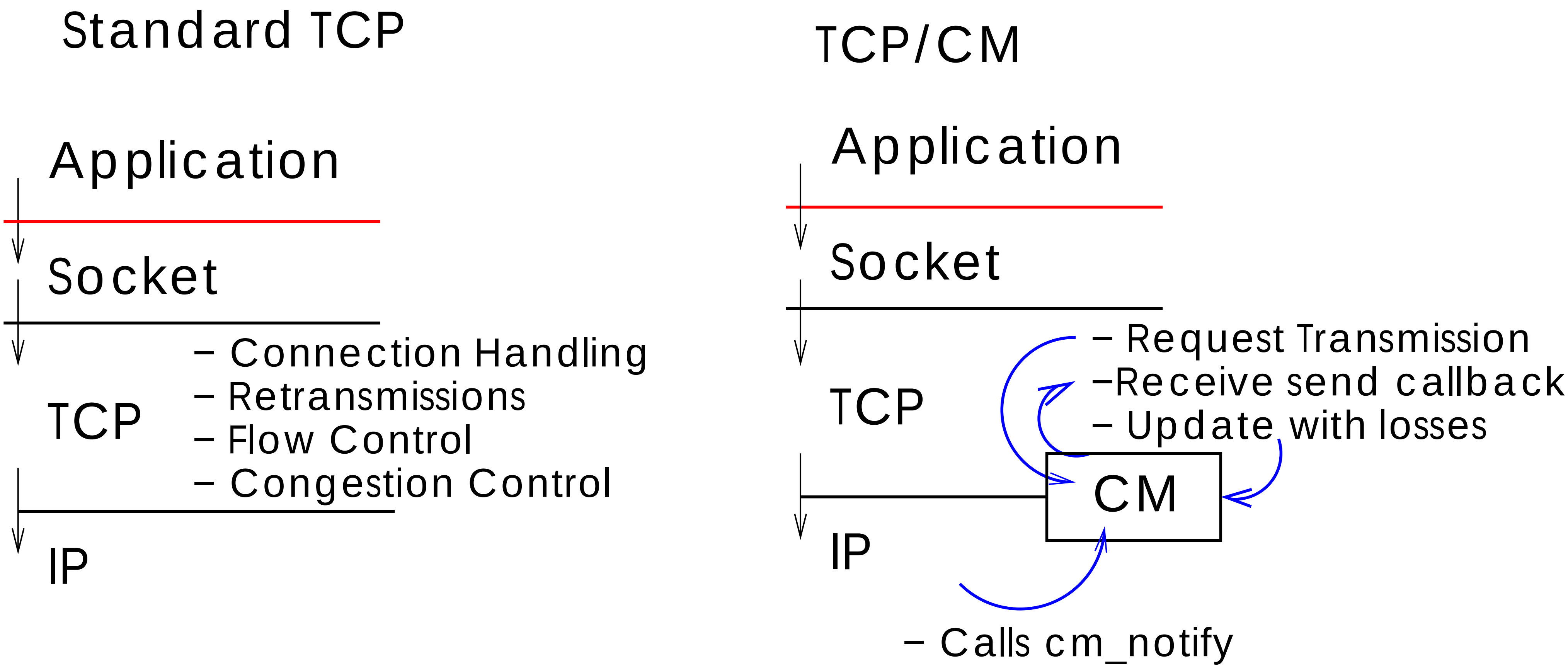
- State Management
  - cm_open() -- returns stream ID
  - cm_close() -- closes session
  - cm_mtu() -- get path MTU for flow
- Data transmission options
  - Buffered send
  - Request/callback
  - Rate callback
- Application Notification
  - cm_update() -- get new rate
  - cm_notify() -- tell CM about any losses
- Queries: cm_query()

Different applications, different needs

- Buffered Send
  - Data-driven applications (send a single file and exit)
- Request/Callback
  - TCP (retransmission decision)
  - Asynchronous apps, last minute adaptation...
  - Video streaming apps, last minute decisions, etc.
- Rate Callback
  - Synchronous event-driven apps (rate-clocked)

Buffering reduces application control,
limits the application to do "last minute adaptation"...

