A Markovian Model for TCP Analysis in a DiffServ Network

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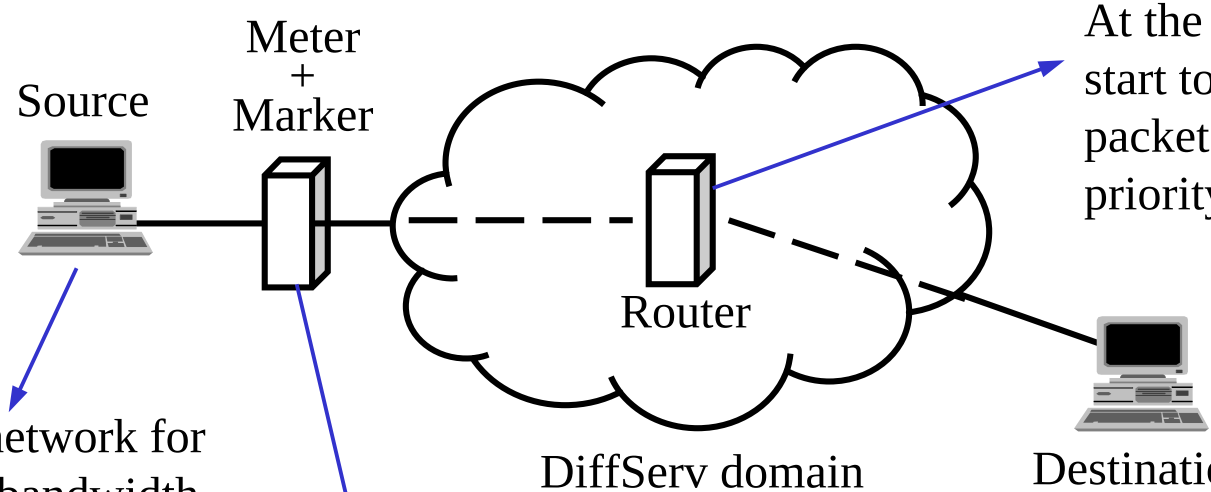
Outline

- Introduction
  - Problems of TCP-based applications in a DiffServ network
  - Ideal service differentiation for TCP traffic
  - Overview of DiffServ schemes for TCP
- Our general Markovian fluid model
- Specification of the model to some DiffServ schemes
- Numerical results

Differentiated Services framework

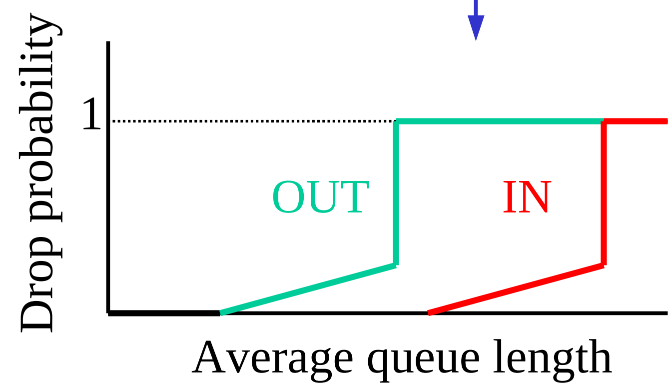


At the onset of congestion, start to drop low priority packets followed by high priority packets

Ask the network for a certain bandwidth

1- Measure the flow rate
2- Compare it to the user profile
3- Mark packets within the profile
with high priority (IN) and those out
of the profile with low priority (OUT)

RIO



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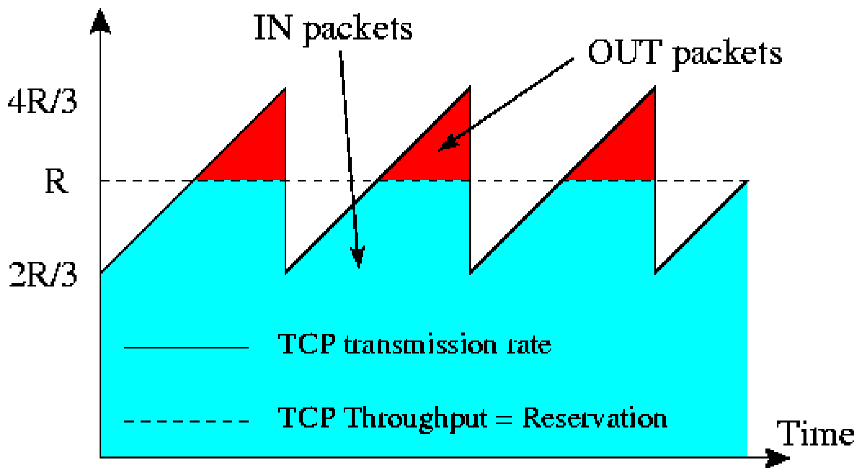
TCP and DiffServ

