TCP Goes to Hollywood

Stephen McQuistin and Colin Perkins
University of Glasgow

Marwan Fayed
University of Stirling
Multimedia Applications and HTTP

- HTTP-based multimedia delivery protocols (e.g., MPEG-DASH, HLS) are popular

- They allow applications to make use of the existing HTTP infrastructure (e.g., CDNs)

- These protocols can be configured for low latency applications: smaller segment sizes and buffers, for example

- … but latency is added at the transport layer
TCP adds latency

- In-order delivery means buffering out-of-order segments, waiting for the delivery of earlier data
- Reliability involves detecting that a segment has been lost, and retransmitting it
- Both of these mechanisms add latency, making TCP a poor choice for real-time multimedia applications
Introducing TCP Hollywood

• Uses TCP as a substrate, to overcome ossification, but modified to reduce latency

• Message-oriented to allow application data units to be sent

• Unordered delivery of messages, given independent utility

• Partially reliable based on time and dependency information
Architecture

- Functionality split between user-space intermediary layer, and kernel extensions
- Intermediary layer works over either standard TCP or TCP Hollywood
- Supports partial deployments
Unordered message delivery

• Builds on standard TCP’s byte stream, so need to frame messages

• At sender, applications pass messages to intermediary layer, for encoding (to escape framing bytes), and framing

• Nagle’s algorithm disabled — it would add latency

• At receiver, incoming segments delivered as they arrive, decoded, and passed to application — no latency added by buffering

• ACKs generated as with standard TCP
Partial reliability

- Applications pass metadata with messages: deadline and dependency information

- Messages might expire — either they won’t arrive on time to be played out, or they depend on an undelivered message

- Expired messages aren’t retransmitted — a live message is sent instead, as an *inconsistent retransmission*

- Payload is different, but with the same TCP sequence number and length

- Recovers utility lost by retransmitting expired data
TCP Hollywood in action

Diagram showing the interactions between Sender, Network, and Receiver. The processes are labeled as user and kernel. A box labeled $T_{\text{framing}}$ is connected to the Sender, and a box labeled Buffers is located in the Network. The Receiver is divided into kernel and user sections. Arrows indicate the flow of time and data.
TCP Hollywood in action

Sender

Network

Receiver

user  kernel

kernel  user

time
TCP Hollywood in action

Sender  
user  
kernel

Network

Receiver  
kernelp  
user

time
TCP Hollywood in action
TCP Hollywood in action

$T_{\text{playout}}$ reduces gaps in playback due to jitter.
TCP Hollywood in action
TCP Hollywood in action

Segment lost
TCP Hollywood in action

Segment arrives out-of-order, but is delivered under TCP Hollywood
TCP Hollywood in action
TCP Hollywood in action

\[ T_{\text{retransmit}} = 4 \times T_{\text{framing}} + T_{\text{rtt}} \]

The original message wouldn’t arrive on time to be played out
TCP Hollywood in action

TCP Hollywood sends an inconsistent retransmission: a different message, but with the same TCP sequence number.
TCP Hollywood in action

Gap where segment was lost, but no bandwidth wasted in retransmitting it.
TCP Hollywood in action

These segments wouldn’t have arrived on time under standard TCP
TCP Hollywood helps when $T_{\text{playout}}$ is less than $T_{\text{rexmit}}$
Feasibility Region

$T_{\text{playout}}$

Time between a frame arriving at the receiving application, and being played out
Feasibility Region

$T_{\text{playout}}$ vs. $T_{\text{rtt}}$ (Network round-trip time)
Feasibility Region

Plotting the region of feasible values of $T_{\text{playout}}$ across round-trip times
Feasibility Region

$T_{\text{framing}}$

$T_{\text{playout}}$

$T_{\text{rtt}}$

Duration of media in each message
Message needs to be decoded before being played out
Feasibility Region

![Diagram showing the relationship between T_{playout}, T_{framing}, and T_{rtt}. The diagram illustrates the feasibility region defined by application delay bound: T_{max} - T_{framing} - T_{rtt}/2.](image)
Feasibility Region

\[ T_{\text{playout}} \leq \text{Trtt} + 4 \cdot T_{\text{framing}} \]

\[ T_{\text{playout}} \leq T_{\text{max}} - T_{\text{framing}} - \text{Trtt}/2 \]

\[ T_{\text{frame}} \]

\[ T_{\text{rtt}} \]
Feasibility Region

Standard TCP retransmissions are useful, and no head-of-line blocking.
Feasibility Region

Standard TCP retransmissions arrive too late to be used, and head-of-line blocking possible.
Feasibility Region

Standard TCP retransmissions arrive too late to be used, and head-of-line blocking possible

TCP Hollywood helps: removes head-of-line blocking, and sends inconsistent retransmissions
Example Application

- IPTV application, using MPEG-DASH configured for low-latency delivery

- $T_{\text{max}} = 1$ second, within zap time recommendations

- $T_{\text{framing}}$ determined by number of frames in message

- Trade-off between size of $T_{\text{framing}}$, and utility of standard TCP retransmissions
Standard TCP retransmissions are useful when a small number of frames are sent — but overheads are higher.

$T_{framing} = 1$ frame

Example
Example

\[ T_{\text{framing}} = 2 \text{ frames} \]
Example

$T_{\text{framing}} = 3$ frames
Example

$T_{\text{framing}} = 4$ frames
Example

\[ T_{\text{framing}} = 5 \text{ frames} \]
Example

$T_{framing} = 6$ frames

$T_{playout}$ (seconds)

$T_{rtt}$ (seconds)
The utility of standard TCP retransmissions decreases as $T_{\text{framing}}$ increases (and overheads become lower).
Example

$T_{\text{framing}} = 8$ frames

$T_{\text{playout}}$ (seconds)

$T_{\text{rtt}}$ (seconds)
Example

$T_{framing} = 9$ frames
Example

$T_{\text{framing}} = 10 \text{ frames}$
Example

\[ T_{\text{framing}} = 11 \text{ frames} \]
Example

Standard TCP retransmissions are effectively useless; TCP Hollywood recovers this lost utility.
Deployability

• Inconsistent retransmissions are the only wire-visible modification vs. standard TCP — same TCP sequence number, different payload

• Middleboxes performing payload inspection may interpret the behaviour as an attack — man on the side

• Experiments between TCP Hollywood server, and 14 UK clients

• 8 fixed-line ISPs, 4 cellular operators - all major UK ISPs
TCP Hollywood is deployable

- Tested on two ports to check if HTTP traffic treated differently
  - inconsistent retransmission delivered successfully
  - original segment delivered instead
- Intermediary layer handles cases where original delivered - performance no worse than standard TCP
TCP Hollywood

- Unordered, partially reliable message-oriented TCP-based transport protocol
- Eliminates head-of-line blocking, reducing latency
- Prevents retransmission of expired data, increasing utility
- Deployable across all major UK ISPs