An integrated congestion management architecture for Internet hosts

Hari Balakrishnan[1], Hariharan S. ahul[1], and Srinivasan Seshan[2]

[1]M.I.T. Laboratory for Computer Science

[2]IBM T. J. Watson Research Center

ACM SIGCOMM, 1999

Outline

- Introduction
- CM algorithms
  - Rate-based control is TCP-friendly
  - Receiver feedback
  - Better than best-effort networks
  - CM Scheduler
- The CM API
- Application performance
- Conclusions

Introduction (1/2)

- Several trends in traffic patterns that threaten the long-term stability.
  - multiple independent concurrent flows by Web application
  - transport protocols and applications that do not adapt to congestion

- Ensure proper congestion behavior and allows applications adapt to network congestion and varying bandwidth.

Introduction (2/2)

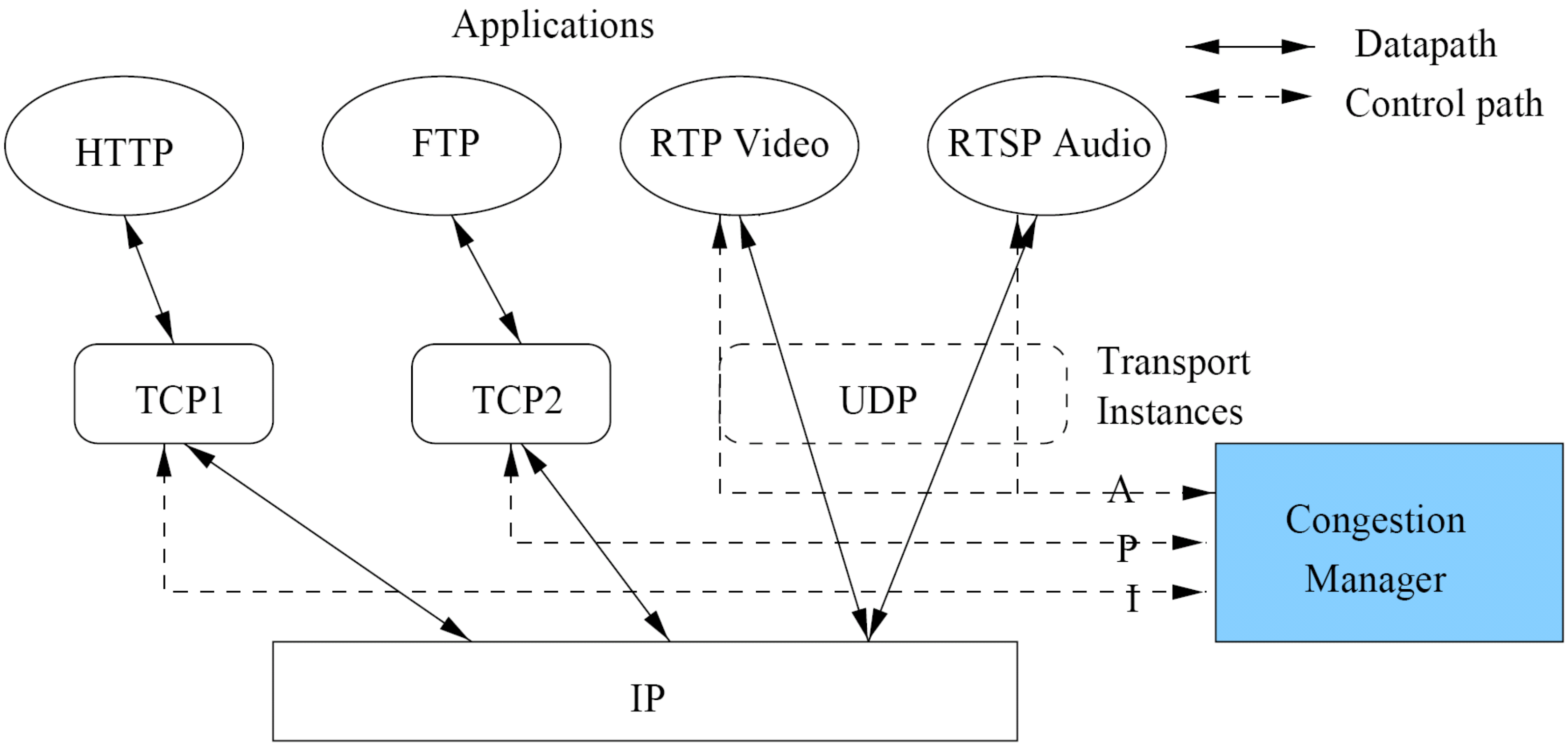


Fig.1 New sender architecture with centered around the Congestion Manager.