- TCP is designed for best effort networks
  - Divide the window by two regardless of the priority of the lost packet
- A TCP source needs to transmit some OUT packets to realize its reservation, and a source with a large reservation needs to transmit more OUT packets than a source with a small one
- **Problems:**
  - A TCP source may be unable to realize its reservation
  - A source with a small reservation achieves better performance than a source with a small one
  - The service differentiation is a function of the round-trip time

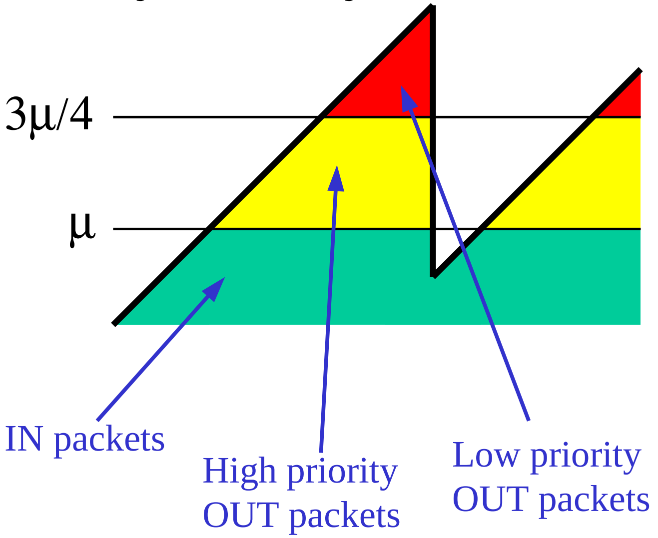


Ideal behavior

- If the network is under-subscribed:
  - Every connection must realize its reservation
  - The unreserved bandwidth must be fairly shared between the different connections
- If the network is over-subscribed:
  - The available bandwidth must be shared between the connections proportionally to their reservations
- **Proposed modifications to the original RIO scheme:**
  - Changes are proposed at the source, at the marker, or to the drop probability function in network routers ...

Some proposed solutions

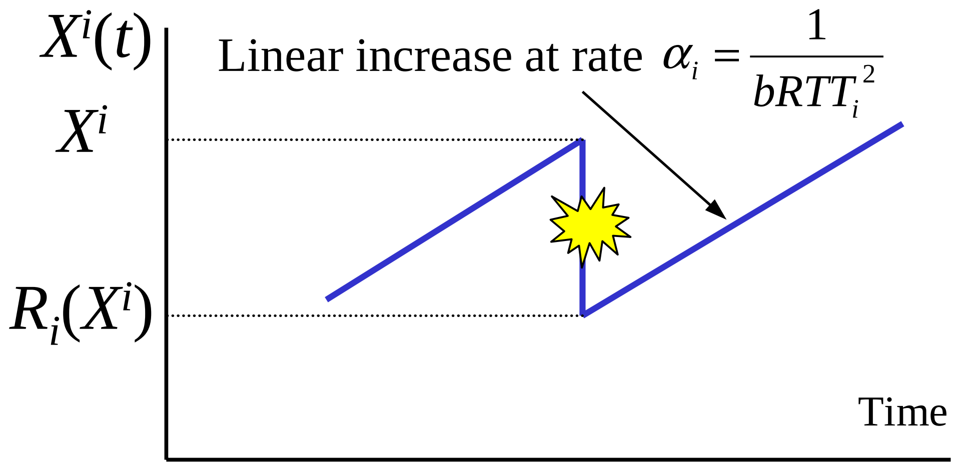
- Change the TCP code so that when an OUT packet is lost, the window is reduced by half the number of OUT packets
- Mark packets as OUT when the rate of the connection exceeds 4/3 of the reservation
- Drop OUT packets from a connection with a probability inversely proportional to its reservation
- Three color scheme:
  - Add a medium priority level to give OUT packets required to realize the reservation more priority than the other OUT packets, but less priority than the IN packets



