Resource pricing and the evolution of congestion control

Overview

- Introduction
- Pricing Model
- Simulations and Results
- Conclusions
Motivations

TCP is breaking down for two related reasons:

- Incentive to strive more aggressively for a larger share of bandwidth.
- Applications are becoming more heterogeneous, with widely differing sensitivities to delay.
Basic Idea

- End-to-end congestion control is not reliable (end-users are selfish) which may incur congestion collapse (do not have enough info about the network dynamics).

- Should be implemented within the network itself to restrict the bandwidth of flows and to discriminate between the services.

- Premise: if the resource implications of their actions can be made known to end-nodes, then the end-nodes themselves are best placed to determine what should be their demands upon the resources of the network.
Resource pricing and the evolution of congestion control

Features

- Conveying information on congestion from the network to intelligent end-nodes rather than by requiring the users to classify their flows.
- Investigate the possibility that the end-nodes may be allowed uninhibited access to the algorithms used for congestion control while still maintaining incentive-compatibility.
Overview

- Introduction
- Pricing Model
- Simulations and Results
- Conclusions
Resource pricing and the evolution of congestion control

Network’s Cost

- The network model:
  1. $N$: maximal capacity of the resource.
  2. $Y$: the sum of $m$ independent Poisson R.V. $X_1, X_2, \ldots, X_m$, which have means $x_1, x_2, \ldots, x_m$ respectively.

- The network cost is described by the expected number of packets lost:
  1. $y$: the mean of $Y$ which is equal to $\sum_{1}^{m} x_r$.
  2. Cost function $C(y) = E(Y - N)^+ = \sum_{n \geq N} (n - N)e^{-y} \frac{y^n}{n!}$
The price for change the capacity:

1. $p(y)$: the partial differentiation of $C(y)$.
2. Simple relation to derive $p(y)$:
   
   $$C'_N(y) = -C_N(y) + C_{N-1}(y).$$
3. $p(y) = \sum_{n\geq N} e^{-y} \frac{y^n}{n!} = P\{Y \geq N\}$
4. We interpret $p(y)$ as the **shadow price** of the resource: it is the marginal increment in expected cost at the resource for a marginal increment in load.
Marking Mechanism

- Whenever the number of packets arriving in a slot exceeds $N$, a mark is placed on each of these packets.
- We shall not distinguish between packets which are lost and those which are merely marked, and treat them all as marked packets.
End-node’s Cost

- We describe the end-node’s cost as the expected number of marks per unit time placed on packets from the $r^{th}$ flow is

$$E(X_r I\{Y > N\}) = \sum_{n > N} E(X_r | Y = n) P(Y = n) \quad (1)$$

$$= \sum_{n > N} \frac{x_r}{y} n e^{-y} \frac{y^n}{n!} \quad (2)$$

$$= x_r \sum_{n > N} e^{-y} \frac{y^n}{n!} \quad (3)$$

$$= x_r p(y). \quad (4)$$

- Note that conditional on the event $Y = n$, $X_r$ has a binomial distribution with parameter $n$ and $x_r/y$. 
Key Relationship

- Relationship between the expected increase in system cost caused by a given load increment, and the expected charge to that load increment.

- Suppose load $Y$ on the resource is a positive R. V., and that we wish to assess the impact of an additional load $X$.

- Then the increase in the number of packets lost is

$$[X + Y - N]^+ - [Y - N]^+ = XI\{X + Y > N\}$$

$$-(N - Y)I\{X + Y > N > Y\}$$

Thus $E[X + Y - N]^+ - E[Y - N]^+ \leq E(XI\{X + Y > N\})$
Key Relationship

- If $X$ is a small increment, satisfying $P\{X = 0 \text{ or } 1\} = 1$, the event $X + Y > N > Y$ is impossible. So we have

$$E[X + Y - N]^+ - E[Y - N]^+ = E(X I\{X + Y > N\})$$

- It is natural to define the sample path shadow price of a packet to be one if the packet’s deletion from the sample path describing arrivals at the resource would result in one less packet drop at the resource.
Overview