CM algorithms

- Rate-based AIMD control
- Loss-resilient feedback protocol
- Exponential aging when feedback is infrequent
- Flow segregation to handle non-best-effort networks
- Scheduler to apportion bandwidth between flows

Rate-based control is TCP-friendly (1/2)

- Ensure proper congestion behavior
  - *rate-based* AIMD control scheme
- Rate changes as
  - learns from active flows about the state of the network
  - probes for spare capacity
- AIMD

- Why choose rate-based instead of window-based scheme?

Rate-based control is TCP-friendly (2/2)

- TCP-friendliness relationship:

$$\lambda = K / \sqrt{p}$$

λ :throughput, p:loss rate,

K:constant depends on the packet size and RTT

$$\lambda \ \alpha \ n_r$$

$$p \ \alpha \ n_d / n$$

$$n_r^2 = K^2 (n_r / n_d) + K^2$$

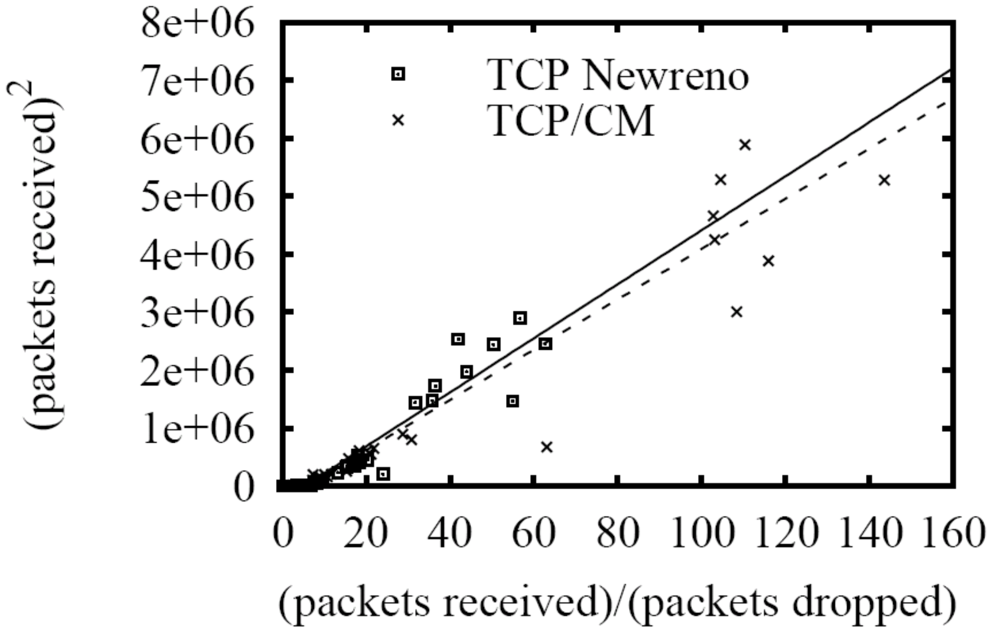


Fig.2 CM's rate control is TCP-friendly.

Receiver feedback (1/3)

- Why do we need feedback?
  - to be communicated to the sender
- Implicit: hints from application
- Explicit: CM probes
  - Probe every half RTT
  - tracks of the number of packets sent per flow, loss rate, and updates RTT estimate.