Request/Callback API



Application achieves TCP-like behavior,
but has control over *what to send* .

Asynchronous Transmission for Everyone?

- Request API works for asynchronous sources --

```
asyncronous() {
    wait for (event) {
        get_data();
        send();
}
```

- What about synchronous sources? (e.g., audio)

```
do_every_10_ms () {
    get_data();
    send();
}
```

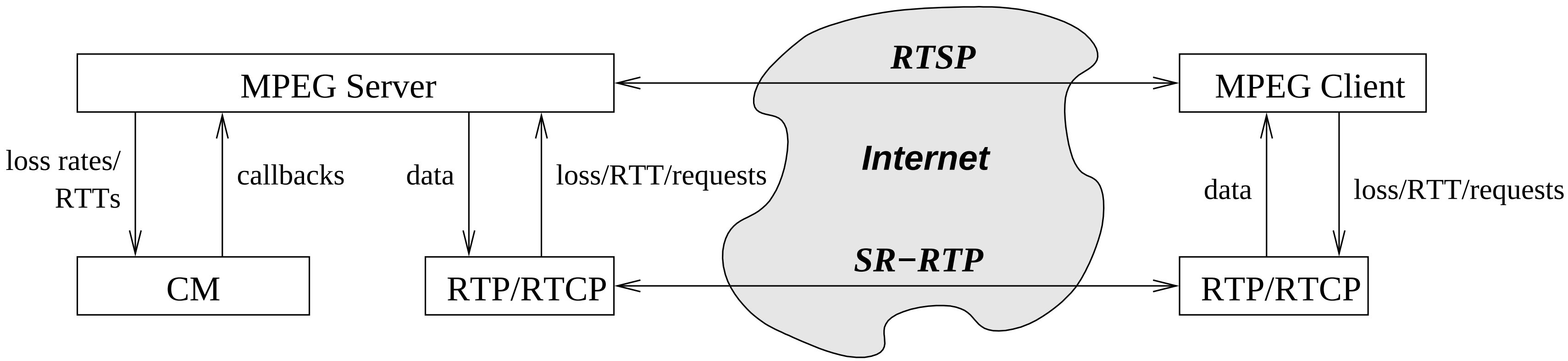
Synchronous Transmission

- Asynchronous callbacks are not appropriate for applications that must transmit at a constant rate (e.g., audio servers)
- A more appropriate API:
  - Register info on RTT, rate thresholds
  - cmapp_update(newrate, new_rtt, new_rttdev)
- Application adjusts sending interval, packet size, etc.

Congestion Controller

- Obtains feedback about past transmissions
- Adjusts the aggregate transmission rate between sender and receiver
- Decides when a macroflow should send
- Modular: Congestion control algorithms on per-macroflow basis

