Updates on NADA: Stability Analysis and Impact of Feedback Intervals

draft-ietf-rmcat-nada-02

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Outline

- Update on draft -02
- Stability analysis of NADA feedback control loop
- Numerical results on NADA with varying feedback intervals
- Simulation results on NADA with varying feedback intervals
- Summary and next steps

Changes in Draft -02

- No algorithm changes
- Added a section on feedback requirements of NADA in Sec. 5.3
- Addressed review comments from Stefan and Zahed (Thanks!)
- Minor adjustment in notations, fixed various errors and typos.

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Simplifying Assumptions for Stability Analysis

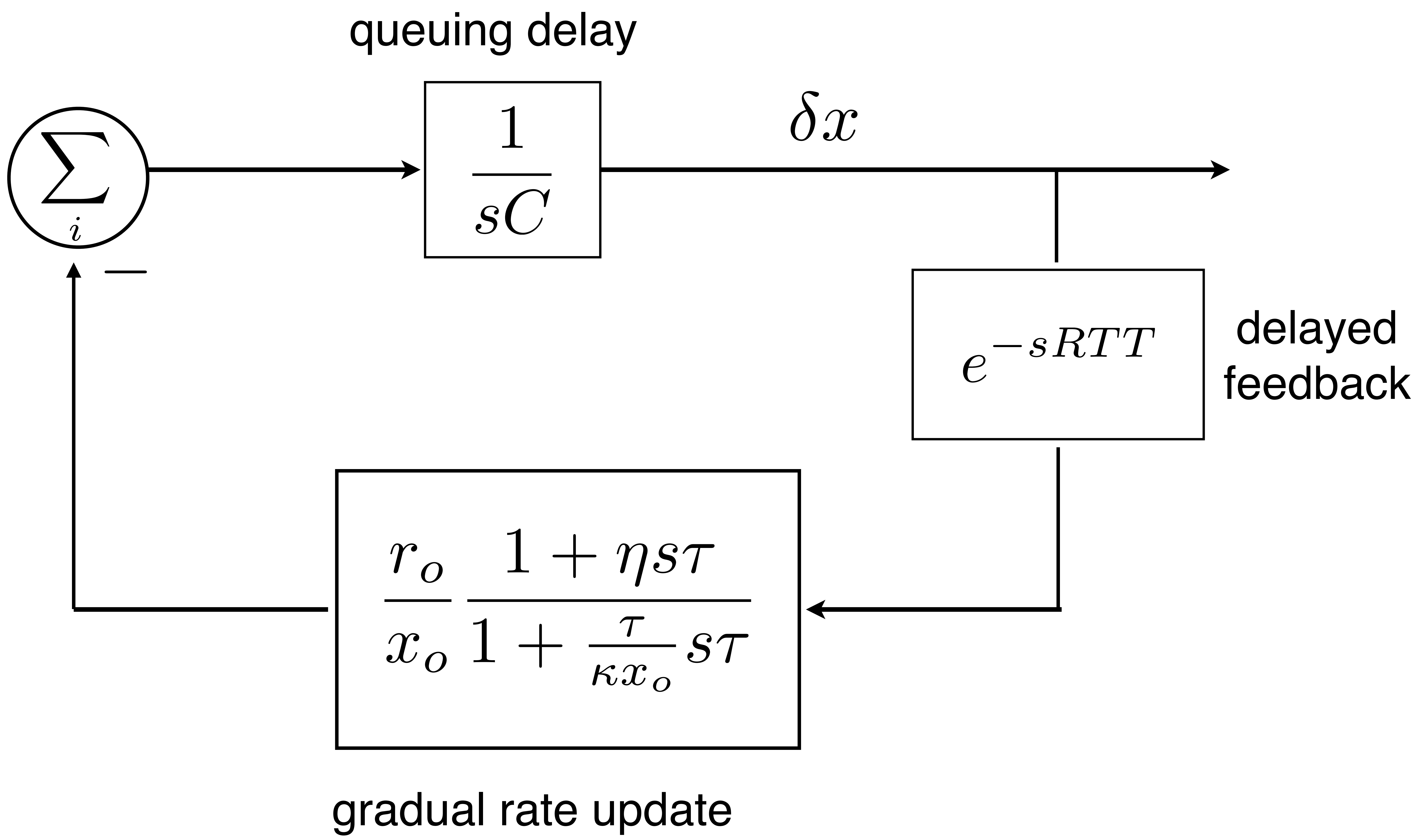
- Considers only gradual rate update mode, w/o packet losses or marking: `x_curr = d_queue`
- Ignores effect of 15-tap minimum filtering
- Rate update equation reduces to (see Eq(5)-(7) in draft):

$$x_o = PRIO \frac{R_{MAX}}{r_o} x_{ref}$$

$$r_i = r_{i-1} - \kappa \frac{\Delta}{\tau} \frac{x_i - x_o}{\tau} r_{i-1} - \kappa\eta \frac{x_i - x_{i-1}}{\tau} r_{i-1}$$

$$\Rightarrow \quad \frac{r_i - r_{i-1}}{\Delta} = -\frac{\kappa}{\tau}\left[\frac{x_i - x_o}{\tau} + \eta \frac{x_i - x_{i-1}}{\Delta}\right] r_{i-1}$$

Feedback Control Loop in Laplace Transform



System at equilibrium:

$$r_o = PRIO \frac{x_{ref}}{x_o} R_{max}$$

For single flow:

$$r_o = C$$

Open Loop Transfer Function

$$\mathcal{G}(s) = -\frac{r_o}{C}\frac{1+\eta s\tau}{1+\frac{\tau}{\kappa x_o}s\tau}\frac{e^{-sRTT}}{sx_o}$$

At low frequency, $s \to 0$

$$\mathcal{G}(s) \approx -\frac{r_o}{C}\frac{RTT}{x_o}$$

Bandwidth sharing proportional to

$$PRIOR_{max}$$

At high frequency, $s \to j\infty$

$$\mathcal{G}(s) \approx -\kappa\eta\frac{r_o}{C}\frac{RTT}{\tau}\frac{e^{-sRTT}}{sRTT}$$

Guarantees stability for

$$\kappa\eta\frac{RTT}{\tau} < \frac{\pi}{2}$$ and $\eta\tau >> 1$

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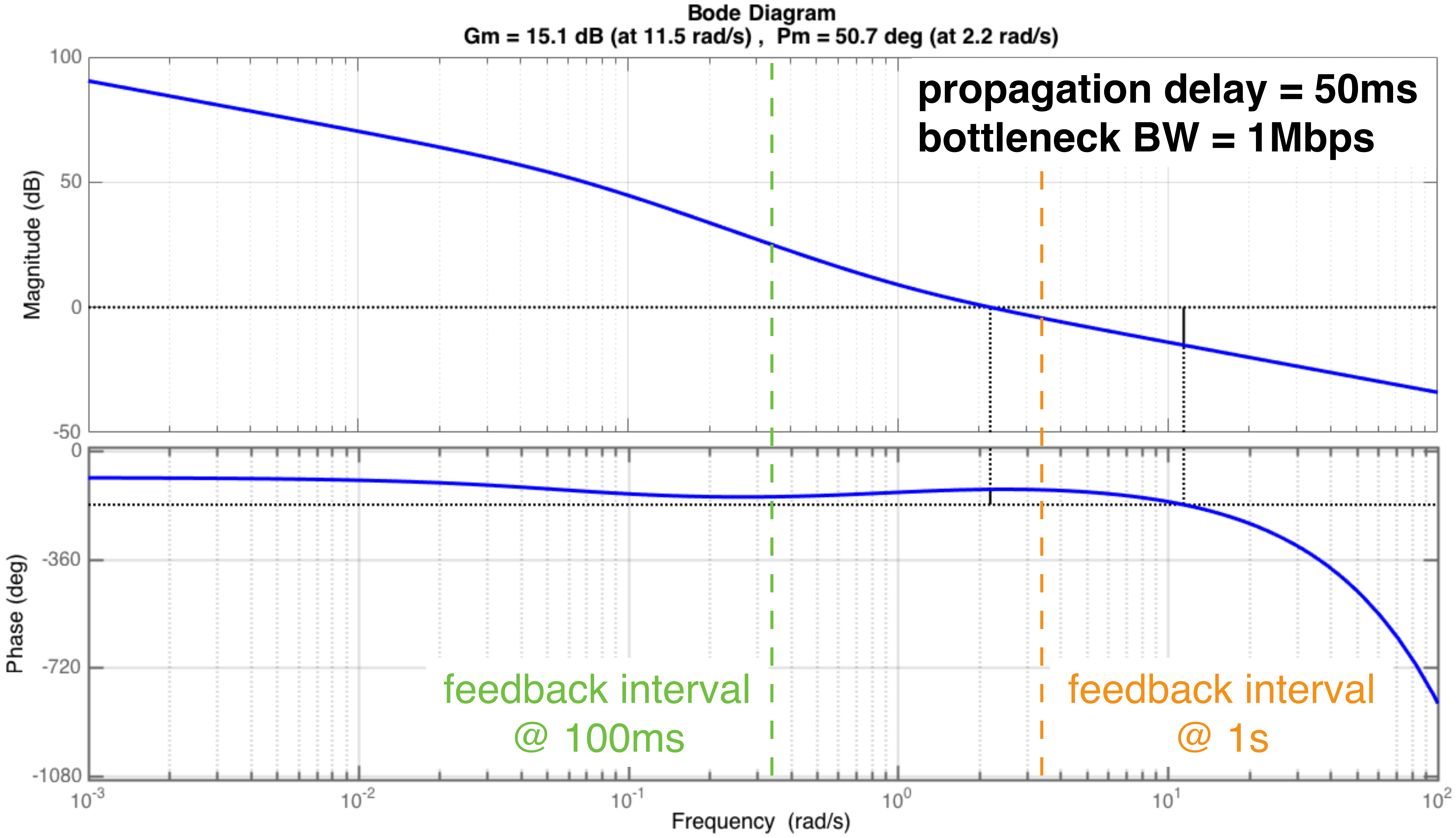
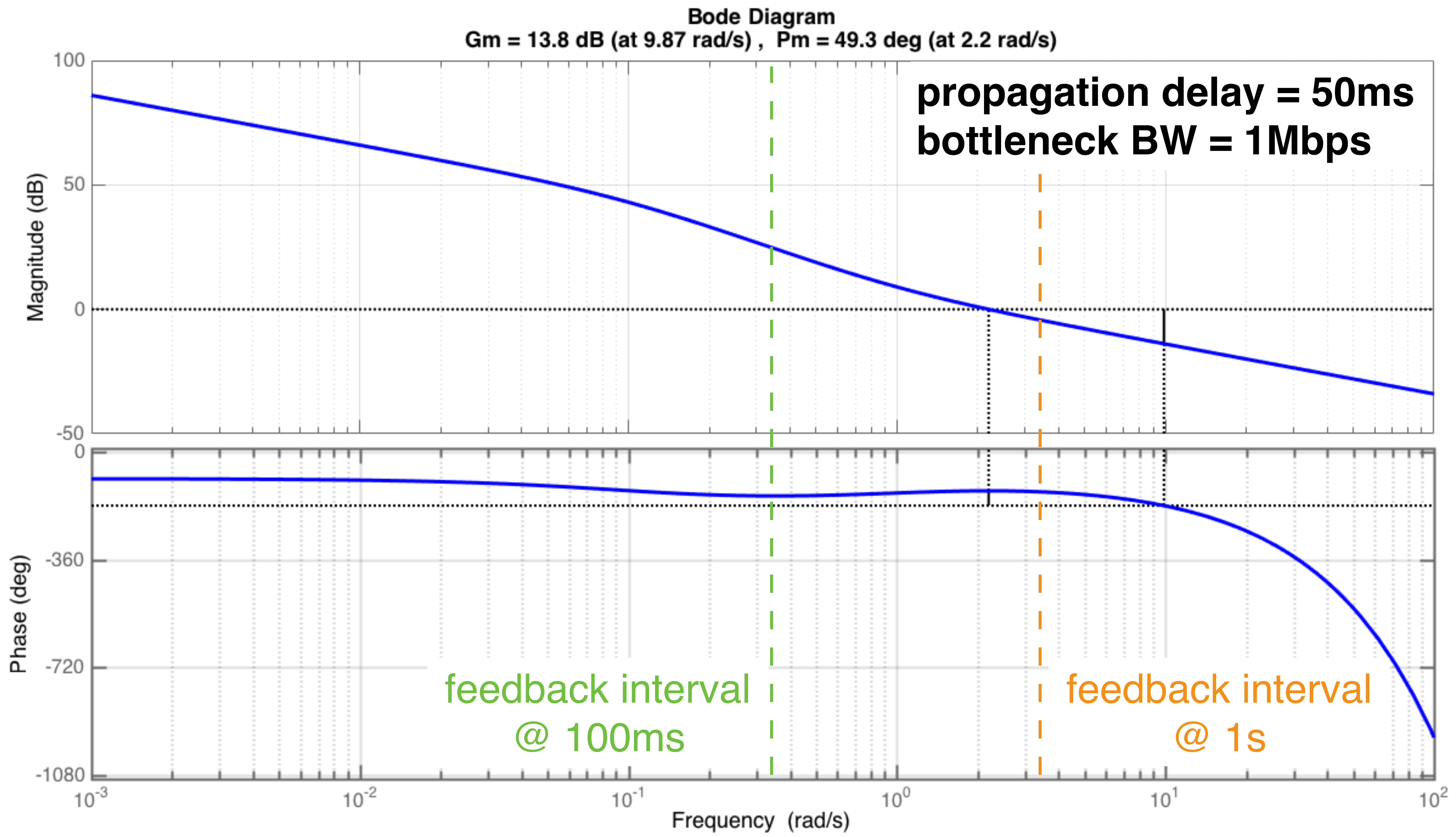
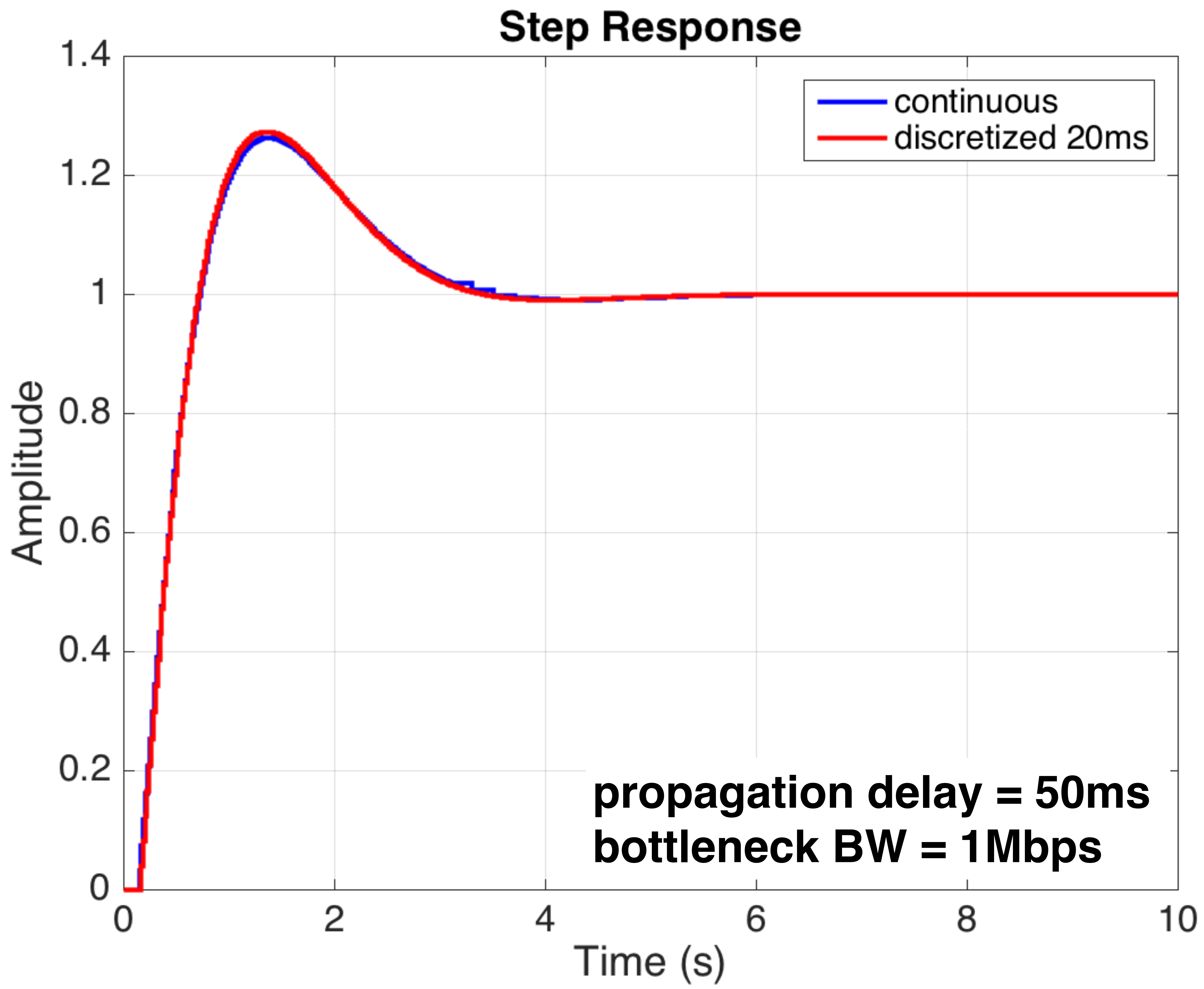
Bode Diagram with Gain/Phase Margins



