On Modeling Feedback Congestion Control Mechanism of TCP using Fluid Flow Approximation and Queuing Theory

Hisamatu Hiroyuki
Department of Infomatics and Mathematical Science, Graduate School of Engineering Science, Osaka University, Japan
hisamatu@ics.es.osaka-u.ac.jp
Background

• TCP (Transmission Control Protocol)
  – Transport layer protocol
  – Congestion control mechanism

• Analysis of the TCP until today
  – Assuming a constant packet loss probability
  – Statistical behavior

• Real Network
  – Packet loss probability has changed according to packet transmission rate
Objective

- Model the interaction between two systems as a feedback system
  - Network seen by TCP
    - M/M/1/m queuing system
  - Congestion control mechanism of TCP
    - Fluid flow approximation
- Background Traffic are also taken account of
Analytic Model

- TCP connections
- Take account of background traffic
Modeling total TCP and Network

- Modeling Network as a feedback system
  - Network seen by TCP
  - Congestion control mechanism of TCP seen by network
Modeling Network using Queuing Theory

- Assume bottleneck router is a Drop-Tail router
- Model by M/M/1/m queue
- Incoming traffic
  - TCP traffic
  - Background traffic

\[
\lambda = \sum_{i=1}^{N} \frac{W_i}{r_i} + \lambda_B
\]

Arrival rate of the background traffic

TCP Window size

\(W_1, W_2, \ldots, W_N\)

M/M/1/m

Packet loss probability

\(p\)

\(\mu\)
Changes of TCP Window Size

• Congestion avoidance phase
  – Increase window size at every receipt of ACK packet

\[
w \leftarrow w + \frac{1}{w}
\]

  – Decrease window size at every detection of packet loss
    • Detect from receipt of duplicate ACKs
      \[
      w \leftarrow \frac{w}{2}
      \]
    • Detect from time-out mechanism
      \[
      w \leftarrow 1
      \]
Modeling TCP using Different Approaches

- 4 analytic models
  - Model A1:
    - Assume a constant packet loss probability
    - Derive window size of TCP connection in steady state
  - Model A2:
    - Approximate A1 when packet loss probability is very small
  - Model B:
    - Window size change at every receipt of ACK packet and detection of packet loss
  - Model C:
    - Evolution of window size between two succeeding packet loss
Simulation Model

\( \lambda \) : arrival rate

\( \mu_i, \tau_i \) : link capacity, propagation delay

\( m \) : buffer size

\( \lambda \) : 2 [packet/ms]

\( \mu_i \) : 5 + 0.5i [packet/ms]

\( \tau_i \) : 5 + i [ms]

\( \mu_n, \tau_n \) : link capacity, propagation delay

\( m \) : 50 [packet]

\( N \) : 10
Network Model

- Relation between offered traffic load and packet loss probability
  - $M/M/1/m$ queuing system
  - Simulation result

$M/M/1/m$ models dynamics of network correctly
TCP Model

• Relation between packet loss probability and window size
  – Congestion control mechanism of TCP
  – Simulation result

A1, A2, B show good agreement
B and C show good agreement
Transient Behavior

- Transient Behavior
  - Dynamics of the window size form its initial value to its equilibrium value

- Use Model B for Congestion control model of TCP

\[ w \leftarrow w + (1 - p) \frac{1}{w} - p(1 - \hat{Q}(w)) \frac{w}{2} - p\hat{Q}(w)(w - 1) \]
Transient Behavior Analysis

- Modeling the network as a discrete-time model
  - Time slot: duration between succeeding ACK packets received

- Network state
  - \( w(k) \): window size of TCP connections
  - \( P(k) \): packet loss probability

- For given initial values, the evolution of the network state can be obtained

\[
\begin{align*}
\frac{w(k)}{w(k-1)} &= 1 - \frac{p(k - w(k-1))}{w(k-1)} - \frac{p(k - w(k-1))w(k-1)}{2} \\
\rho(k) &= \frac{1 - \rho(k)}{1 - \rho(k)} \rho(k)^m \\
\rho(k) &= \frac{1}{\mu} \left( \frac{w(k)}{r} + \lambda_B \right)
\end{align*}
\]
Numerical Example: Case of Different Propagation Delays

- When propagation delay is small
  - Ramp-up time of the window size becomes short
  - The window size oscillates for long

![Graph showing average window size over time for different propagation delays](#)

- τ = 10 [ms]
- τ = 30 [ms]
- τ = 50 [ms]
Numerical Example: Case of Different Amount of Background Traffic

- When the amount of the background traffic is large
  - The window size of steady state is small
  - The increase rate of the window size is independent of the amount of the background traffic
Conclusion and Future Work

• Conclusion
  – Model the dynamics of TCP
    • Feedback system consisting of two systems
  – Transient behavior Analysis of TCP
    • Propagation delay
    • The amount of the background traffic

• Future work
  – Rigorous analyses of stability and transient behavior of TCP