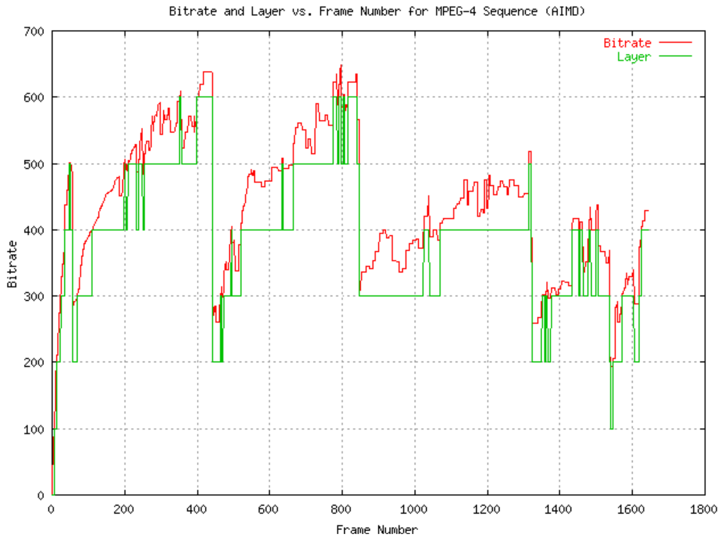
Example: Layered Video

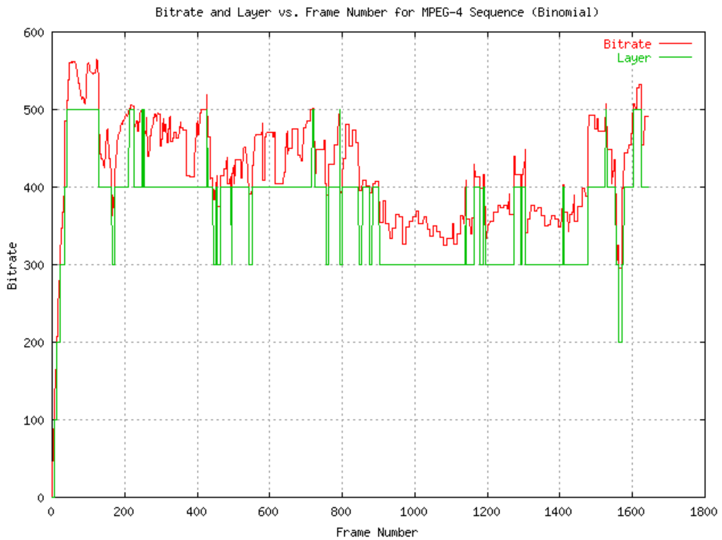


- Track loss rates and RTT using RTP/RTCP, report to CM
- Callbacks from CM control sending rates

Congestion Control Layered Video

Goal: Smooth transmission rate => constant quality video





Scheduler

- Decides which flow on a macroflow should send
- Hints from application/receiver to prioritize flows
- Plug in other scheduling algorithms...

Feedback

- Required for stable end-to-end congestion control
- Probing Protocol
  - optional, can use application feedback instead
- Application
  - cm_update()
  - no changes to receiver stack
- Frequency?

Probing Protocol

- Sender periodically sends out probes
- Receiver responds with
  - Last received sequence number (i.e., this one)
  - SN of last probe received
  - Bytes in between
- Reordering...?
  - Reverse window choices later.
- Lost probes...?
  - Exponential aging
  - Minimim RTT fpr half-life (why stable?)