Our fluid Model

- **Objective:**
  - Come with a general model able to be specified to a large number of DiffServ schemes
  - Account for the parameters of the different concurrent TCP connections
- **Model for TCP sources:**
  - N TCP sources of reservation μ_i sharing the same path
  - A fluid model for the rate evolution of a connection
- **Model for the network:**
  - Single bottleneck node of rate μ and of small buffer so that upon congestion

$$\sum_{i=1}^{N} X^i = \mu$$



Analysis

- **Assumptions:**
  - One connection reduces its rate during congestion
  - The probability that a connection reduces its rate is a function of the rates of all the connections at the moment of congestion
- **Notation:**
  - $\{D_n\}$: Series of time intervals between congestion events
  - X_n^i : Rate of connection i just before the n th congestion event
  - $U_n^i \in \{0,1\}$ indicates whether connection i reduces its rate or not

$$P(U_n^i = 1 \mid X_n^1, X_n^2, \ldots, X_n^N) = p_i\,(X_n^1, X_n^2, \ldots, X_n^N)$$

- **Performance measure:**
  - Find the throughput of a connection as a function of the two general parameters $R_i(X^i)$ and $p_i\,(X^1, X^2, \ldots, X^N)$

Throughput calculation

- **Theorem:** The process $X_n=\{X_n^1, X_n^2,\ldots, X_n^N\}$ can be described as a homogenous Markov chain of dimension N-1

For all $i=1,\ldots,N$,
$$X_{n+1}^i = X_n^i + U_n^i (R_i(X_n^i) - X_n^i) + \alpha_i D_n$$

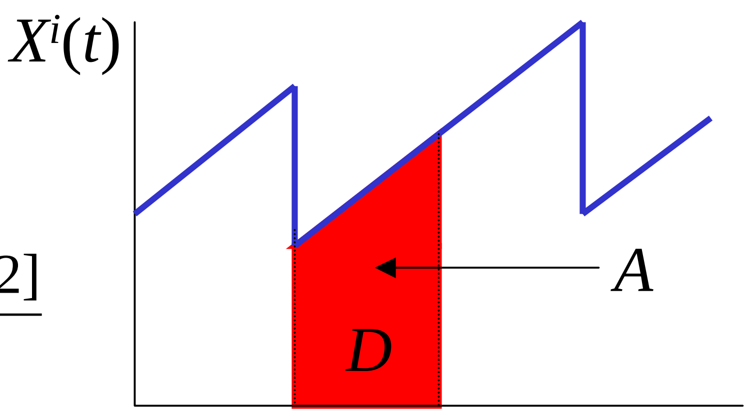
with
$$D_n = \sum_{k=1}^{N} U_n^k (X_n^k - R_k(X_n^k)) / \sum_{k=1}^{N} \alpha_k$$

Let (D, U^i, X^i) denote the process (D_n, U_n^i, X_n^i) in the stationary regime

- **Throughput:**

$$\overline{X}^i = \lim_{t\to\infty} \frac{1}{t}\int_0^t X^i(\tau)d\tau = \frac{\mathrm{E}[A]}{\mathrm{E}[D]}$$

$$= \frac{\mathrm{E}[(X^i + U^i(R_i(X^i) - X^i))D + \alpha_i D^2/2]}{\mathrm{E}[D]}$$



Specification of the model

- By appropriately setting the two functions $p_i(X)$ and $R_i(X^i)$, the general model can be specified to a particular DiffServ scheme

- The original RIO scheme as an example:
  - Reduction factor: $R_i(X^i) = \frac{1}{2} X^i$
  - Reduction probability:

$$p_i(X^i) = \begin{cases} 1 & \text{Only } X^i > \mu_i \\ (X^i - \mu_i) / \sum_{k=1}^{N} (X^k - \mu_k) 1\{X^k > \mu_k\} & X^i > \mu_i \text{ and } \exists k \mid X^k > \mu_k \\ 0 & \text{Only } X^i \le \mu_i \\ X^i / \mu & \forall k, X^k \le \mu_k \end{cases}$$