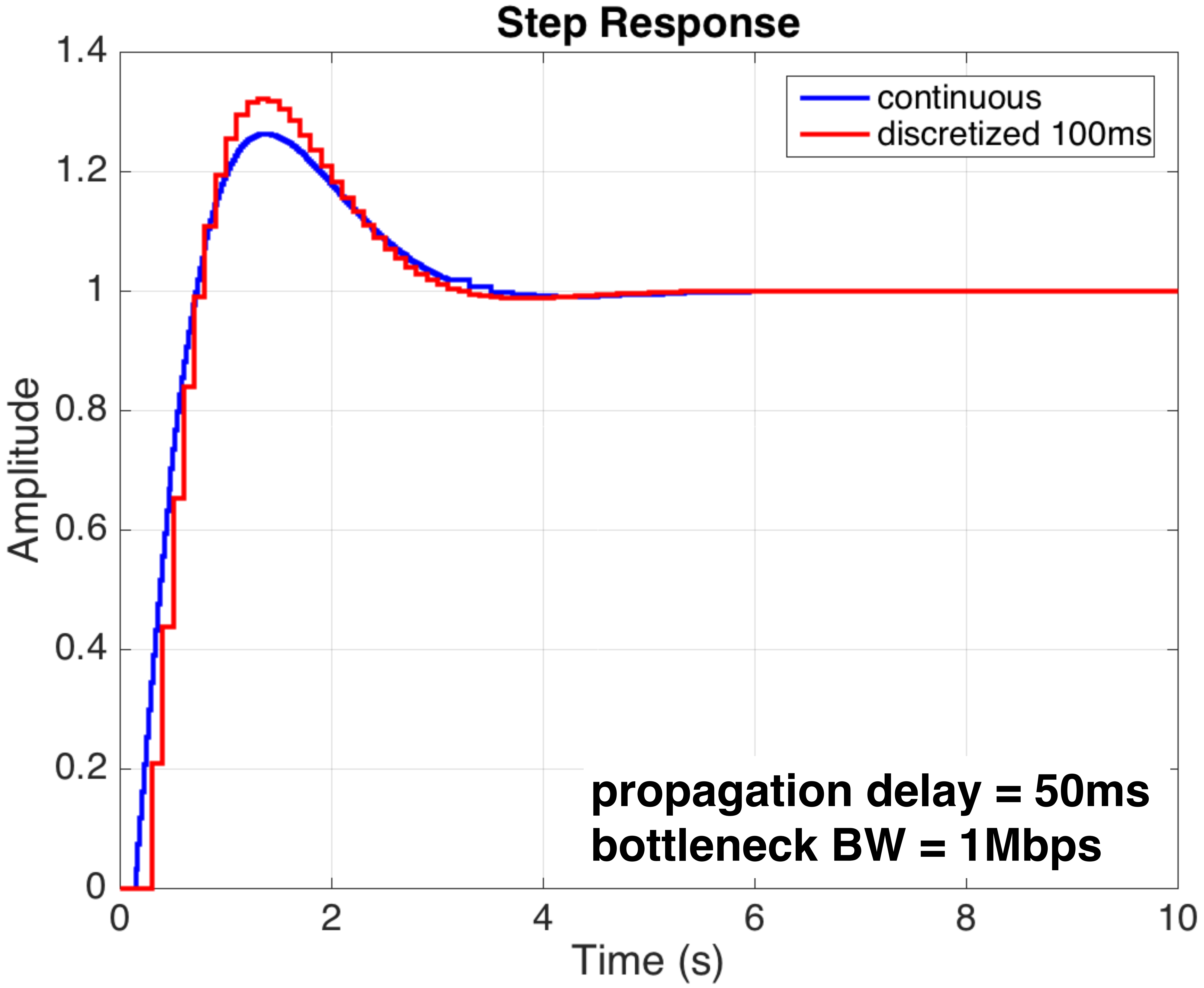
Bode Diagram with Gain/Phase Margins



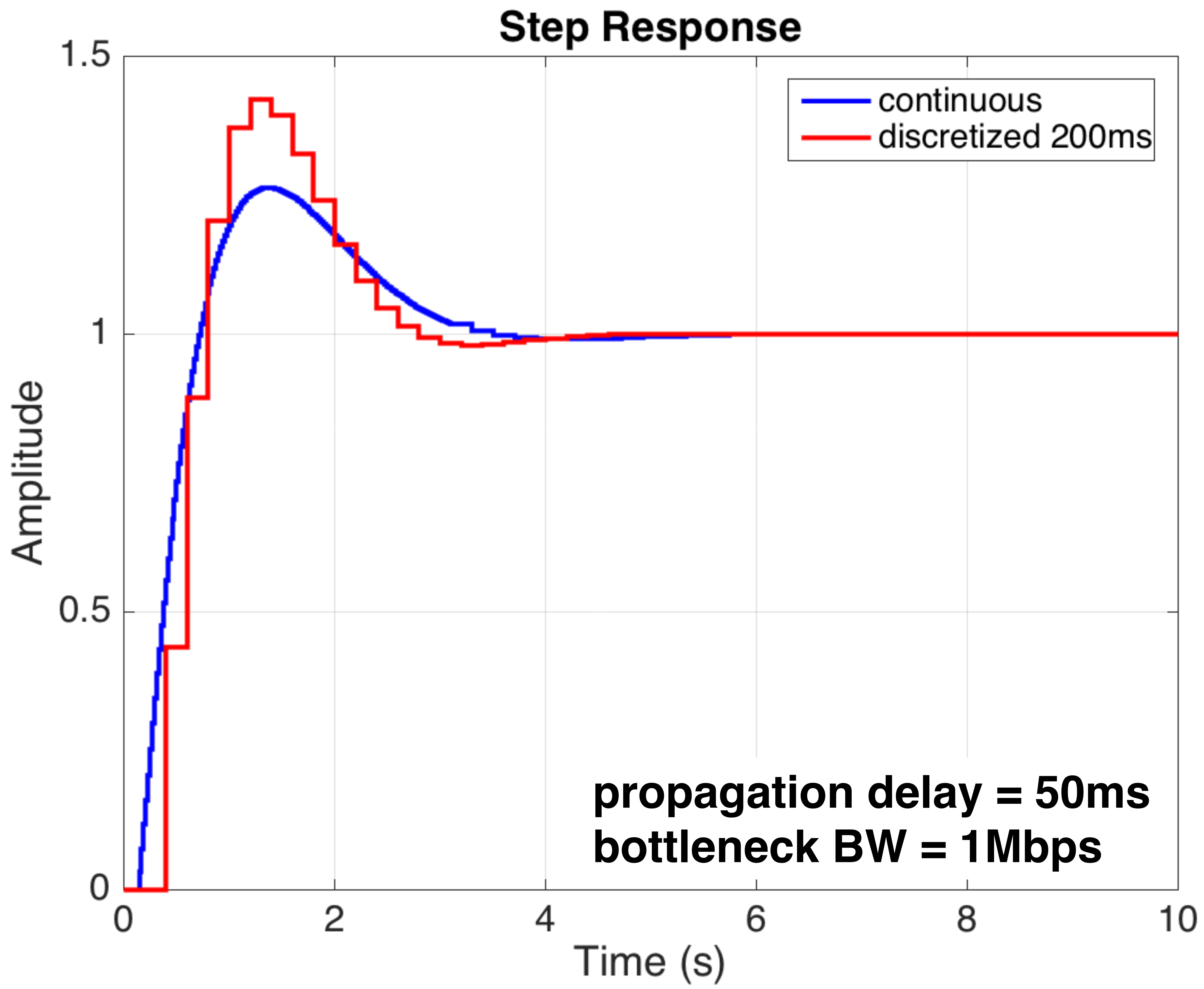
Step Response of Closed-Loop System



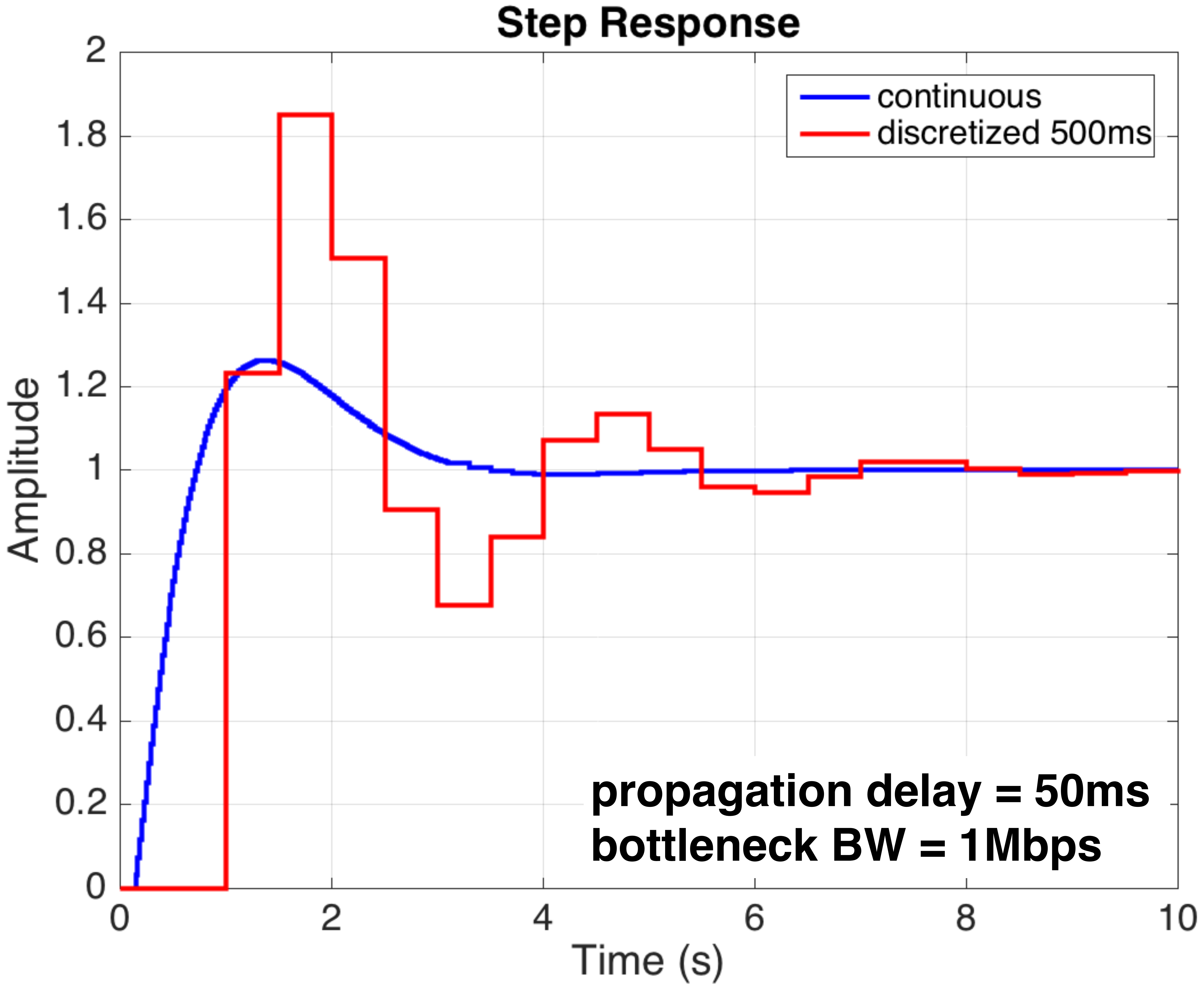
Step Response with Feedback Interval @ 100ms