Application Feedback

<table>
<tr><td>0</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>2</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>3</td><td></td></tr>
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<tr><td colspan="2">V</td><td colspan="1">P</td><td colspan="5">RC</td><td colspan="8">Payload Type=RR</td><td colspan="16">Length</td></tr>
<tr><td colspan="32">SSRC of packet sender (Receiver ID)</td></tr>
<tr><td colspan="32">SSRC_1 (SSRC of first source)</td></tr>
<tr><td colspan="8">fraction lost</td><td colspan="24">cumulative number of lost packets</td></tr>
<tr><td colspan="32">extended highest sequence number received</td></tr>
<tr><td colspan="32">Interarrival Jitter</td></tr>
<tr><td colspan="32">Timestamp Echo (LSR)</td></tr>
<tr><td colspan="32">Processing Time (DLSR)</td></tr>
<tr><td colspan="16">Window Size (kB)</td><td colspan="16">Padding</td></tr>
<tr><td colspan="32">ADU Sequence Number</td></tr>
<tr><td colspan="32">ADU Fragment Length (bytes)</td></tr>
<tr><td colspan="32">ADU Offet (bytes)</td></tr>
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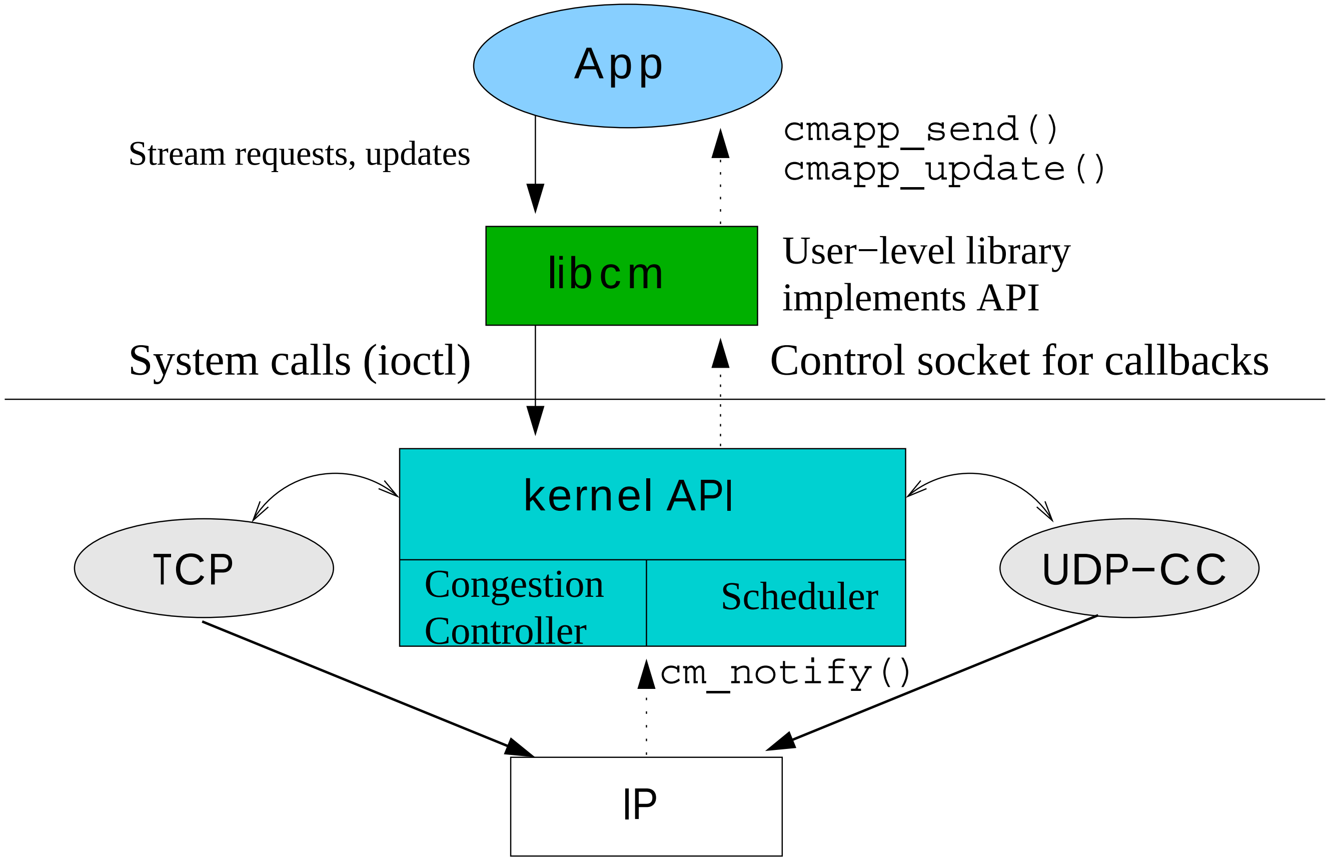
CM Implementation



