Optimal Internal Congestion Control in A Cluster-based Router

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Congestion in the Cluster-based Router

Optimal Utility-based Control

Simulation With NS-3

Evaluations In the Real System

Conclusions and Related Work
Figure: Cluster-based Router Architecture
Figure: IP Forwarding Path
Optimal Utility-based Control

An optimization approach to congestion control problems
- Objective: maximize the aggregate source utility
- Constraints: network link capacities.

The network links and traffic sources are viewed as a distributed system that acts to solve the optimization problem
- Traffic sources adjust their transmission rates in order to maximize their own benefit
- The network links adjust bandwidth prices to coordinate the sources decisions on the evolution of their transmission rates
Classification of Optimal Utility-based Control

According to the controlled objects:

- Primal algorithms (TCP)
- Dual algorithms (Active Queue Management)
- Primal-dual algorithms (Combination of TCP and AQM)
Consider a network with unidirectional links. There is a finite forwarding capacity $C$ associated with the egress. The egress is shared by a set $S$ of sources, where source $s \in S$ is characterized by a utility function $U_s(x_s)$ that is concave increasing in its transmission rate $x_s$ to the egress.

Model:

$$P : \sum_{s \in S} U_s(x_s)$$  \hspace{1cm} (1)$$

subject to

$$\sum_{s \in S} x_s \leq C$$  \hspace{1cm} (2)$$
Decentralized Approach

- The dual theory of optimization leads us to a distributed and decentralized solution which results in the coordination of all sources implicitly.

- Lagrangian function:

\[
L(x, p) = \sum_{s \in S} U_s(x_s) - p(\sum_{s \in S} x_s - C) \\
= \sum_{s \in S} U_s(x_s) - \sum_{s \in S} x_s \cdot p + p \cdot C
\]  

(3)
Decentralized Approach

- The objective function of the dual problem:

\[
D(p) = \max_{x_s} L(x, p) \\
= \sum_{s \in S} \max(U_s(x_s) - x_s \cdot p) + p \cdot C
\]  

(4)

- The dual problem:

\[
D : \min_{p \geq 0} D(p)
\]  

(5)
Decentralized Approach

- The congestion control problem can be generalized to tasks of finding distributed algorithms that can make sources adapt transmission rates with respect to the egress price and make egress adapt prices with respect to loads.

- The optimal solution to the distributed congestion control problem satisfies:

\[
\begin{align*}
\frac{\partial D(p)}{\partial x_s} &= \frac{\partial U_s(x_s)}{\partial x_s} = U'_s(x_s) - p = 0 \\
\frac{\partial D(p)}{\partial p} &= \sum_{s \in S} (-x_s) + C = 0
\end{align*}
\]
To reduce the overhead of transferring the link price, we only send the price from the egress to the sources at the beginning of each control interval, which results in a discrete-time control model:

\[
\begin{align*}
x_s(k+1) &= \left[x_s(k) + K \cdot x_s(k) \cdot (U'_s(x_s(k)) - p(k))\right]_x^{+} \\
&= \left[x_s(k) + K \cdot (W - x_s(k) \cdot p(k))\right]_x^{+} \\
p(k+1) &= \left[p(k) + \left(\sum_{s \in S} x_s(k) - C\right)/R\right]_p^{+}
\end{align*}
\]

Here

\[
[g(x)]_y^{+} = \{ \begin{array}{ll} g(x), & y > 0 \\ \max(g(x), 0), & y = 0 \end{array}
\]

and K and 1/R are step sizes.
Queue Status as an Indicator of Congestion

- In real system, the transmission capacity of the egress in the model vary for different situations or times
  - More than one port may share the same bus
  - Sharing of a single egress port by multiple egress queues
- Queue-based approach:
  \[
  x_s(k + 1) = [x_s(k) + K \times (W - x_s(k) \times p(k))]_{x_s[k]}^+
  \]
  \[
  p(k + 1) = [p(k) + (\text{delta}(q))/R]_{p(k)}^+
  \] (7)
Queue Status as an Indicator of Congestion

- The system may be stable at large queue length.
- To reduce the stable queue length:

\[
\begin{align*}
  x_s(k + 1) &= [x_s(k) + K \ast (W - x_s(k) \ast p(k))]^+_{x_s[k]} \\
  p(k + 1) &= [p(k) + (\text{delta}(q) + f(q))/R]^+_{p(k)}
\end{align*}
\]  

(8)

- Let \( f(q) = (q - q_o) \ast u \), where \( q_o \) is the objective of egress queue length and \( u \) is the degree that the queue length would be taken into the price calculation.
Figure: IP Forwarding Path in Simulation
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Figure: Optimization utility-based scheme transmission rate behavior
Figure: AIMD scheme transmission rate behavior
Figure: Optimization utility-based scheme queue behavior
Figure: AIMD scheme queue behavior
**Figure:** Fairness - Optimization utility-based scheme transmission rate behavior
Figure: Transmission rate comparison
Queue Length With Increasing Offered Traffic

Figure: Queue variance comparison
Figure: Fairness comparison
Optimal Utility-based Congestion Control

- Fair to different flows
- Efficient to reduce the injection rates of traffic to the internal network to avoid congestion

Related Work

- Analyze and improve the Internet congestion control schemes such as TCP and AQM
- In wireless cross-layer congestion control:
  - Lijun Chen, Stevenh. Low, Mung Chiang, John C. Doyle, "Optimal cross-layer congestion control, routing and scheduling design in ad hoc wireless networks"
  - WeiQiang Xu, etc., "Dual decomposition method for optimal and fair congestion control in Ad Hoc networks: Algorithm, implementation and evaluation"
  - Matthew Andrews, "Joint Optimization of Scheduling and Congestion Control in Communication Networks"
  - Danhua Zhang, Chao Zhang and Jianhua Lu, "Joint congestion control, contention control and resource allocation in wireless networks"