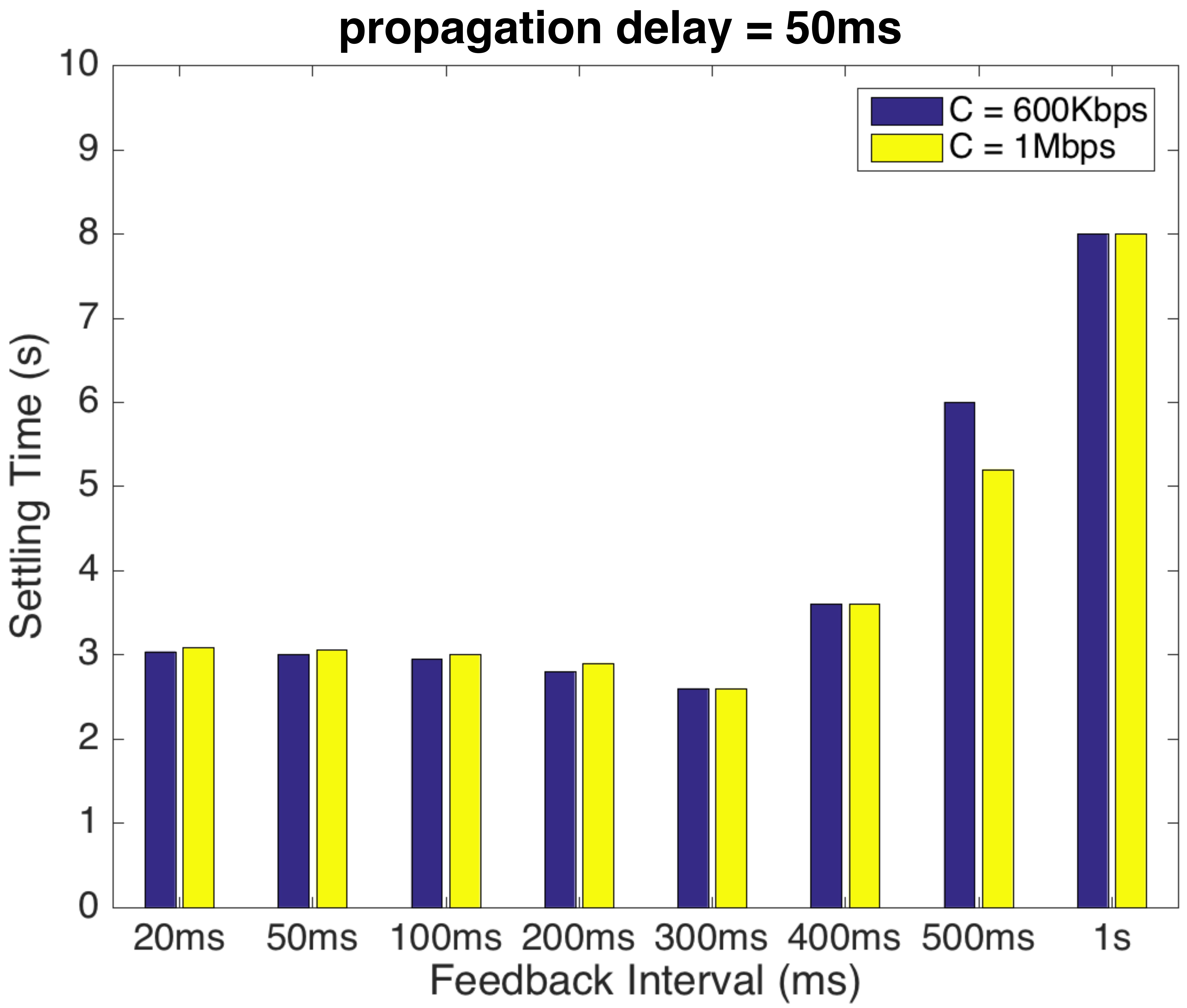
Step Response with Feedback Interval @ 200ms



Step Response with Feedback Interval @ 500ms



Settling Time vs. Feedback Interval



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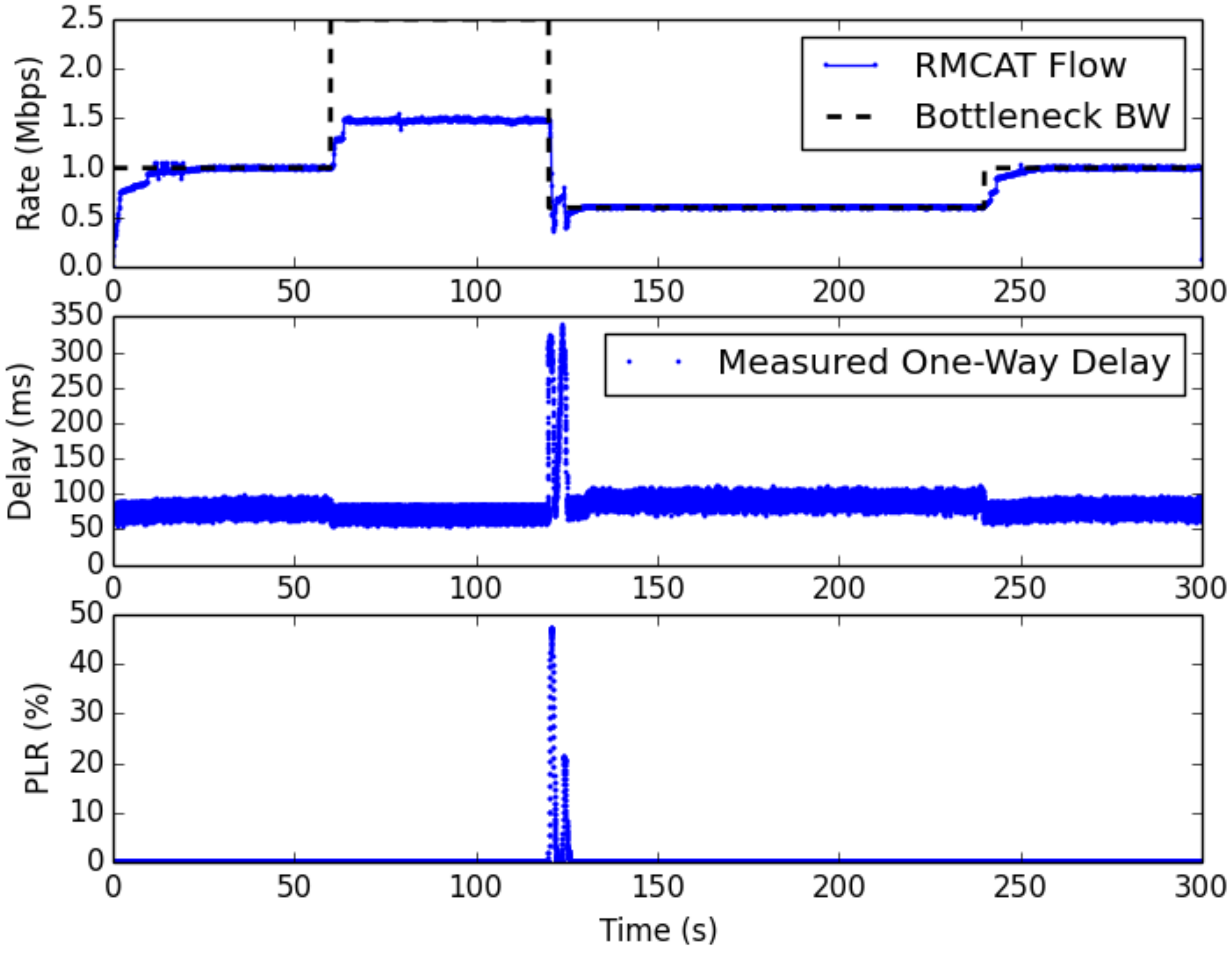
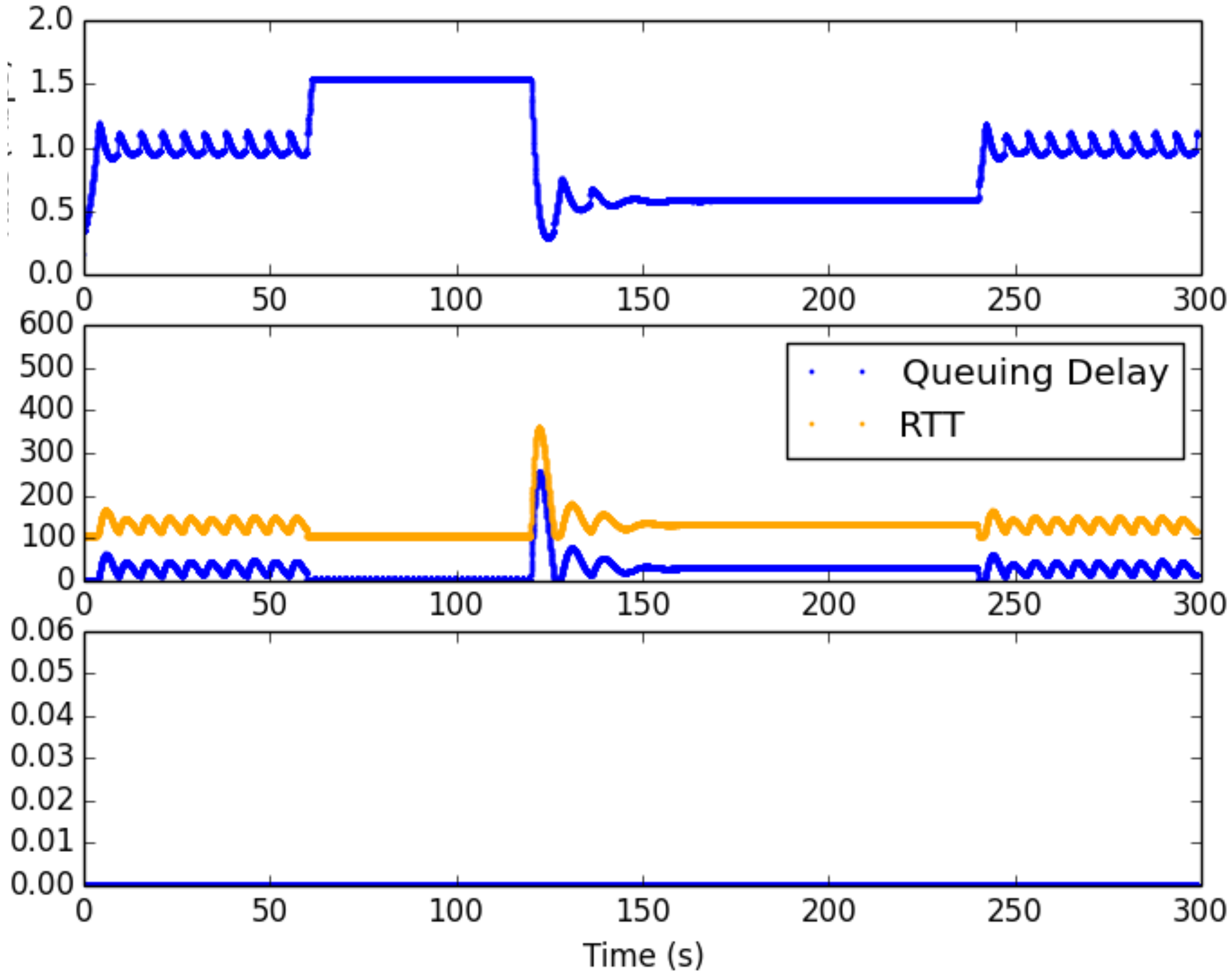
Propagation Delay @ 50ms, Feedback Interval = 20ms