- IP notifies CM about data transfer on output

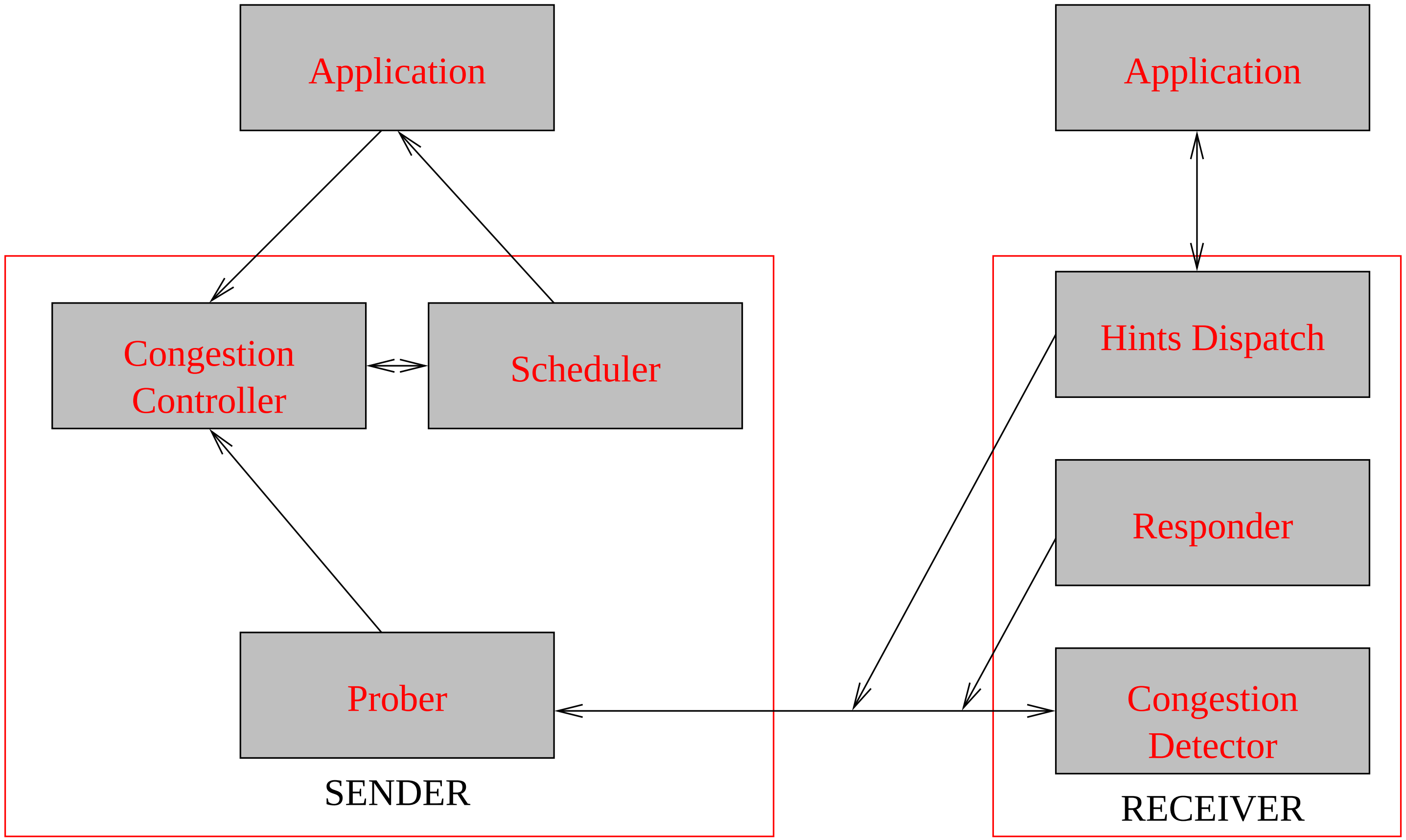
Related Work: HTTP/TCP Interactions

- Connection Establishment
  - 3-Way Handshake, Timeouts (what’s the RTO?)
  - "Stop and Reload" ...manual SYN retransmit
- Persistent Connections
  - *Good:* Can avoid slow-start, 3-way handshake, etc.
  - *Bad:* What’s the congestion window?
  - Solutions: pacing, slowly decrease window, etc.
- Nagle’s Algorithm: limits number of small packets sent
  - *Good:* Interactive apps (e.g., ssh) send fewer small packets.
  - *Bad:* HTTP response delayed if not aligned on packet boundaries.