Receiver feedback (2/3)

Sending a probe to the receiver

```
message = <probe,probeseqnum>;
send(message);
probe(probeseqnum) = {probeseqnum, now, nsent};
nsent = 0;
probeseqnum = probeseqnum+1;
```

Responding to probe number `thisprobe`

```
message=<response,thisprobe,lastprobe,nrecd>;
send(message);
lastprobe = thisprobe;
nrecd = 0;
```

Receiver feedback (3/3)

Sender action on receiving a response

`<response,thisprobe,lastprobe,nrecd>`

```
nsent = 0;
for(i=lastprobe+1; i<=thisprobe; i++) do
  nsent += probe(i).nsent;
end;
lossprob = nrecd/nsent;
Delete all entries in probe less than
thisprobe;
```

Handling infrequent feedback

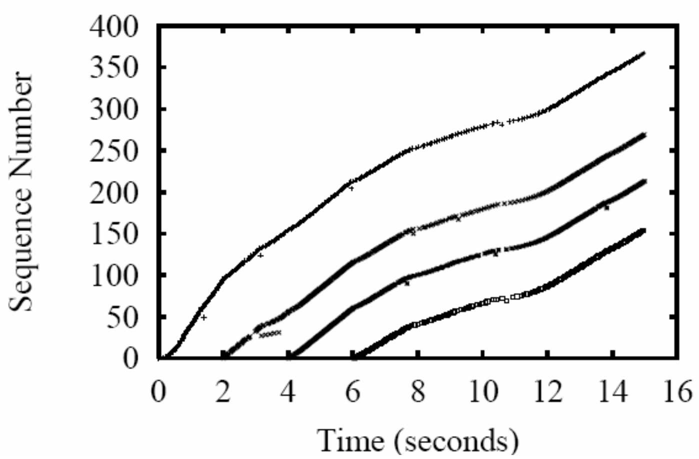
- During times of congestion, probe messages or responses are lost
- Exponential aging: reduce rate by half, every *silent* RTT
  - Continues transmissions at safe rate without clamping apps

Better than best-effort networks

- Future networks will not treat all flows equally
  - differentiated services, prioritization based on flow identifiers, etc
- Solution: flow segregation
  - If an application knows beforehand, it can inform the CM
  - the CM incorporates a segregation algorithm
  - based on per-flow loss rates and bandwidths

CM Scheduler

- Using Hierarchical Round Robin (HRR) scheduler for rate allocation
- Uses receiver hints to apportion bandwidth between flows
- Exploring other scheduling algorithms for delay management as well
  - currently implemented only bandwidth allocation



The CM API

- Goal: To enable easy application adaptation

- Guiding principles:
  - Put the application in control
  - Accommodate application heterogeneity
  - Learn from the application

Put the application in control

- Application decides *what* to transmit
- CM does not buffer any data
  - allows applications the opportunity to adapt to unexpected network changes
- Request/callback/notify API
  - *cm_request(nsend);*
  - *app_notify(can_send);*
  - *cm_notify(nsent);*
- learn about available bandwidth and the RTT
  - *cm_query(&rate, &srtt);*

Accommodate application heterogeneity

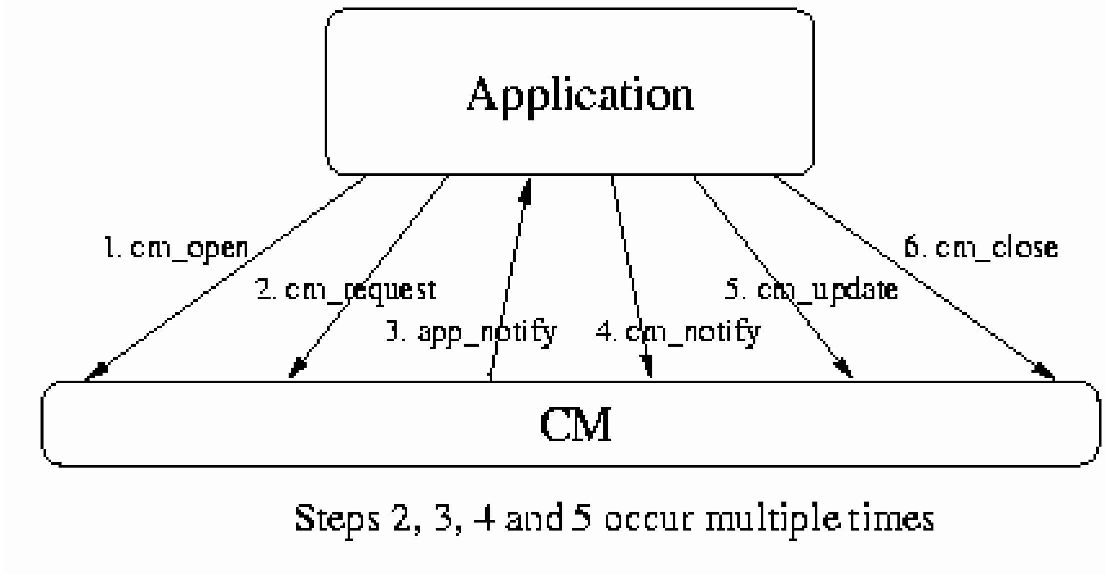
- API should not force particular application style
- Asynchronous transmitters
  - triggered by events (ex. file reads) rather than periodic clocks
  - request/callback/notify works well
- Synchronous transmitters
  - Maintain internal timer for transmissions
  - Need rate change triggers from CM *change_rate(newrate);*