NS2: physical link rate change

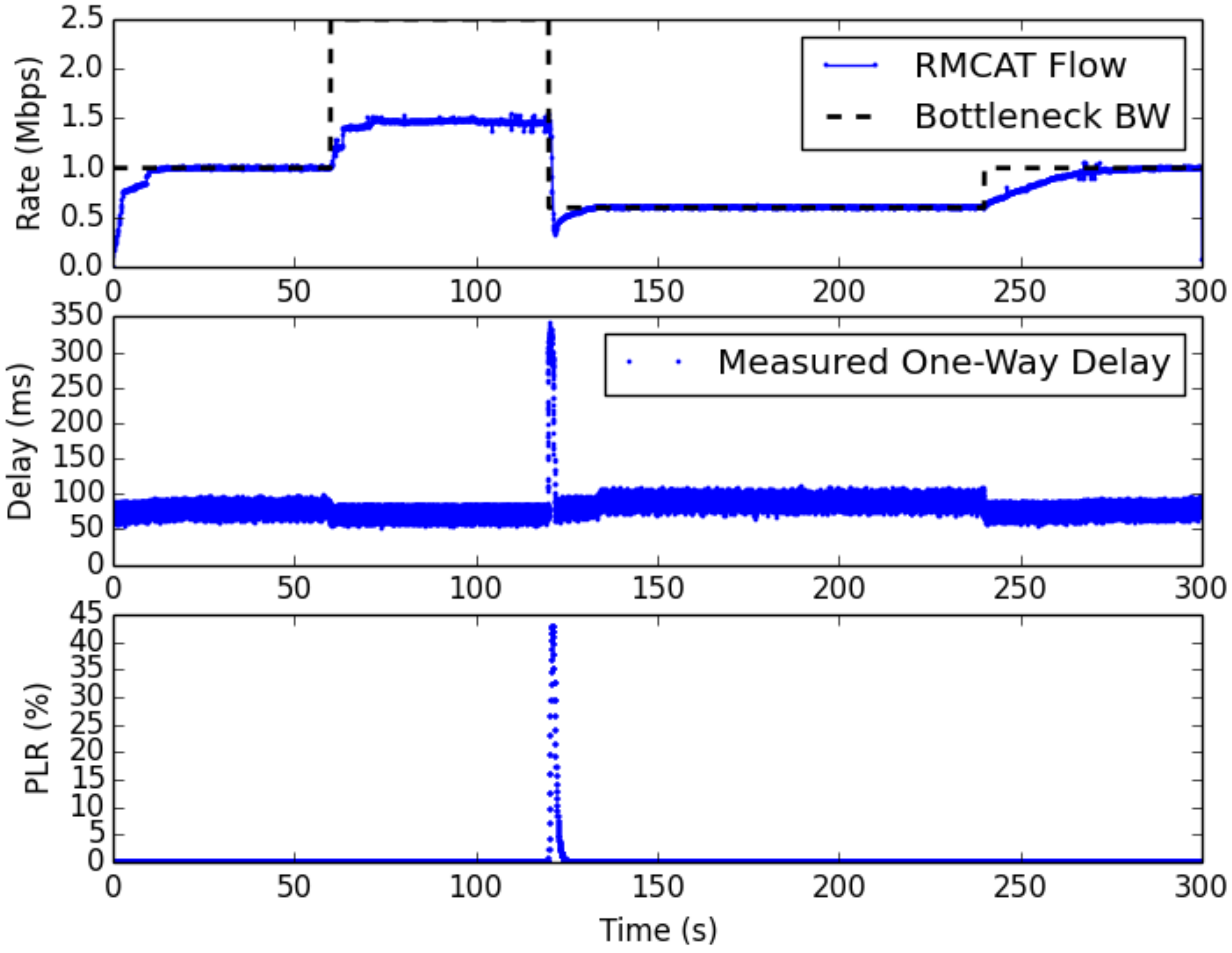


NS3: time-varying background UDP flow

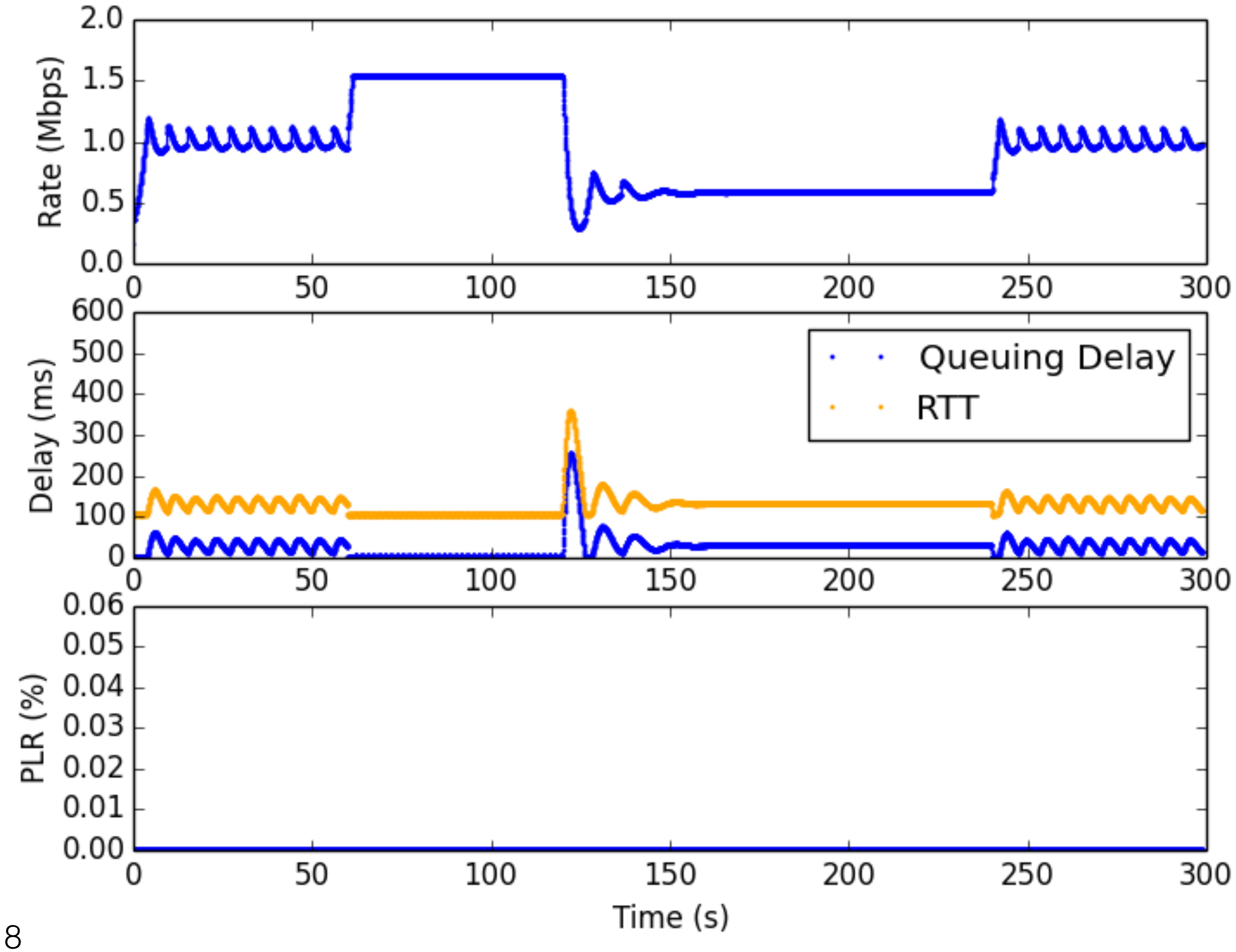


Propagation Delay @ 50ms, Feedback Interval = 50ms

NS2: physical link rate change

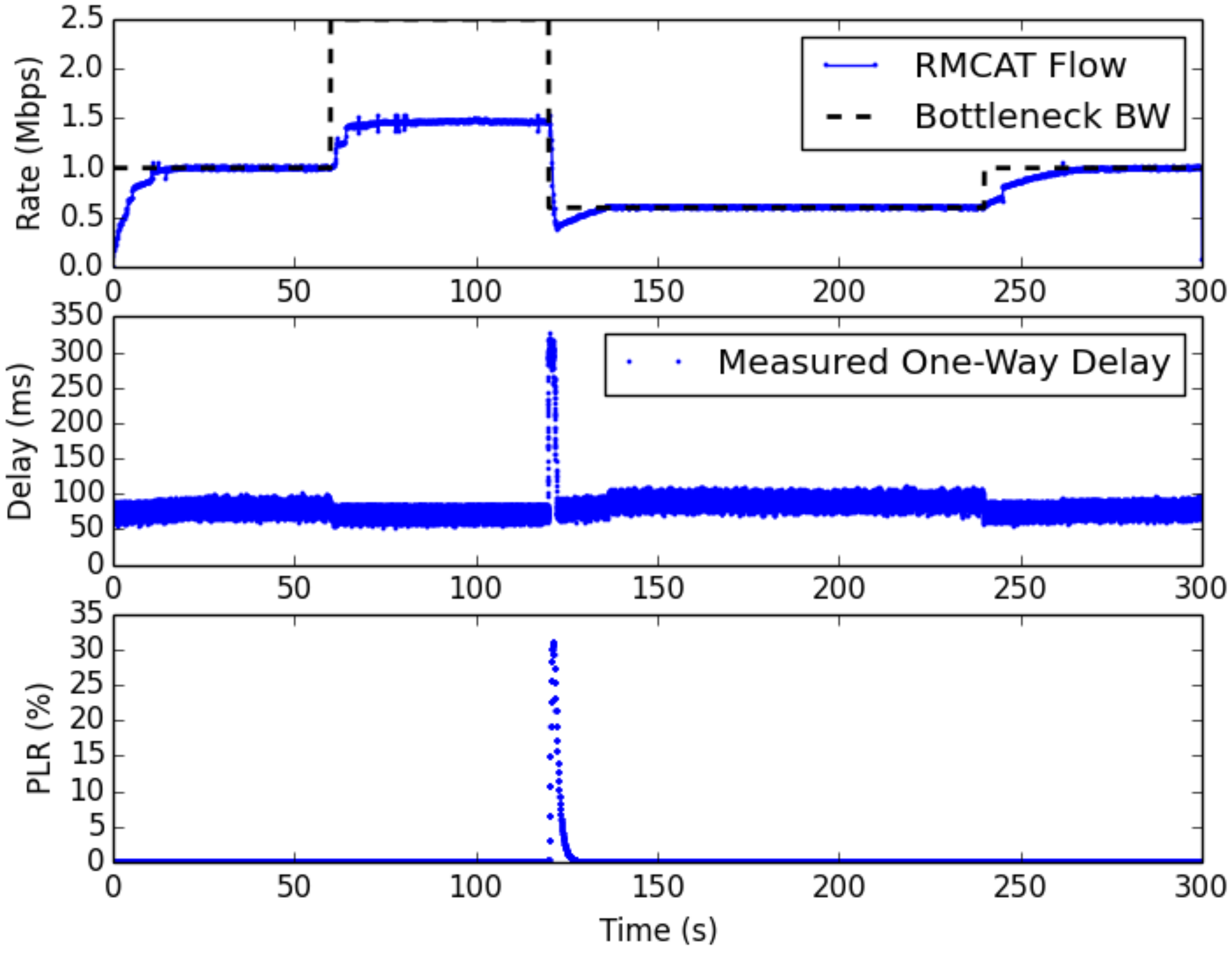


NS3: time-varying background UDP flow

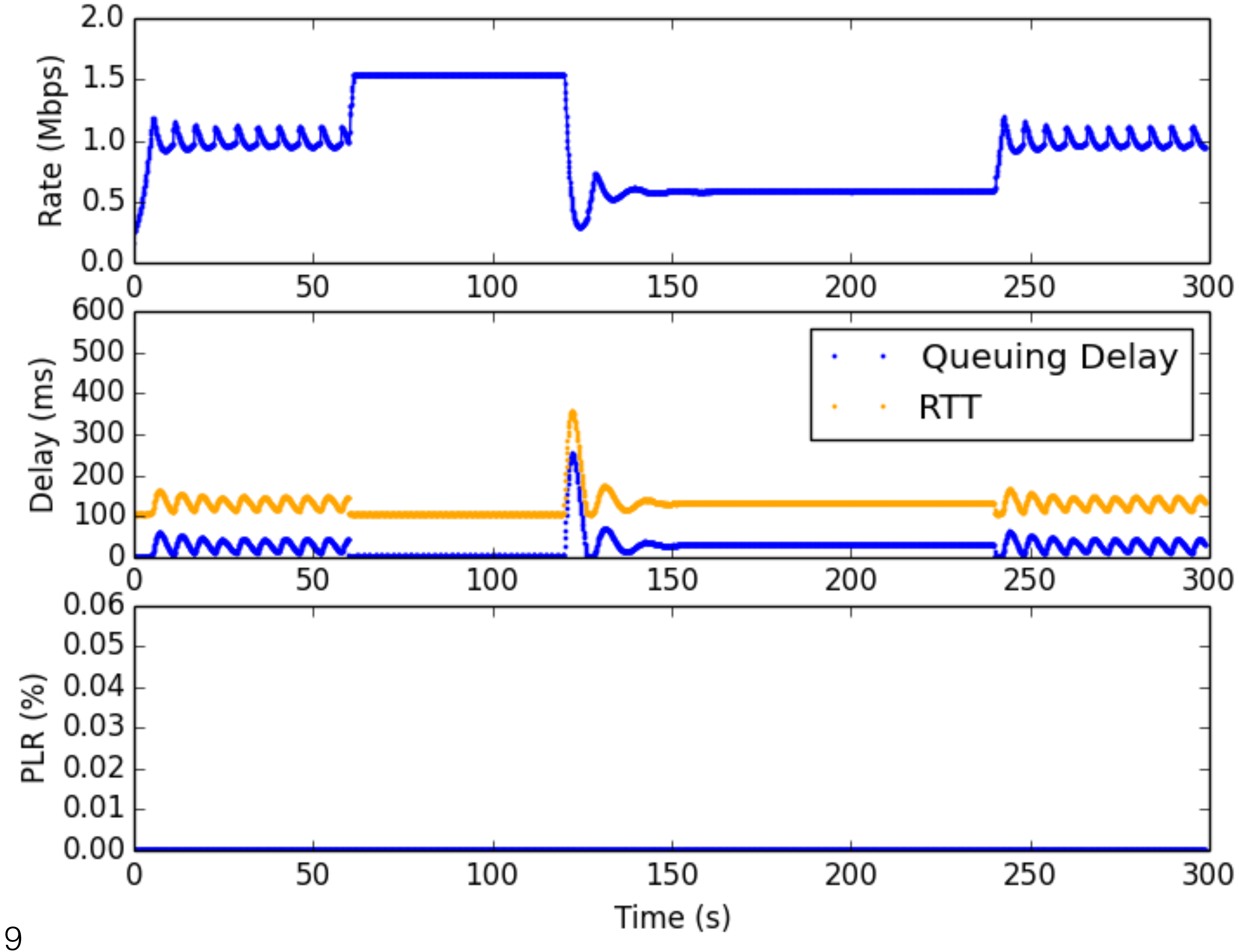


Propagation Delay @ 50ms, Feedback Interval = 100ms

NS2: physical link rate change

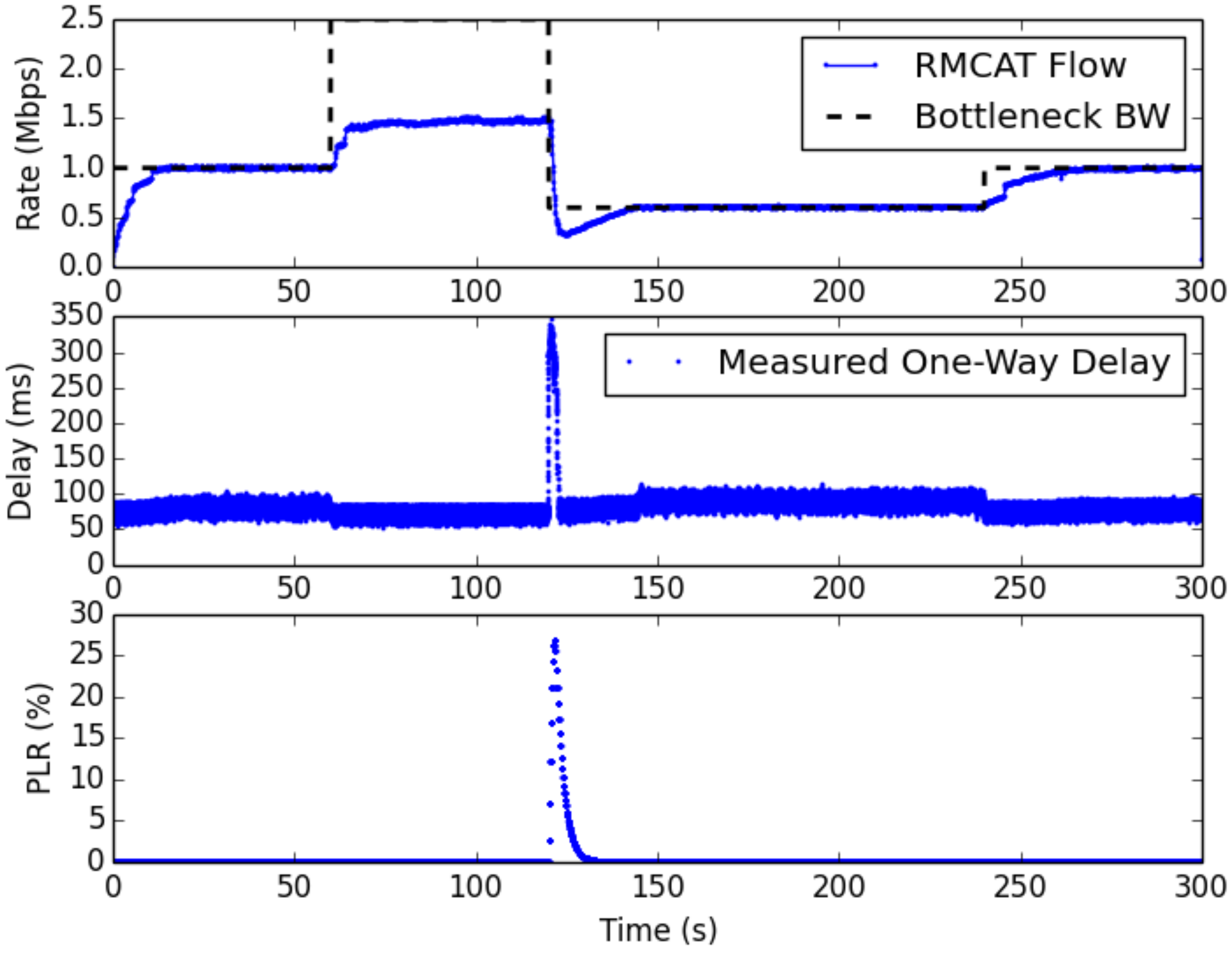