- Introduction
- Pricing Model
- Simulations and Results
- Conclusions
Congestion Control Algorithm

- In the simple slotted model, the user transmits
  \[ X(t) = \lfloor x(t) + z(t) \rfloor^+ \]
  packets in the slot \((t, t+1)\), where \(x(t)\) and \(z(t)\) are internal state variables updated as follows:
  \[ z(t+1) = x(t) + z(t) - X(t) \]
  \[ x(t+1) = x(t) + k(w - f(t)). \]
- Here \(f(t)\) is the number of marks received at the end of slot \((t, t+1)\) and \(k\) is a small positive constant.
Resource pricing and the evolution of congestion control

**Congestion Control Algorithm**

- $x(t)$ can be regarded as the rate of the user.
- $z(t)$ can be regarded as a fraction of a packet held over until the next slot.
- The recursion of updating $x(t)$ attempts to stabilize the rate around a value where the expected charge per slot is $w$: observe that

\[
 w - \frac{1}{T} \sum_{t=0}^{T-1} f(t) = \frac{x(T) - x(0)}{kT},
\]

an expression that will go to zero as $T$ increases.
Simulation Settings

- The number of marks feed back to source $i$ at the end of the slot is $X_iI\{Y > N\}$.
- Feedback delay, between the generation of packet and the receipt of feedback concerning that packet, is just one slot.
Scenario I

- Settings:
  1. A resource with a capacity $N = 10$.
  2. Simulate 20 Elastic users ($w_i$): $w_i = i \times 0.01$, $i = 1, 2, \ldots, 20$
  3. $k = 0.1$.

- Remarks:
  1. Varying parameter $w$ can influence throughput.
  2. A higher value of $k$ will result in a higher variance at equilibrium, but will allow a more rapid convergence to equilibrium.
Resource pricing and the evolution of congestion control
Scenario II

- **Settings:**
  1. A resource with a capacity $N = 10$ and set $k = 0.1$.
  2. Intermittent user($w_i$): behaves as Elastic user for a random period with mean 1000, and then sleeps for a random period with mean 4000.
  3. Simulate 100 Intermittent user($w_i$): five copies of $w_i = i \times 0.01$, $i = 1, 2, \ldots, 20$

- **Remarks:**
  1. The demand fluctuates much more than the number of packet transmitted per slot.
  2. The average shadow price tracks the demand $W$.
  3. The percentage of packet lost fluctuates in step with, but at lower level than the percentage of packets marked.
Resource pricing and the evolution of congestion control
One Different Kind of User

- File-transfer(F,W): has a file of size $F$ to transfer, an amount $W$ to spend, and wants to transfer the file as soon as possible.

- Adaptive choice of $w$ to achieve paying the price $W/F$ per packet on average:

$$w(t + 1) = \max\{x(t)W(t)/F(t), w_{min}\}$$

- At a rate $x(t)$ the remainder of the file would be transferred in a time $F(t)/x(t)$: at this rate the user could afford to pay an amount $w(t + 1) = W(t)x(t)/F(t)$ per unit time.

- The lower limit, $w_{min}$ allows the algorithm to occasionally retest the network following period when it appears too expensive to transfer the file.
Scenario III

• Settings:
  1. Set 100 users from scenario II.
  2. Add an additional population of 10 File-transfer($F, W_j$), for $j = 1, 2, \ldots, 10$, where $F = 1000$ and $W_j = 200 + 20j$. All starting at slot 0 and set $w_{\text{min}} = 0.01$.

• Remarks:
  1. High value of $W_j$ tends to complete sooner.
  2. Compare with the shadow price of scenario II, the additional population increases the shadow price at times when file transfers are particularly active.
  3. The delayed file transfers sensed that they could no longer afford the increased shadow price, and were forced to wait until later to complete.
Resource pricing and the evolution of congestion control
Overview

- Introduction
- Pricing Model
- Simulations and Results
- Conclusions
Conclusions

- Distributed congestion controls can be implemented in different end-nodes.
- Based on the shadow price, fairness can be achieved.
- End-nodes have the incentives to behave rational based on the feedback of marks.