Learn from the application

- *cm_notify(nsent)*: upon each transmission
- *cm_update(nrecd, duration, loss_occurred, rtt)*
  - hint to internally update CM sustainable sending rate and RTT estimates.
- *cm_close()*: a flow is terminated and allows the CM to destroy the internal state associated with it.

Application Performance (1/4)

- **Application 1: Web/TCP**
- Web server uses *change_rate()* to pick convenient source encoding



Application Performance (2/4)

- **Application 1: Web/TCP**
  - 1Mbps bottleneck link, 120ms propagation delay

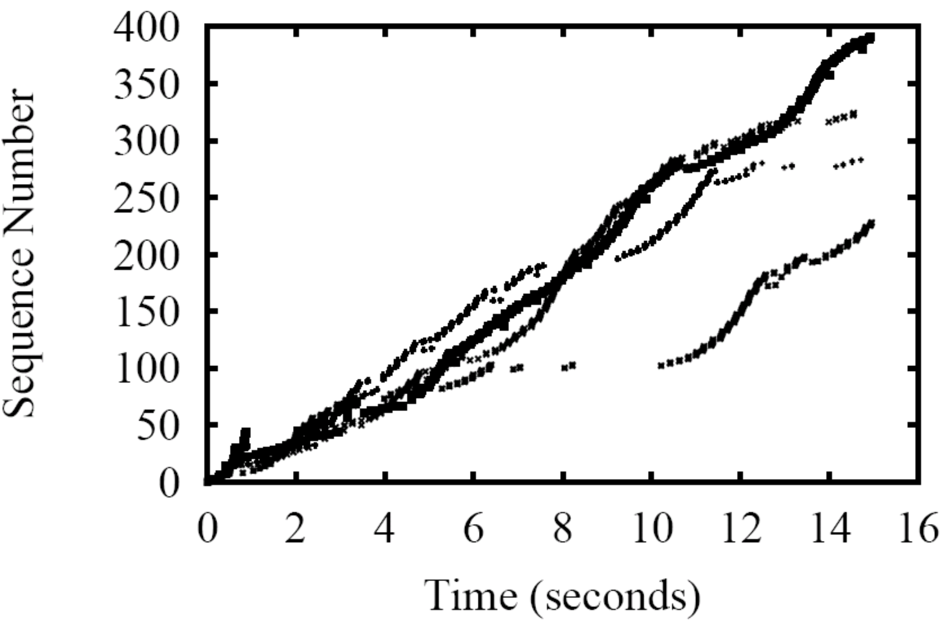


Fig.5 sequence traces for a Web-like workload using 4 concurrent TCP Newreno connections.