NS3: time-varying background UDP flow



Propagation Delay @ 50ms, Feedback Interval = 200ms

NS2: physical link rate change



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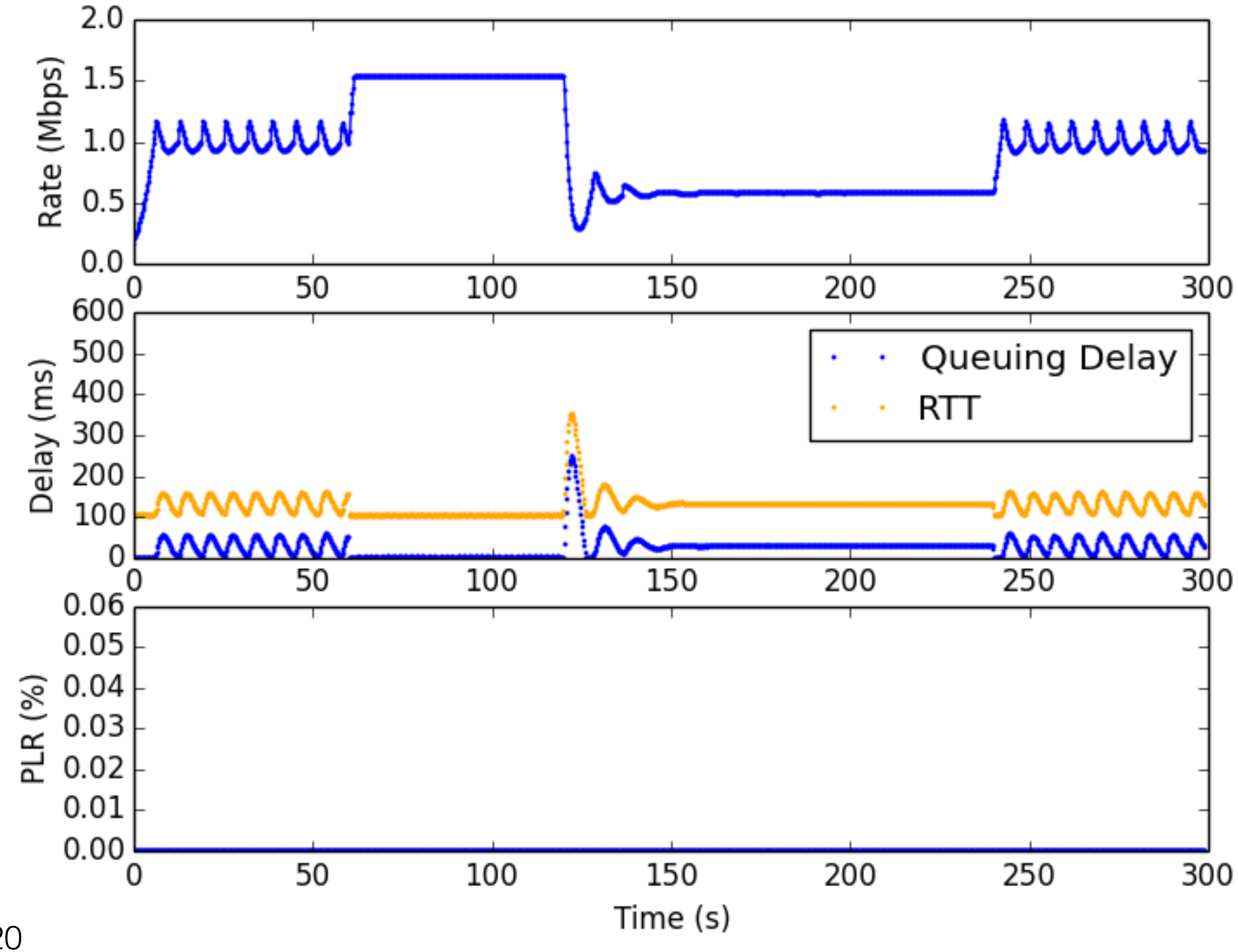
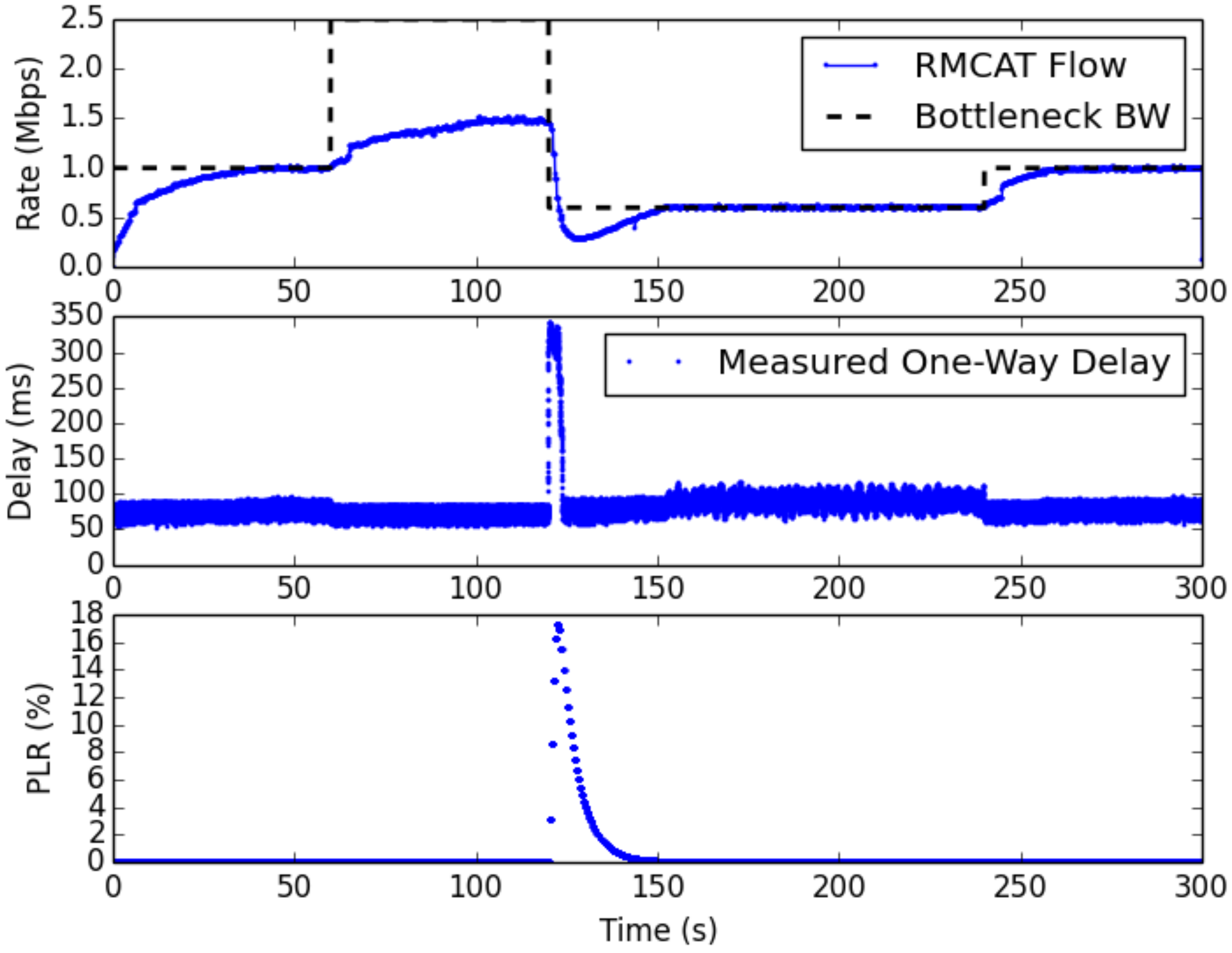


Propagation Delay @ 50ms, Feedback Interval = 500ms

NS2: physical link rate change



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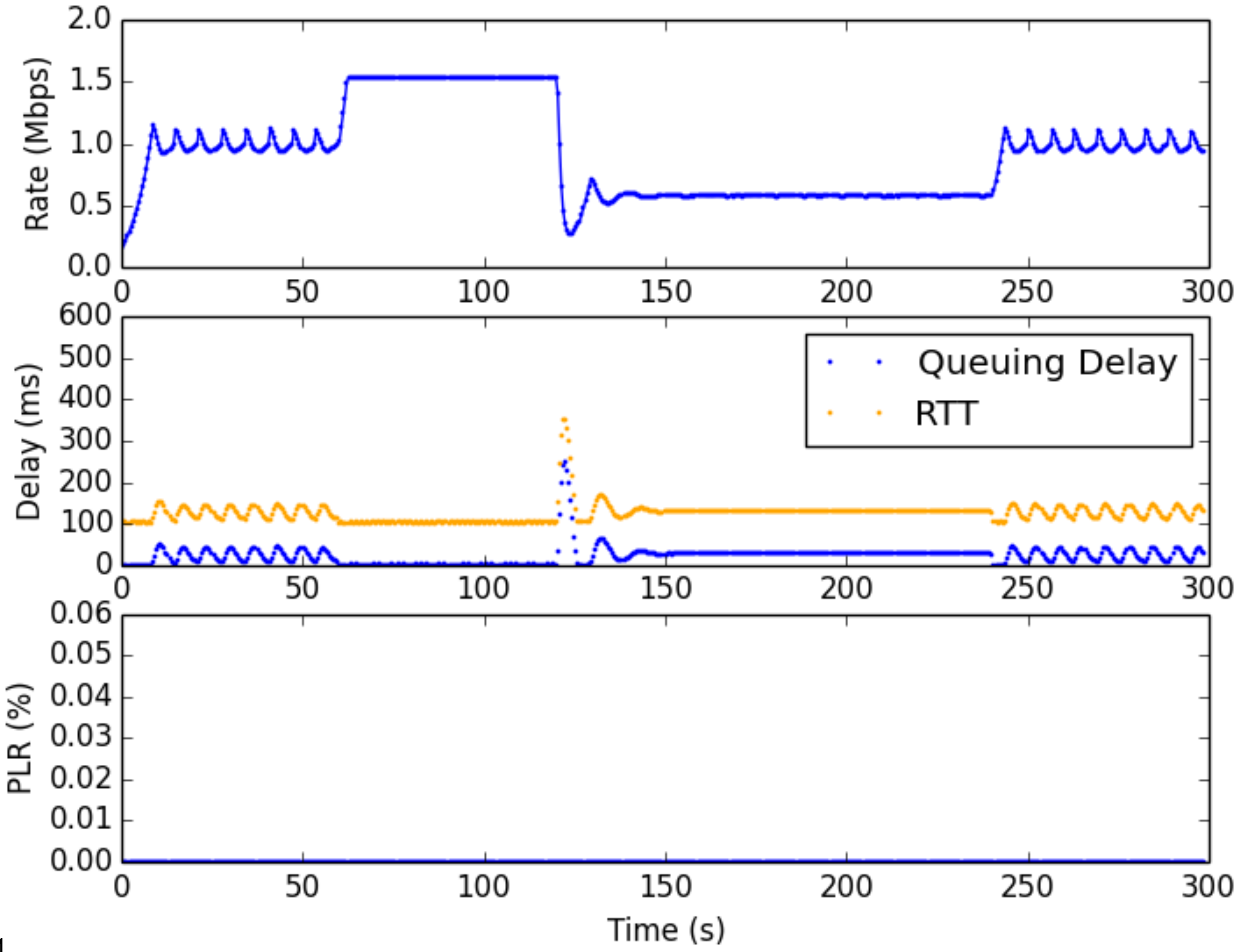
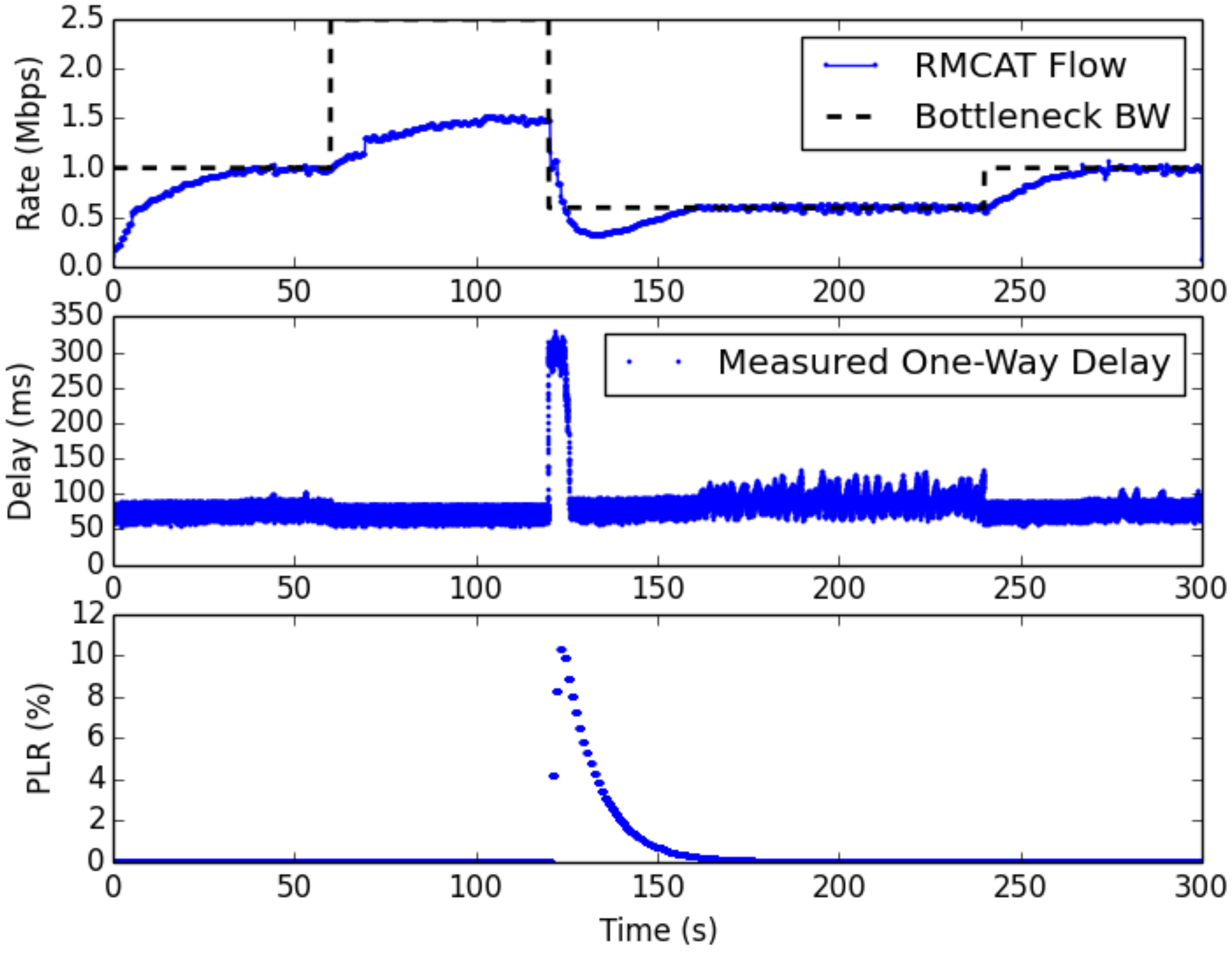
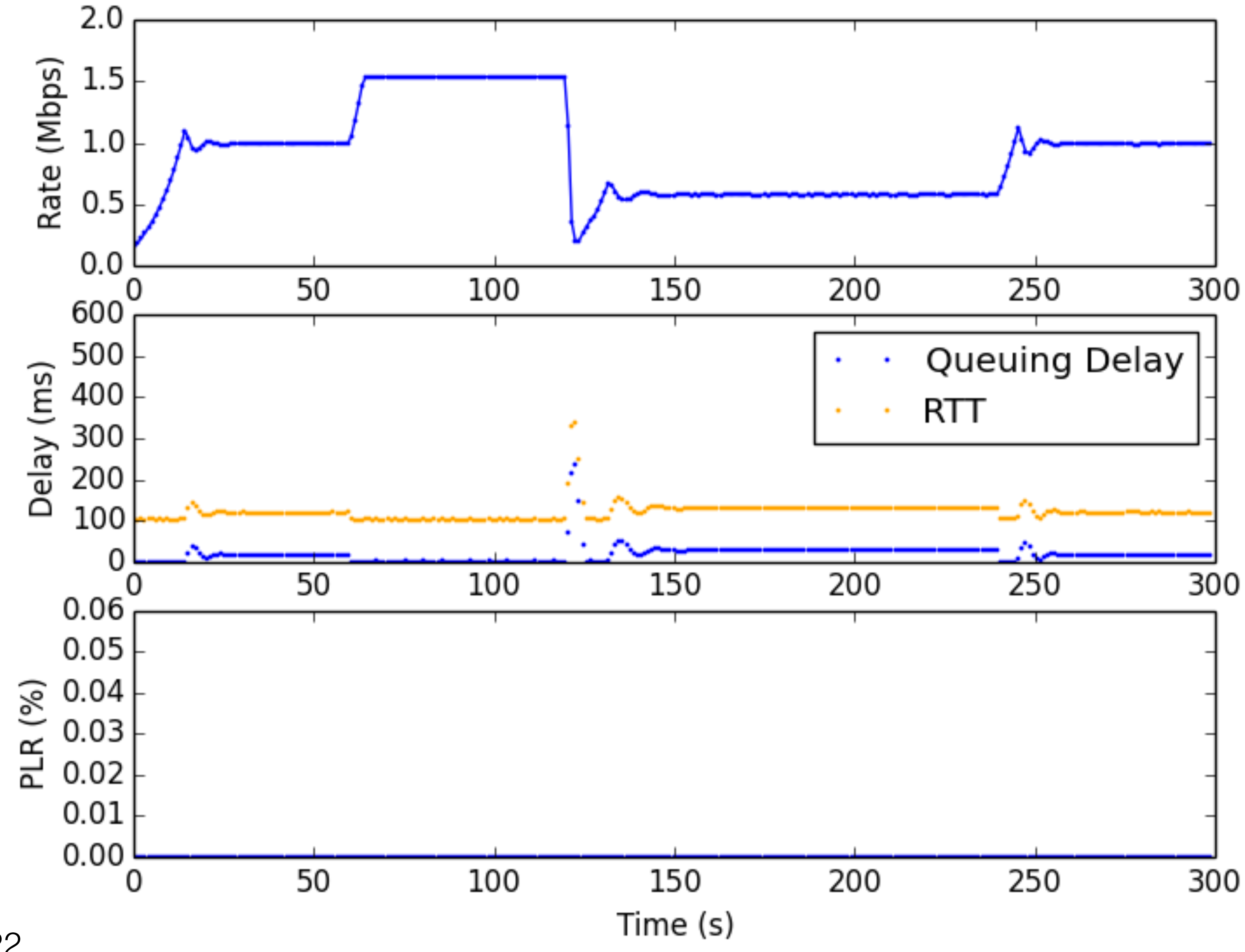


