Some Modeling and Estimation Issues in Control of Heterogenous Networks

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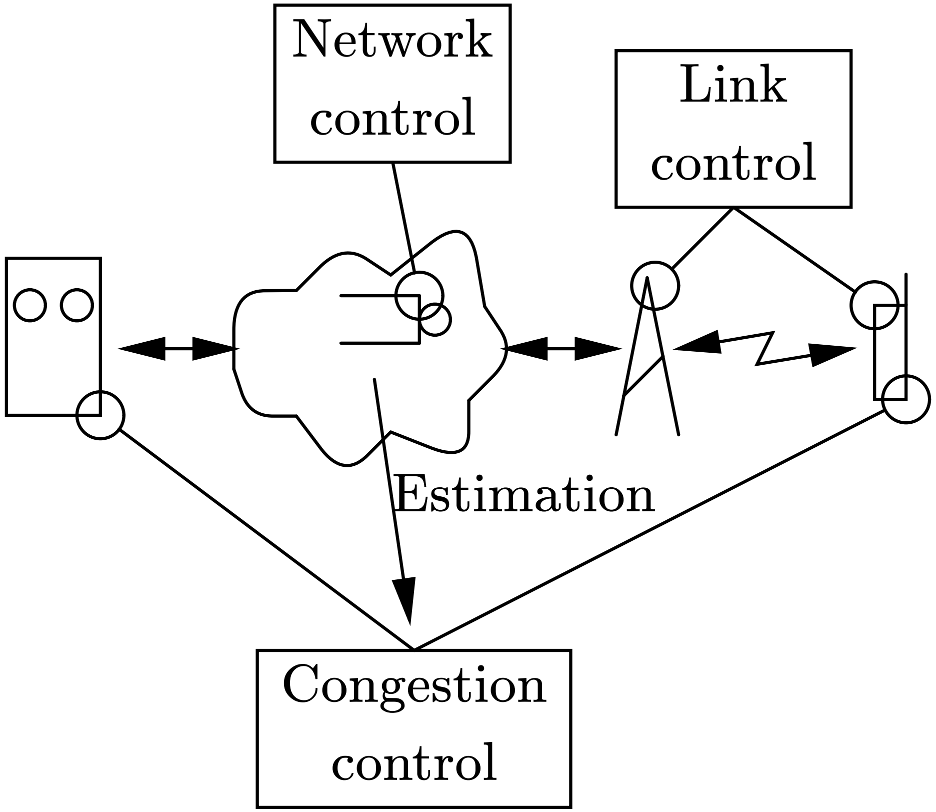
Automatic Control

Overview



Focus of our group:

- Model based estimation.
- Making wireless links friendlier to TCP.

Model Based Estimation

Window-based flow-control objective:

$$w \approx b \cdot \mathrm{RTT}$$

- Estimation of round-trip time (RTT).
- Estimation of available bandwidth (b).
- Trade-off between noise reduction and tracking performance.
- Model-based estimation. Systematic way to make that trade-off.

RTT Estimation

Model:

- Piecewise constant "average RTT" x_k.
- Occasional step changes due to rerouting, bottlenecks appearing...

$$x_{k+1} = x_k + \delta_k v_k \qquad \delta_k \in \{0, 1\}$$

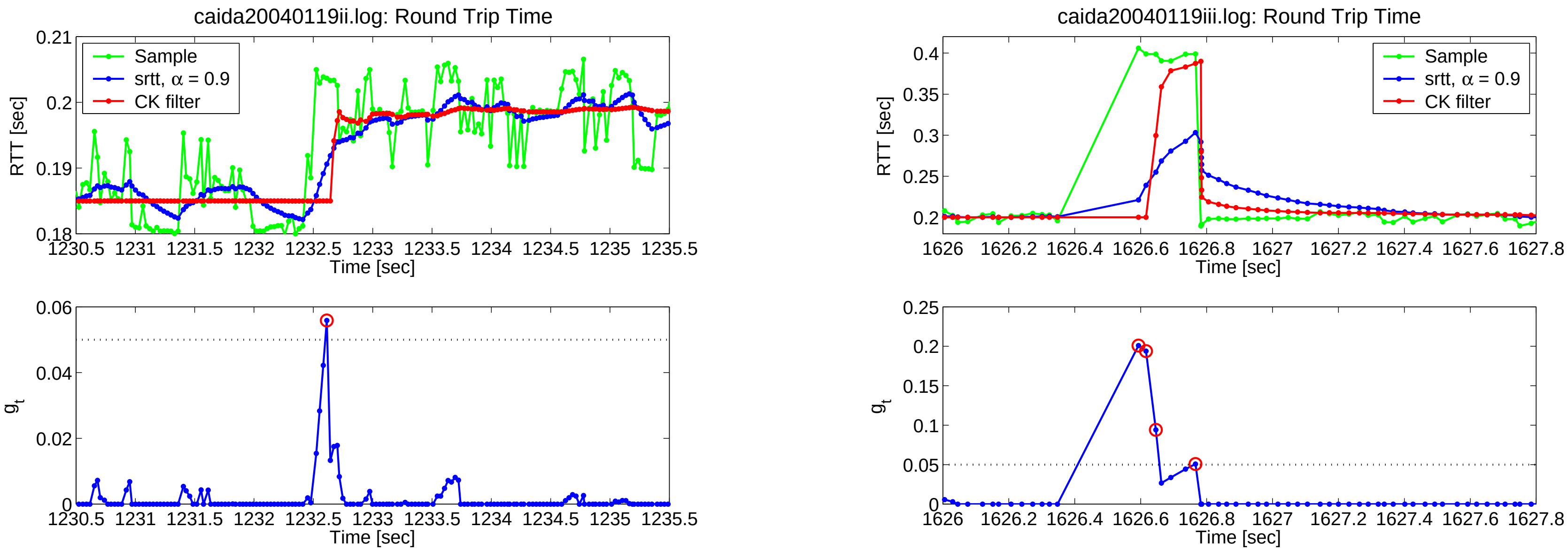
$$y_k = x_k + e_k \qquad \text{Measured RTT}$$