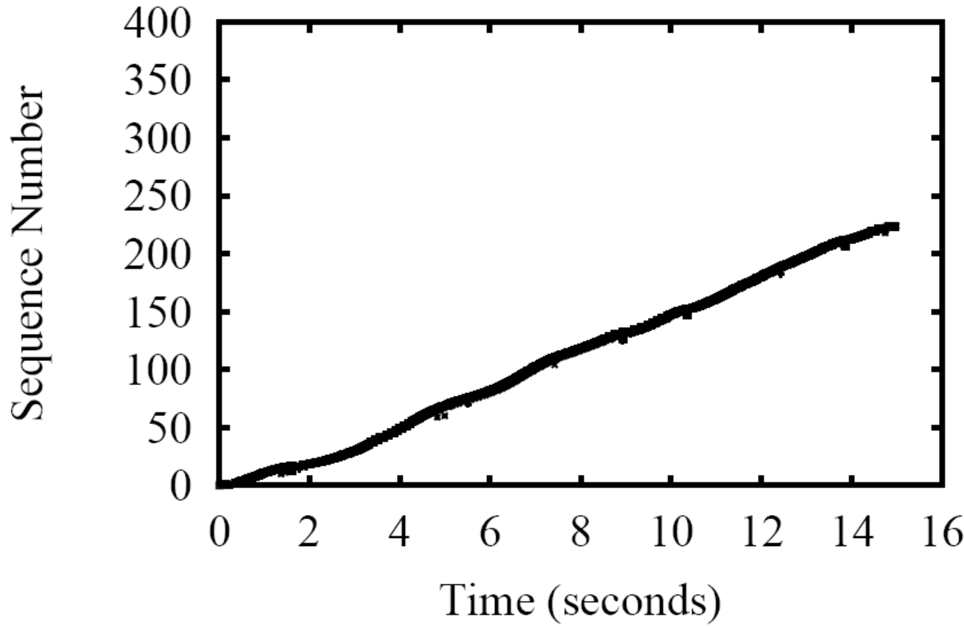


Fig.6 the same workload over TCP/CM.

Application Performance (3/4)

- **Application 2: Layered Streaming Audio**
- The CM enables the audio server to adapt its choice of audio encoding to the congestion state.
- *cm_open()*
- *cm_query()*
- *cm_notify()*

Application Performance (4/4)

- 0.5Mbps bottleneck link, 120ms propagation delay
- choose encodings of 10, 20, 40, 80, 160 and 320 Kbps.
- transmissions of 1KB packets.

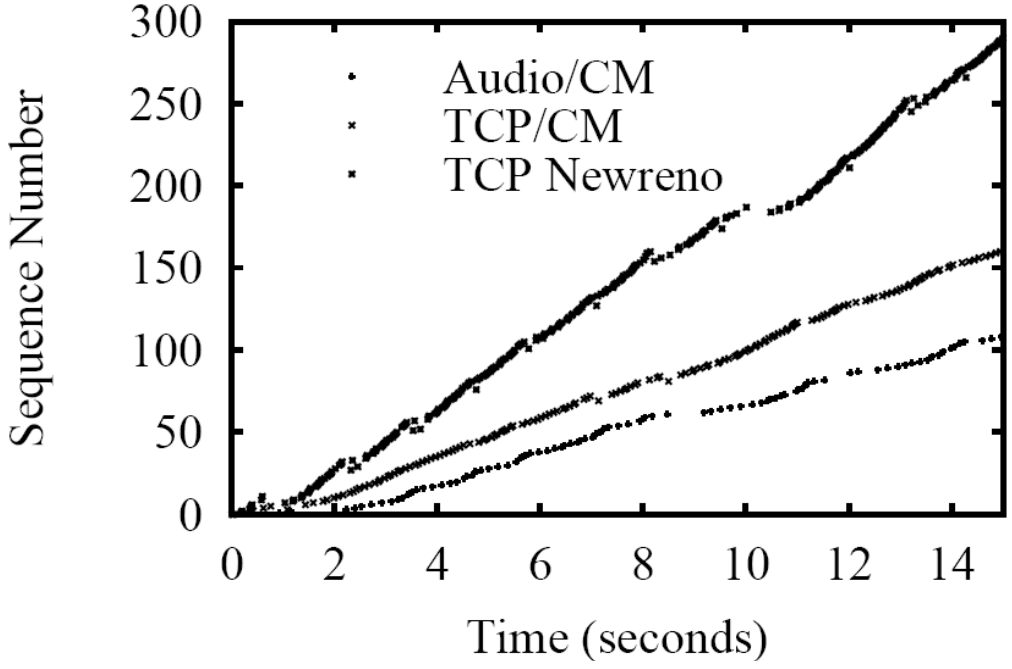


Fig.7 Performance of an adaptive audio application

Conclusions

- CM ensures proper and stable congestion behavior
  - CM tells flows their rates
- Simple, yet powerful API to enable application adaptation
  - Application is in control of what to send
- Improves performance consistency and predictability for individual applications