Propagation Delay @ 50ms, Feedback Interval = 1s

NS2: physical link rate change

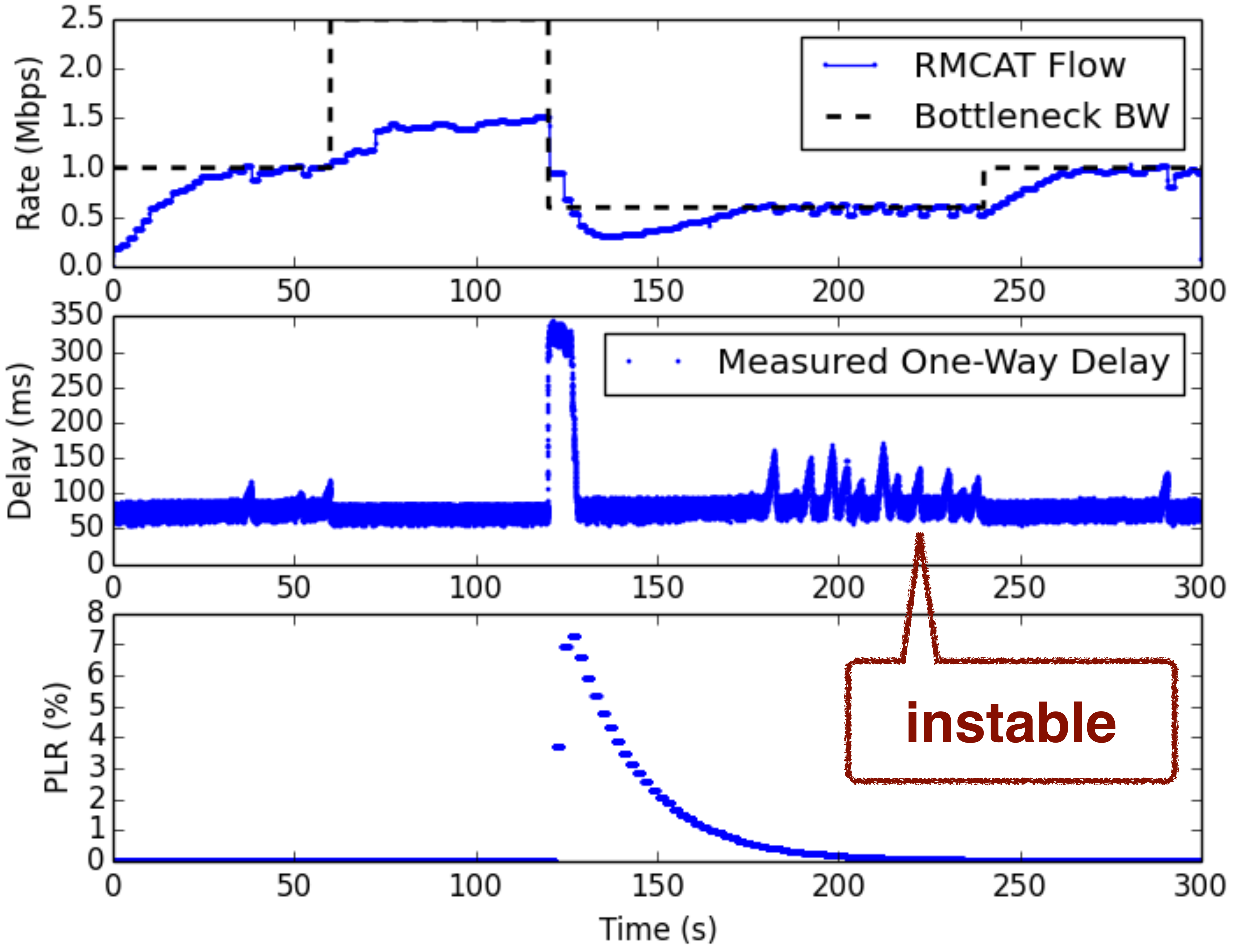


NS3: time-varying background UDP flow

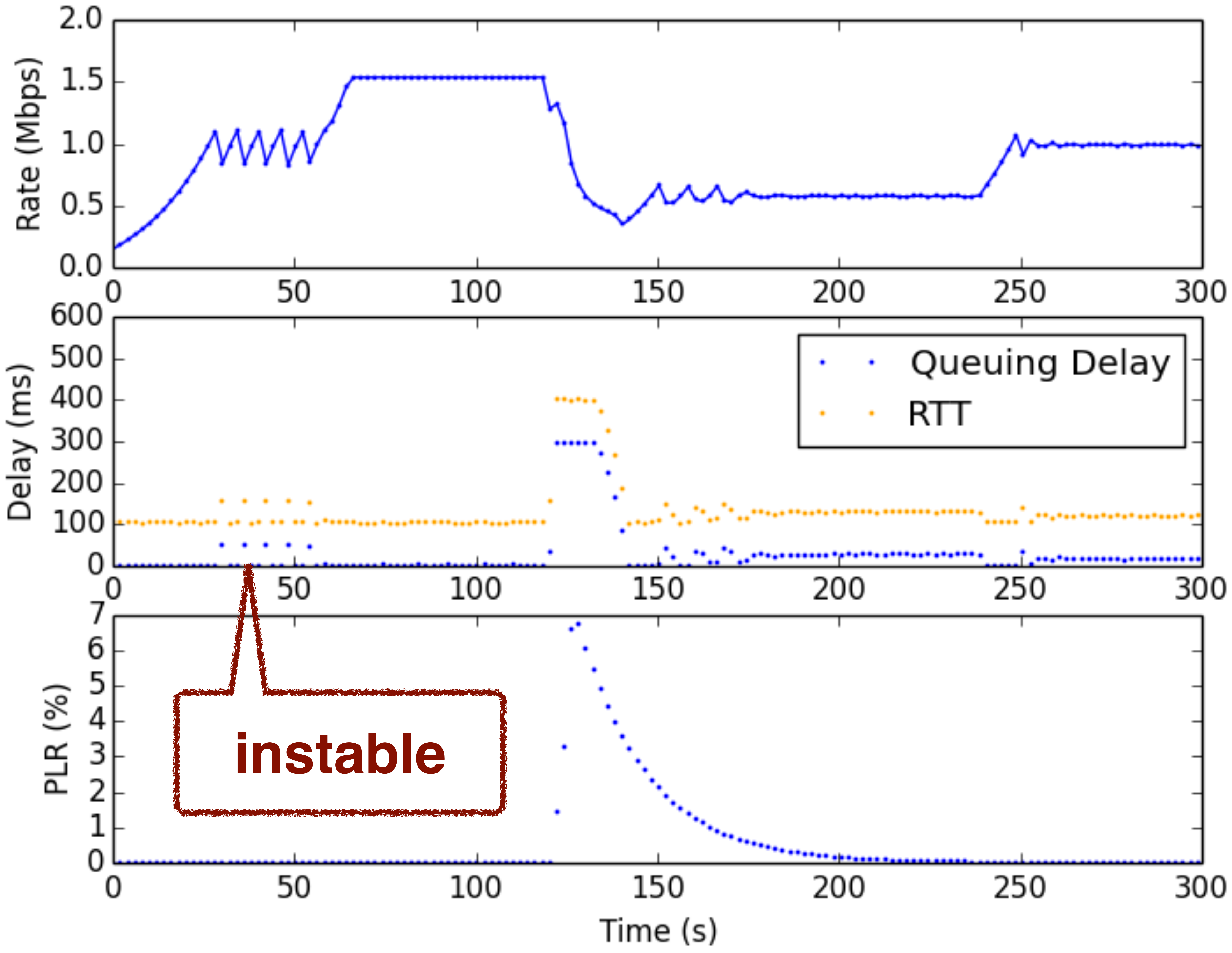


Propagation Delay @ 50ms, Feedback Interval = 2s

NS2: physical link rate change

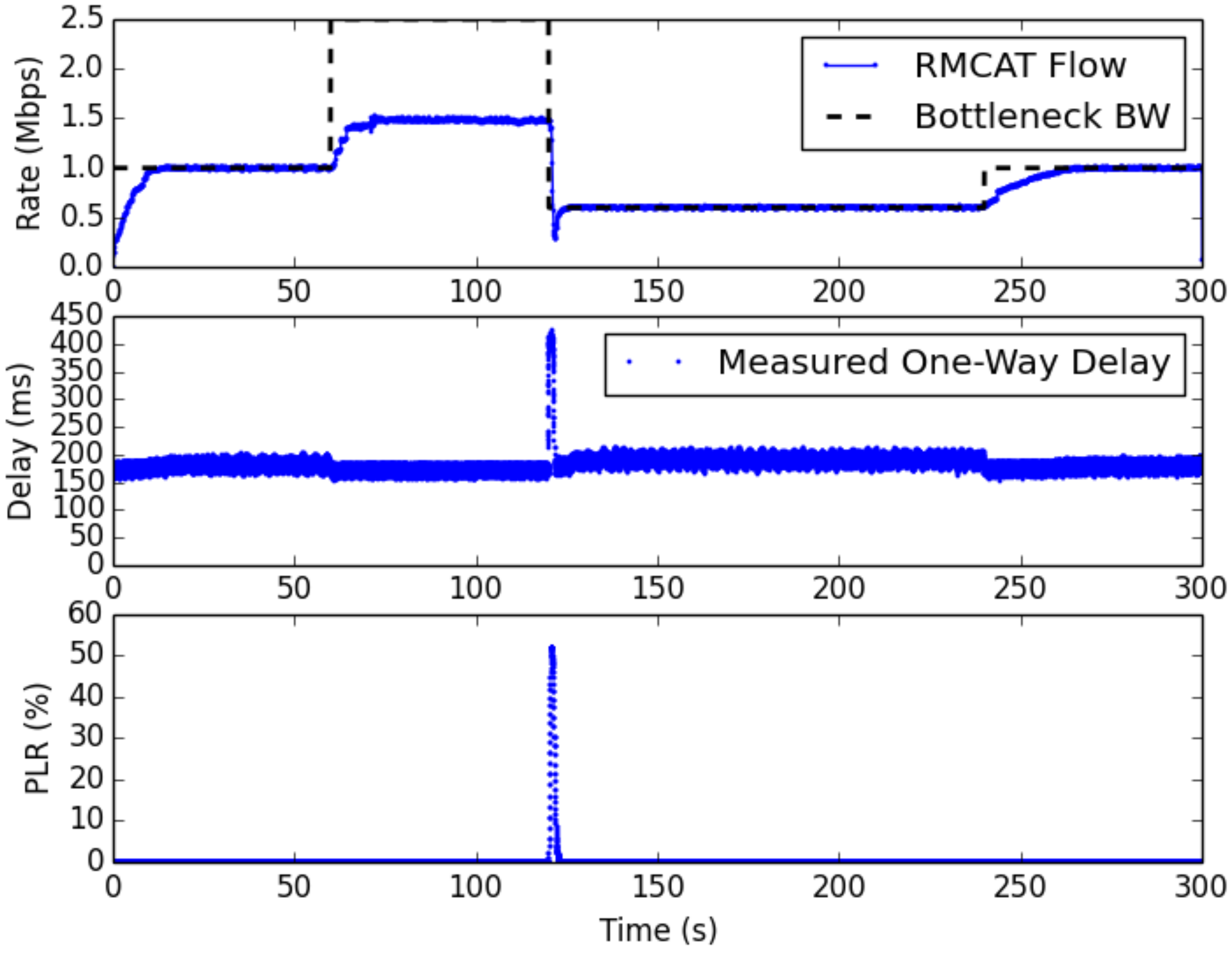


NS3: time-varying background UDP flow

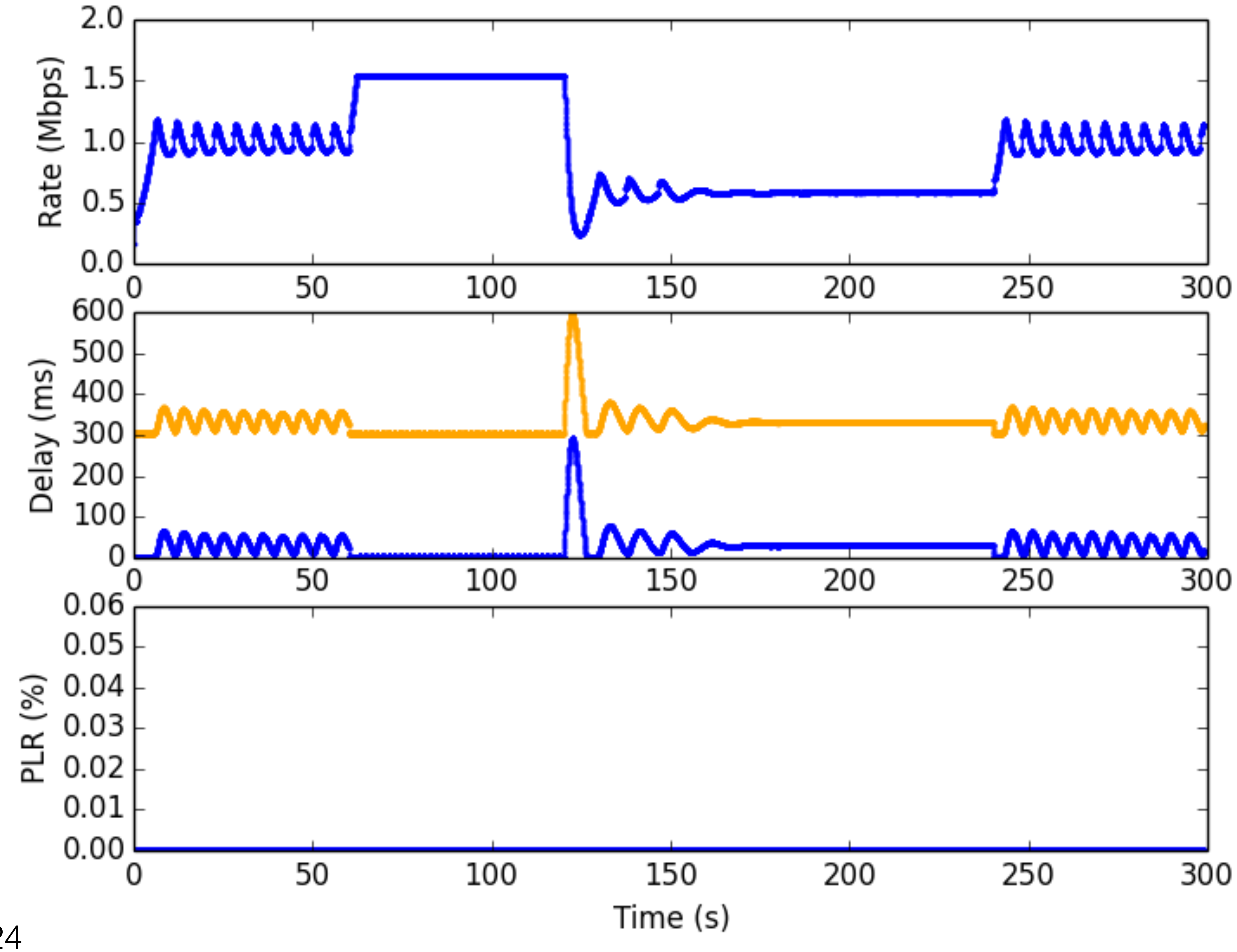


Propagation Delay @ 150ms, Feedback Interval = 20ms

NS2: physical link rate change

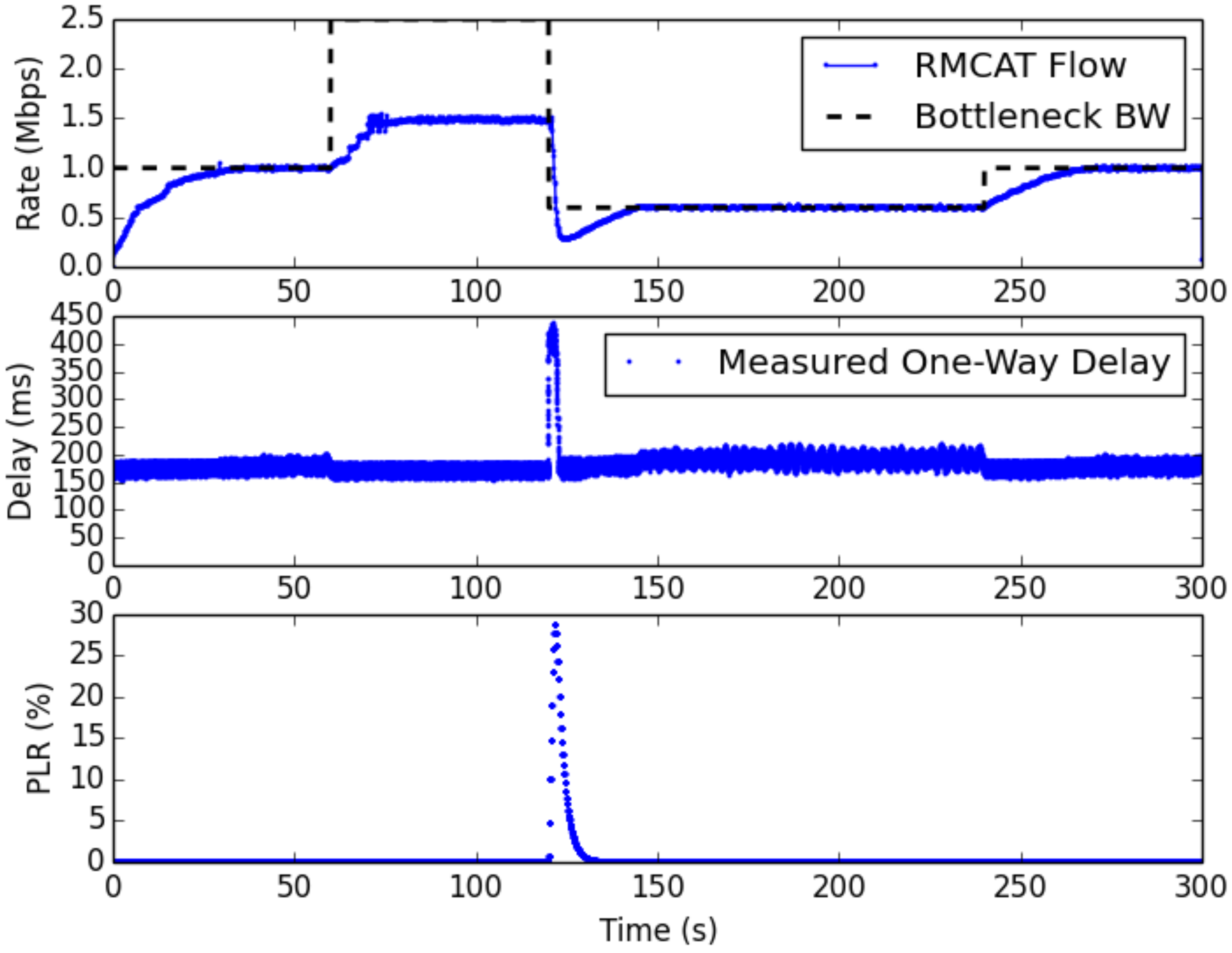


NS3: time-varying background UDP flow

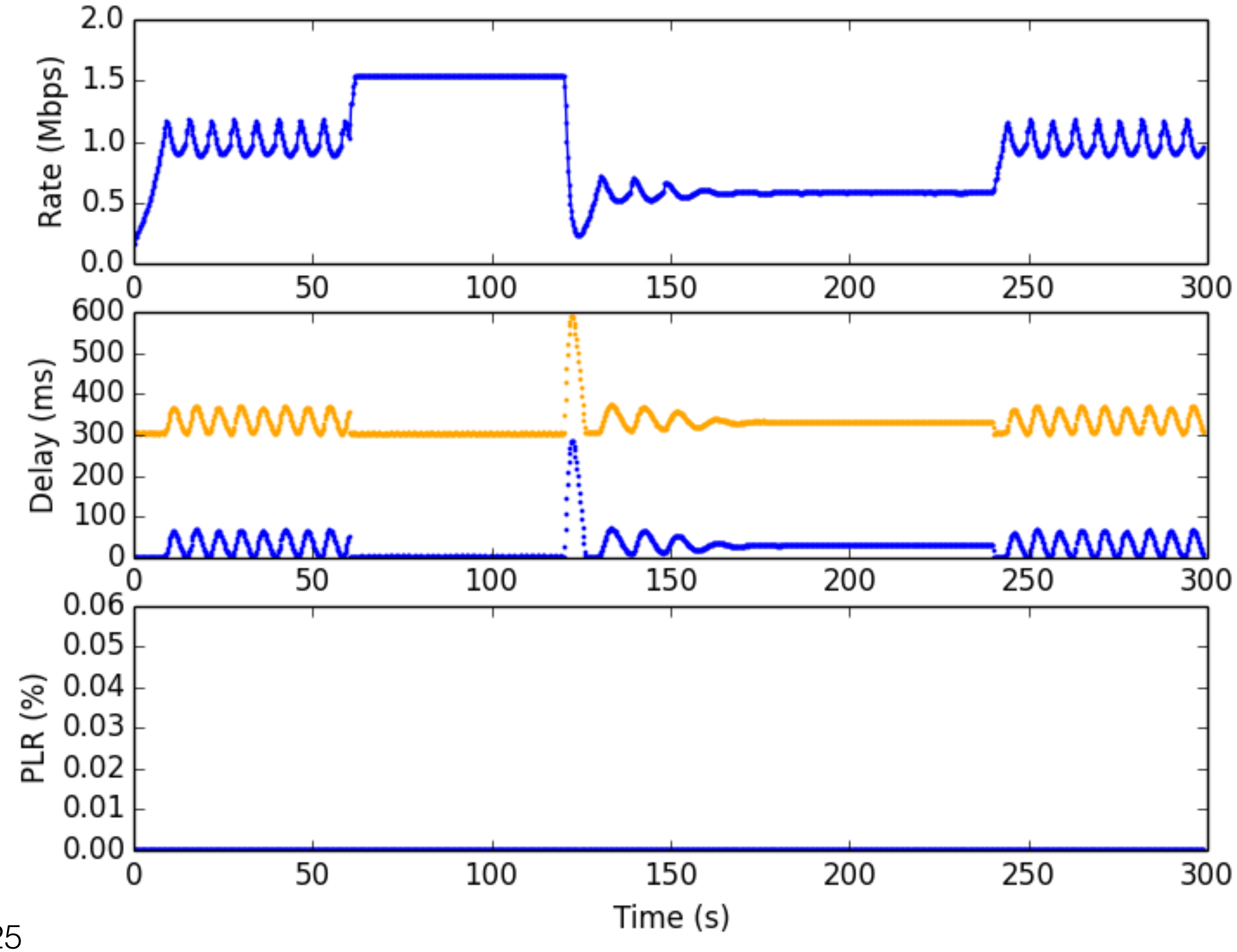


Propagation Delay @ 150ms, Feedback Interval = 200ms

NS2: physical link rate change

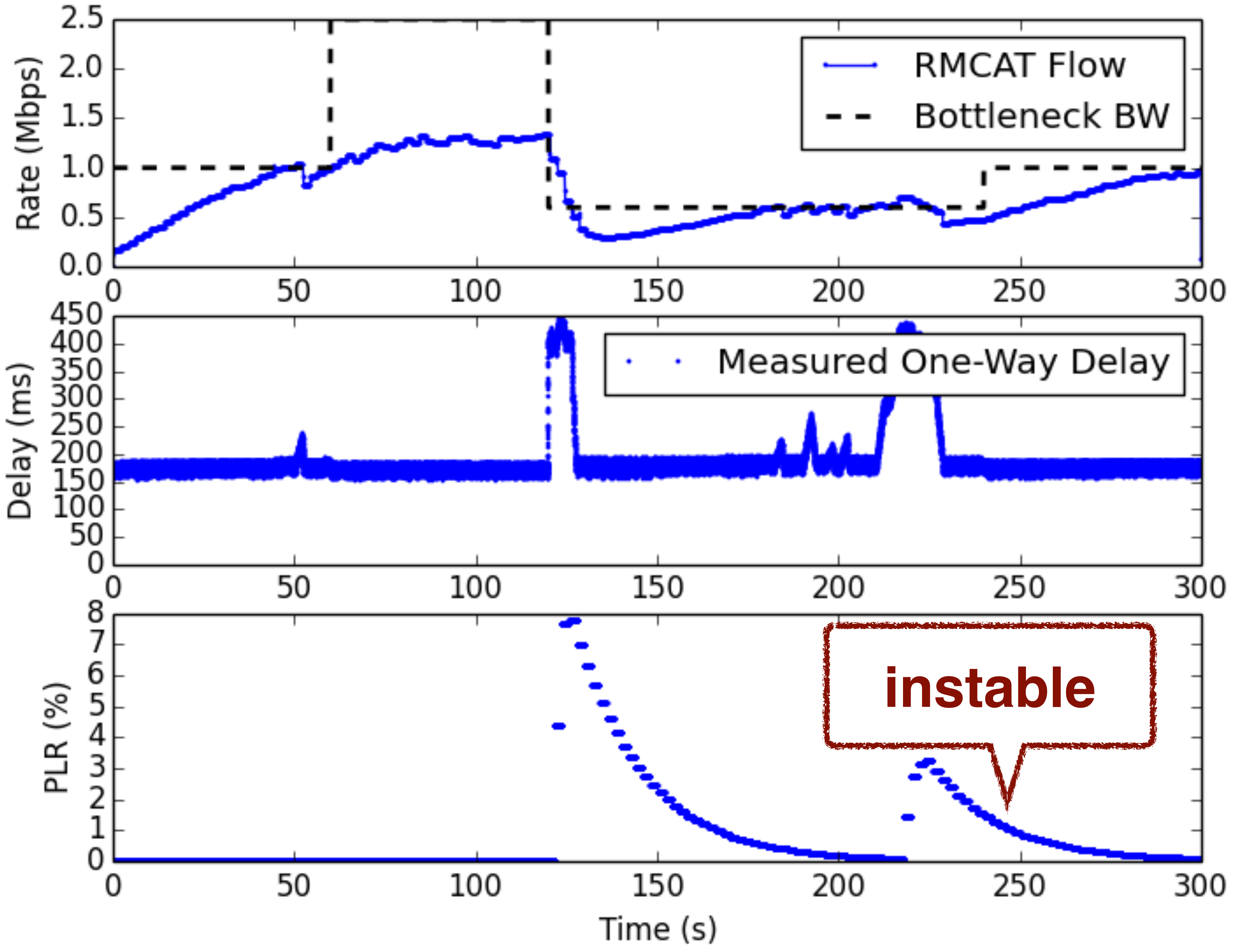


NS3: time-varying background UDP flow