Proposed estimator:

- Kalman filter to suppress noise.
- Change detection to track δ_k.

EVALUATION OF RTT ESTIMATORS

Input: RTT samples KTH ↔ Caida, ≈ 20 hops, interval 30 ms.



Bottom: Output from the change detection.

Bandwidth Estimation

Measurements: ACK inter-arrival times Δ_k.

$$b_N = \frac{Nm}{\sum_k \Delta_k} = \frac{m}{\frac{1}{N}\sum_k \Delta_k} \qquad \text{Constant packet size } m$$

Model: $\Delta_k = b + e_k$, zero-mean noise e_k. Use a low-pass filter:

$$\Delta_k \longrightarrow \boxed{\text{Filter}} \longrightarrow \boxed{\frac{m}{\cdot}} \longrightarrow \hat{b}_k$$

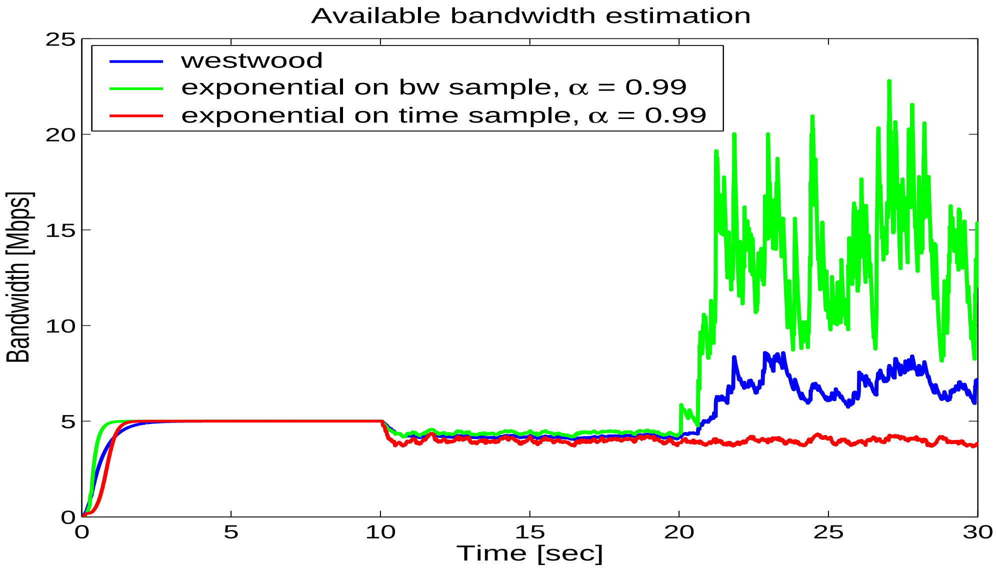
Alternative structure (used in TCP-Westwood):

$$\Delta_k \longrightarrow \boxed{\frac{m}{\cdot}} \longrightarrow \boxed{\text{Filter}} \longrightarrow \hat{b}_k$$

Results in bias *independent* of filter design.

Evaluation of Bandwidth Estimators

Input: TCP simulation in **ns-2**, 5 Mbps bottleneck.