Limitations?

- Buggy/malicious applications
  - Incorrect loss, RTT reports
  - Application "hogging" bandwidth of macroflow
- Aging of congestion information
  - Detriment of low feedback frequency
- Macroflow granularity
  - Current research is addressing this...
- Multicast applications

Conclusion



Application
Application
Congestion Controller
Scheduler
Hints Dispatch
Responder
Prober
Congestion Detector
SENDER
RECEIVER

Conclusion

- The Congestion Manager Architecture:
  - Separates transport protocol from congestion control algorithms
  - Gives application control over what data to send
- Callback-based architecture allows last minute adaptation by adaptation.
- Applications can benefit from sharing information about congestion.

Buffering reduces application control,
limits the application to do "last minute adaptation"...

Congestion Controller

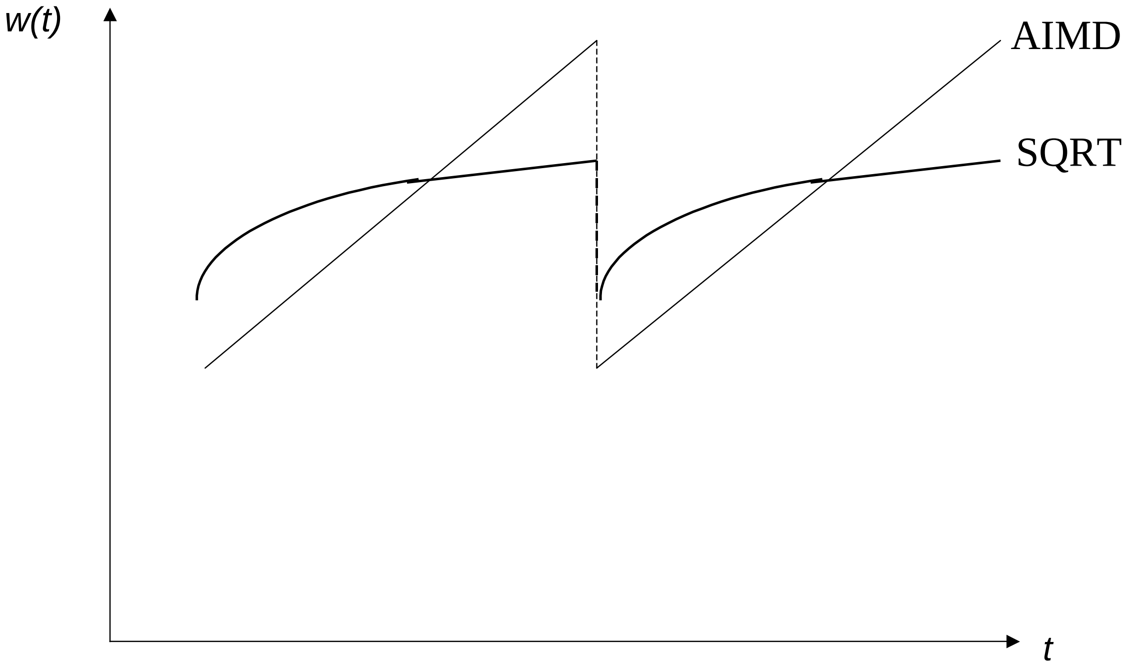
- May want to use something besides TCP’s AIMD
- What applications may be harmed by high oscillations?
- CM allows separation of congestion control algorithms from transport!

Why Sockets?

What about other kernel to user communication:

- Signals
  - Conflict with other applications
  - Receiving a signal is expensive
- System Calls
  - Requires threading support...
- Semaphores
  - Most network apps use sockets instead (??)
  -

Application-Specific Congestion Control



- Applications can employ congestion control algorithms that are more amenable to the task.

...and can experiment with different types of algorithms with relative ease.