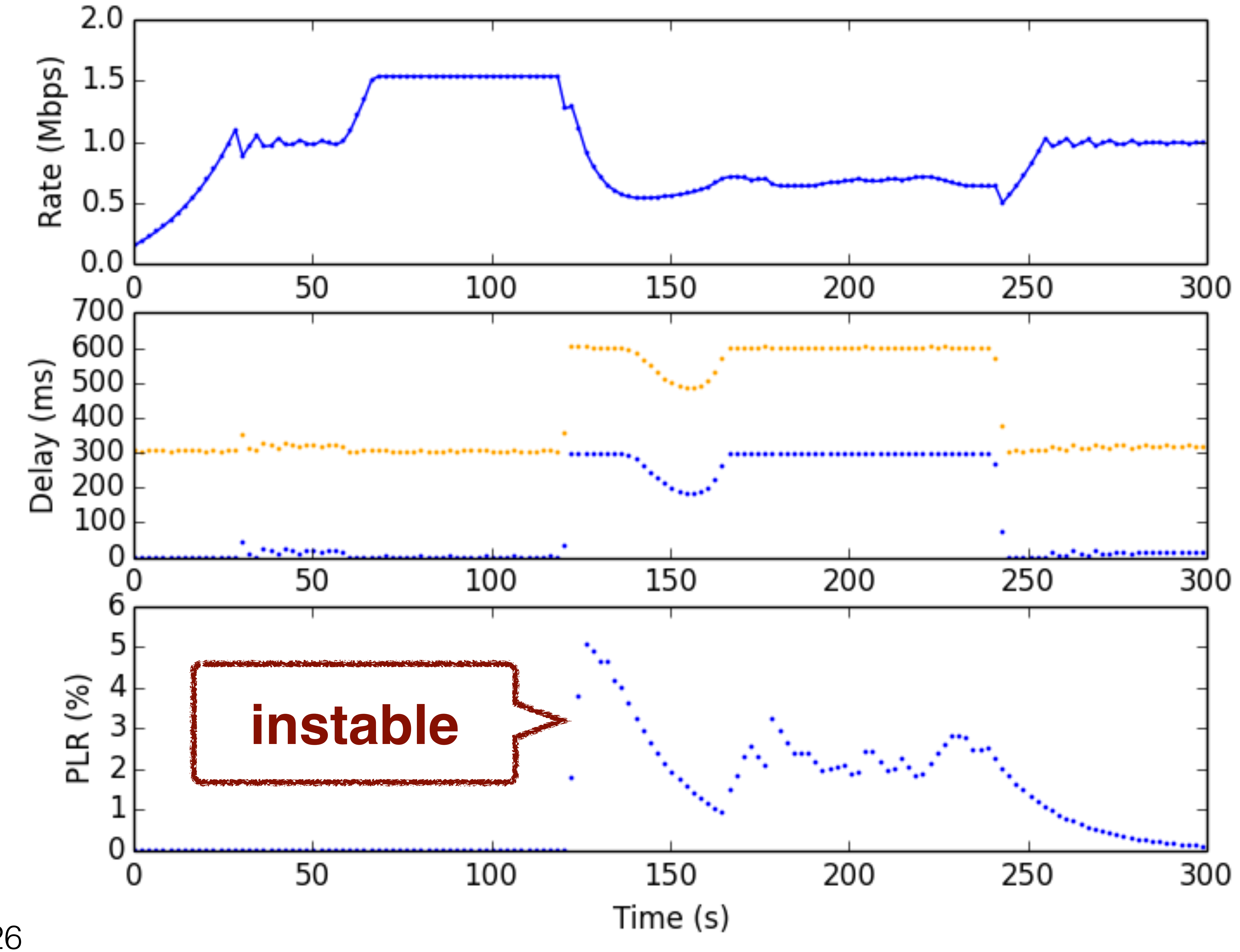


Propagation Delay @ 150ms, Feedback Interval = 2s

NS2: physical link rate change

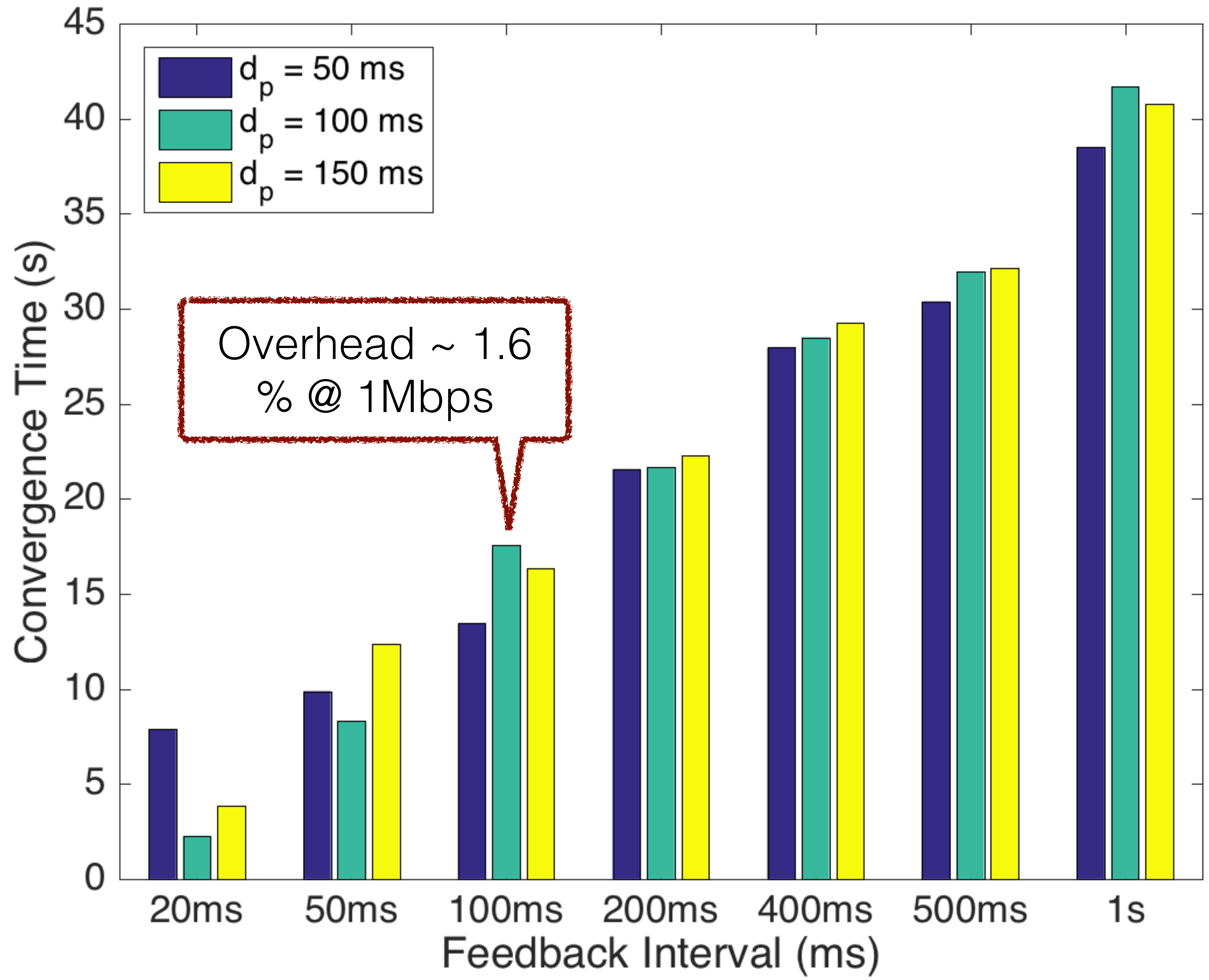


NS3: time-varying background UDP flow

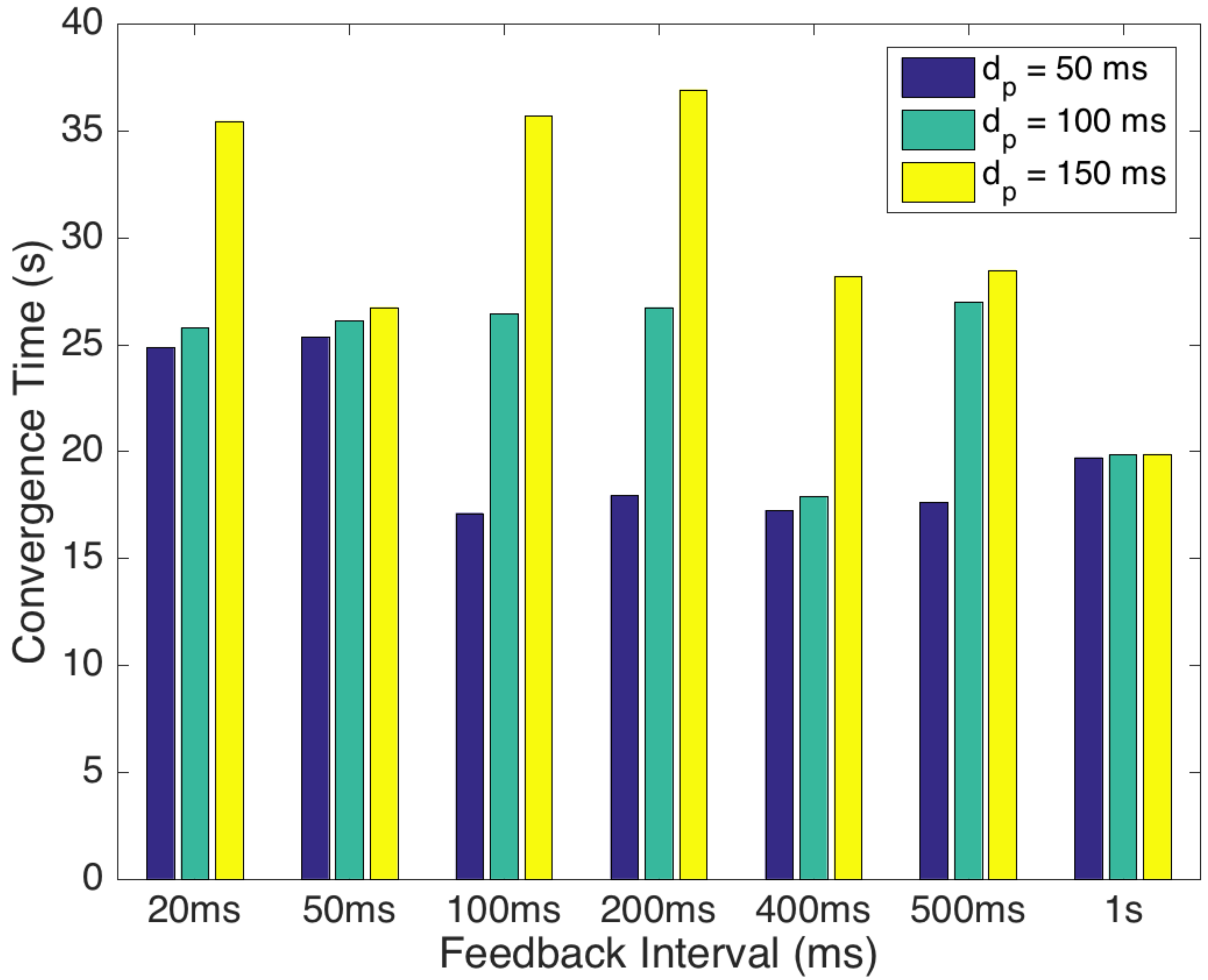


Convergence Time vs. Feedback Interval

NS2: Transition after t=120s



NS3: Transition after t=120s



Summary and Next Steps

- Guaranteed stability of NADA feedback control loop for RTT < 500ms
- Qualitatively matching results from numerical analysis and simulation results:
  - Remains stable for sub-second feedback intervals
  - System response slows down with increasing feedback intervals
  - Recommended feedback interval at 100ms — tradeoff between overhead and response speed
- Next steps:
  - Investigate different convergence behavior with different BW changing mechanisms;
  - Study system stability with varying parameter choice and network settings

Backup Slides

Derivation of Laplace Transfer Function for Gradual Rate Update

Consider small perturbation around equilibrium: $\delta x = x_i - x_o, \quad \delta r = r_i - r_o$

$$\delta \dot{r} = -\frac{\kappa}{\tau}[\frac{\delta x r_o}{\tau} + \frac{x_o \delta r}{\tau} + \eta \delta \dot{x} r_o] \quad \Rightarrow \quad \frac{\kappa x_o}{\tau^2}\delta r + \delta \dot{r} = -\frac{\kappa r_o}{\tau}[\frac{\delta x}{\tau} + \eta \tau \delta \dot{x}]$$

In Laplace domain:

$$\frac{\kappa x_o}{\tau^2}(R(s) + \frac{\tau^2}{\kappa x_o} s R(s)) = -\frac{\kappa r_o}{\tau^2}(X(s) + \eta \tau s X(s)) \quad \Rightarrow \quad \frac{R(s)}{X(s)} = -\frac{r_o}{x_o}\frac{1 + \eta \tau s}{1 + \frac{\tau}{\kappa x_o} s \tau}$$