Numerical results

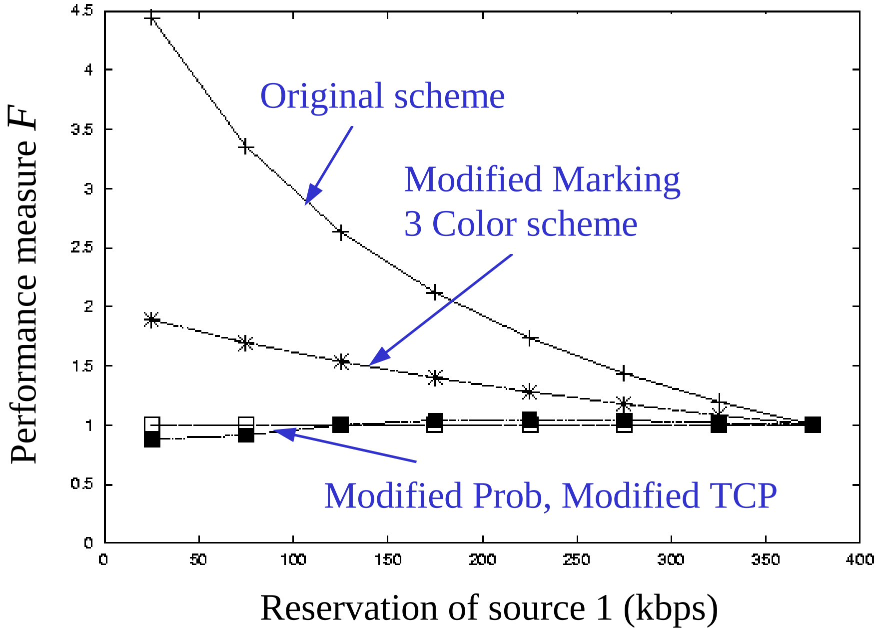
- We solved the problem numerically for the case of two connections:
  - Construct the transition matrix of the (one dimension) Markov chain
  - Solve for the stationary distribution and then for the throughput of every connection
- Take a scenario where μ = 1.5 Mbps, packet size = 512 bytes, and b = 1
- Service differentiation measure:
  - Under-subscription case $$F = (\bar{X}^1 - \mu_1)/(\bar{X}^2 - \mu_2)$$
  - Over-subscription case $$F = (\bar{X}^1 \mu_2)/(\bar{X}^2 \mu_1)$$

- F to be close to 1

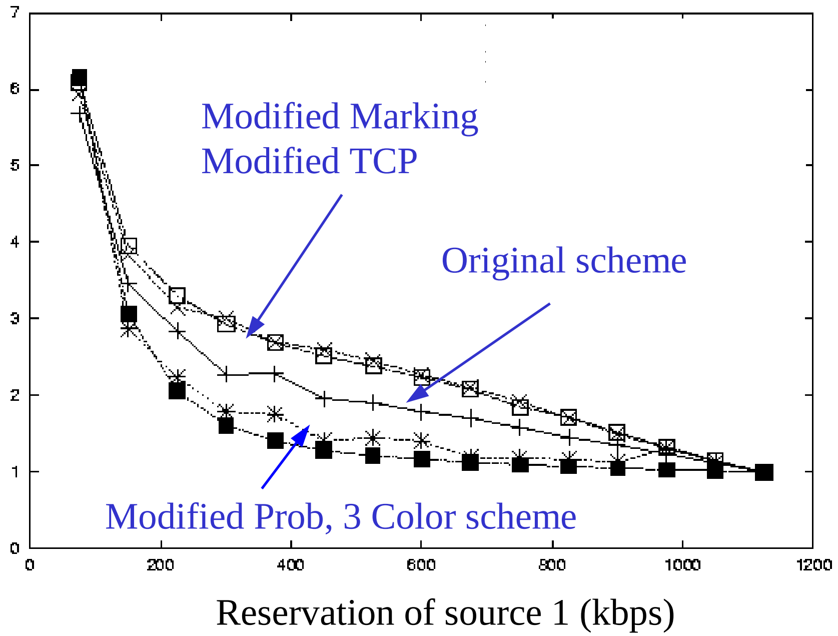
- $F > 1$ (resp. $F < 1$) means a bias of the scheme against connection 2 (resp. 1)

Performance vs. reservations

$\mu_1 + \mu_2 = 0.5\mu$



$\mu_1 + \mu_2 = 1.5\mu$



- The best performance is obtained when accounting for the reservation while dropping
- Giving some priority to OUT packets works only in the under-subscription case
- The Three Color scheme works well in both cases