Should filter before the non-linearity.

$$\Delta_k \longrightarrow \boxed{\text{Filter}} \longrightarrow \boxed{\frac{m}{\cdot}} \longrightarrow \hat{b}_k$$

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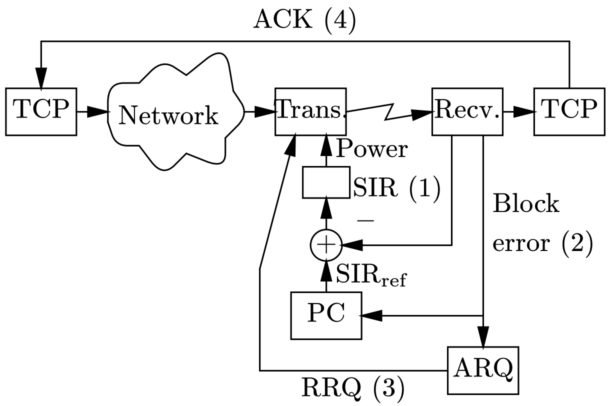
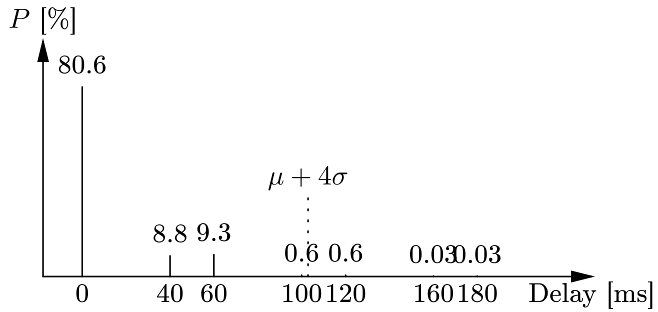
At 10 ms: 1 Mbps cross-traffic in forward direction.

At 20 ms: 1 Mbps cross-traffic in reverse direction.

Influence of Wireless Links on TCP





Without link-layer retransmissions: Constant delay, high loss-rate.

With link-layer retransmissions: Random delay, small loss-rate.

Link delay distribution influences TCP. Spurious timeouts.

A Measure of TCP-friendliness

Let X be the stochastic link delay.

$$\mathrm{P}_{\mathrm{TO}}(X) := \mathrm{P}(X > \mathrm{E}(X) + 4\sigma(X)) \qquad \mathrm{P(Timeout)\ for\ TCP}$$

- Uniform distribution: $\mathrm{P}_{\mathrm{TO}} = 0$.
- Normal distribution: $\mathrm{P}_{\mathrm{TO}} \approx 0.006\%$.
- General distribution: $\mathrm{P}_{\mathrm{TO}} \leq 6.25\%$.
- Wireless link: $\mathrm{P}_{\mathrm{TO}} \approx 0.7\%$.

Tweaking the delay

Original: $\mathrm{P}(X = d_i) = p_i$.

Tweaked: $\mathrm{P}(\tilde{X} = d_i + x_i) = p_i$.

$$\min \; \mathrm{E}(\tilde{X})$$

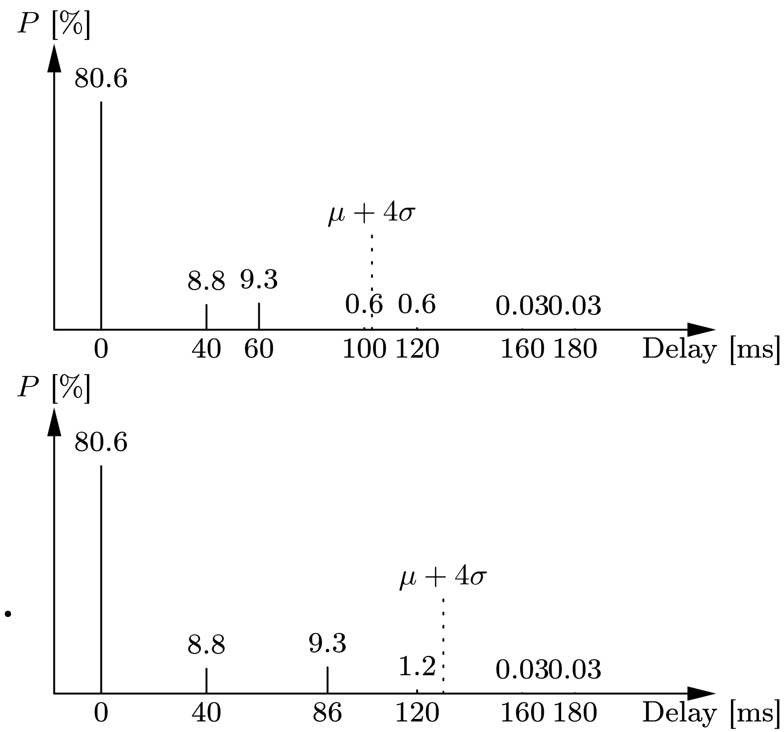
$$\mathrm{P_{TO}}(\tilde{X}) < \epsilon$$

$$x_i \geq 0$$

Decreased $\mathrm{P_{TO}}$, from 0.68% to 0.06%.

Mean delay increased by only 2.5 ms.

Eliminates most spurious timeouts.



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Conclusions

- RTT estimation: Promising model based approach.
- Bandwidth estimation: Average inter-arrival times, not "bandwidth samples".
- Artificial delays at the link-layer improve TCP performance.
- For wireless links: Use engineering freedom in the link layer.

Vision: Systematic design of network control mechanisms:

- End-to-end congestion control.
- Network-layer control in intermediate routers.
- Link-layer control loops.

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