Resistance to difference in RTT

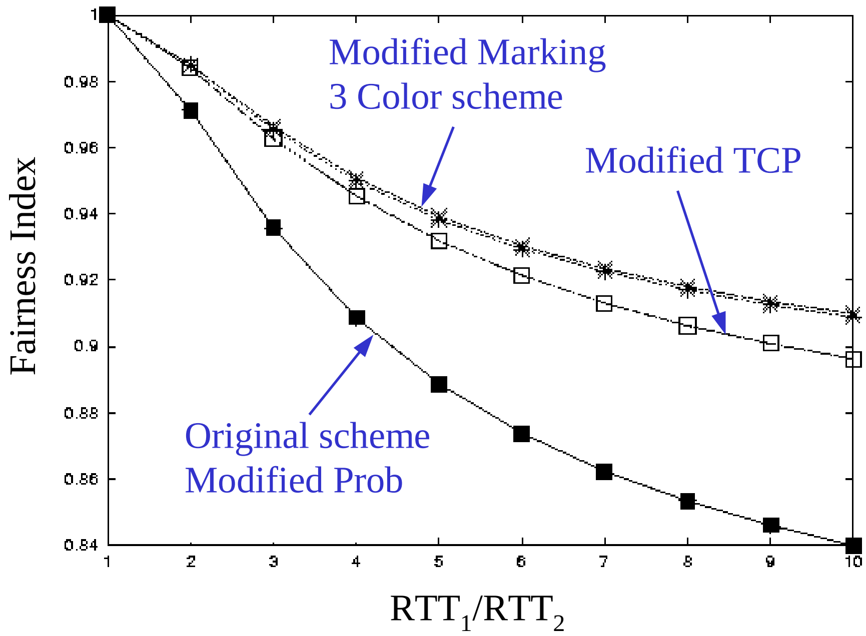
- **Problem:**
  - TCP is known to be biased against connections with long RTT
  - How much a DiffServ scheme resists to a difference in RTT?
- **Scenario:**
  - Associate the same reservation to both connections
  - Set the RTT of connection 2 to 50 ms and change that of connection 1
  - Ideally, both connections should realize the same throughput
  - Performance measure:

The Fairness Index $(\bar{X}^1 + \bar{X}^2)^2 / (2((\bar{X}^1)^2 + (\bar{X}^2)^2))$

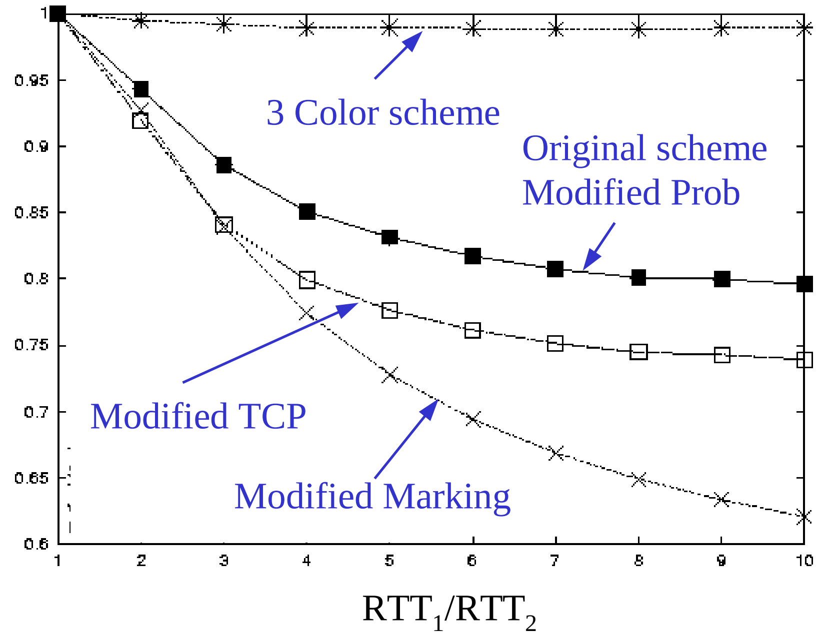
- FI is an increasing function of fairness that varies between 0.5 and 1

Resistance to difference in RTT

$\mu_1 = \mu_2 = 0.25\mu$



$\mu_1 = \mu_2 = 0.75\mu$



- The best resistance is obtained for the Three Color scheme
- The other schemes work well only in the under-subscription case

Discussion of the results

- The original RIO scheme presents problems of fairness …
- A simple solution as changing the marking improves the performance in the under-subscription case but deteriorates it in the over-subscription case
- The Three Color scheme solves the problem in the over-subscription case since the priority it gives to some OUT packets is less than that of IN packets
- Accounting for the reservation in network routers improves considerably the performance in all cases. The difficulty is in the communication of the reservation to network routers. Accounting for the RTT should improve further the performance of this scheme.
- Changing the TCP source improves considerably the performance in the under-subscription case, but deteriorates it in the over-subscription case. The problem is how to infer the priority of the lost packet.