

Enhanced Network-State Estimation Using Change Detection

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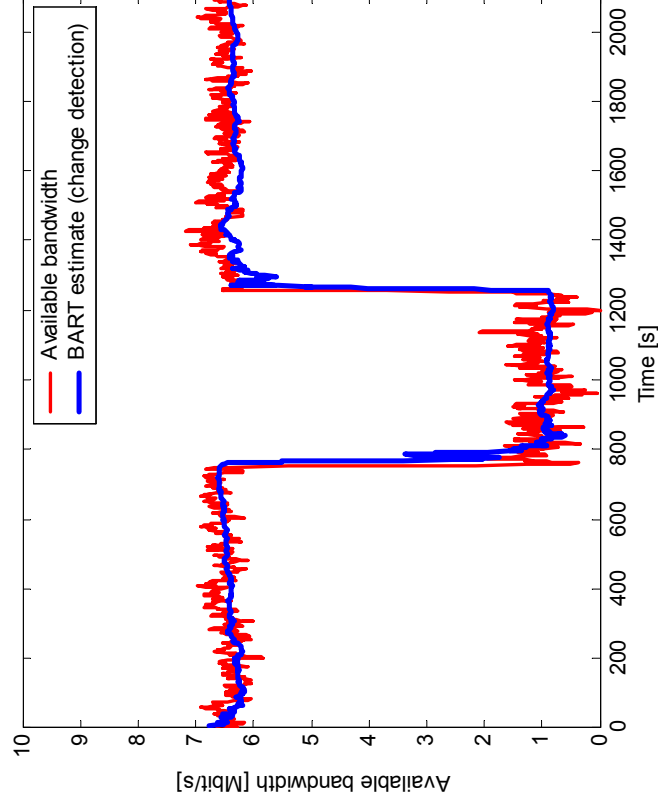
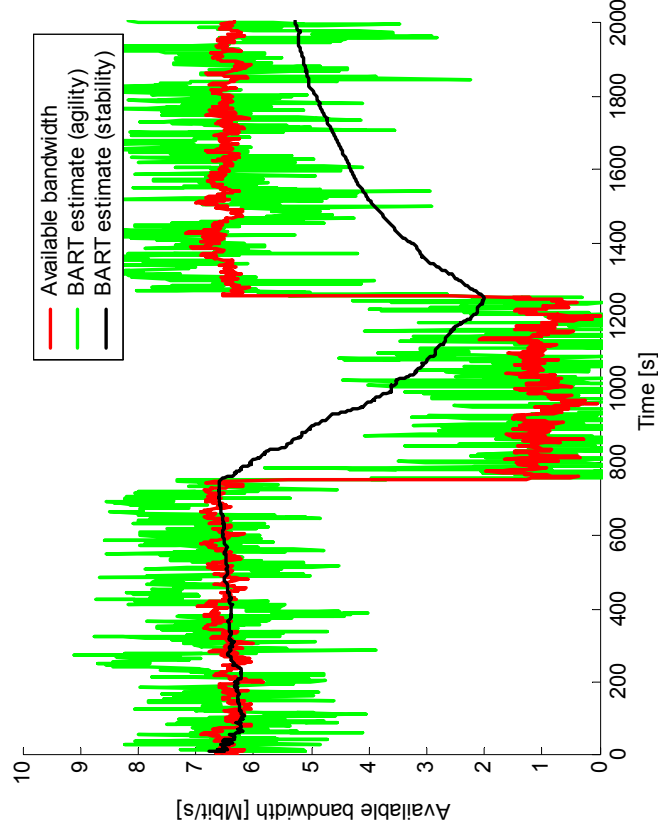


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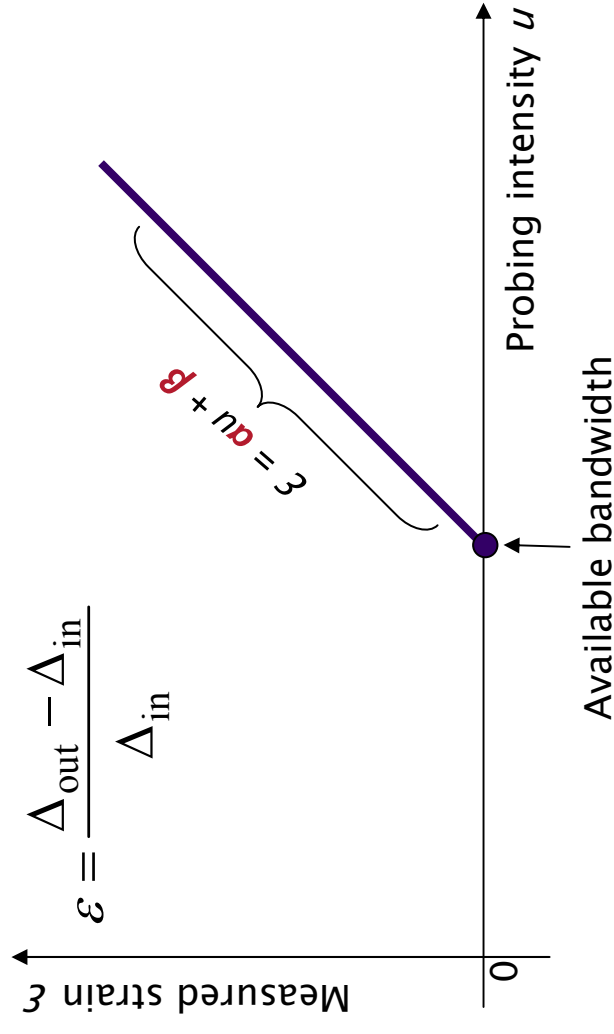
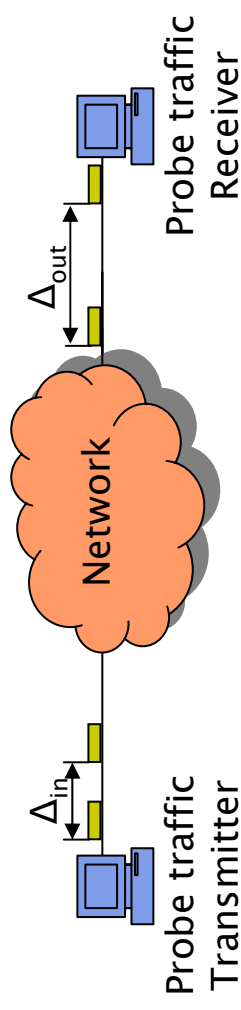
Outline

- BART – Bandwidth Available in Real-Time
- Kalman Filtering
- Change Detection

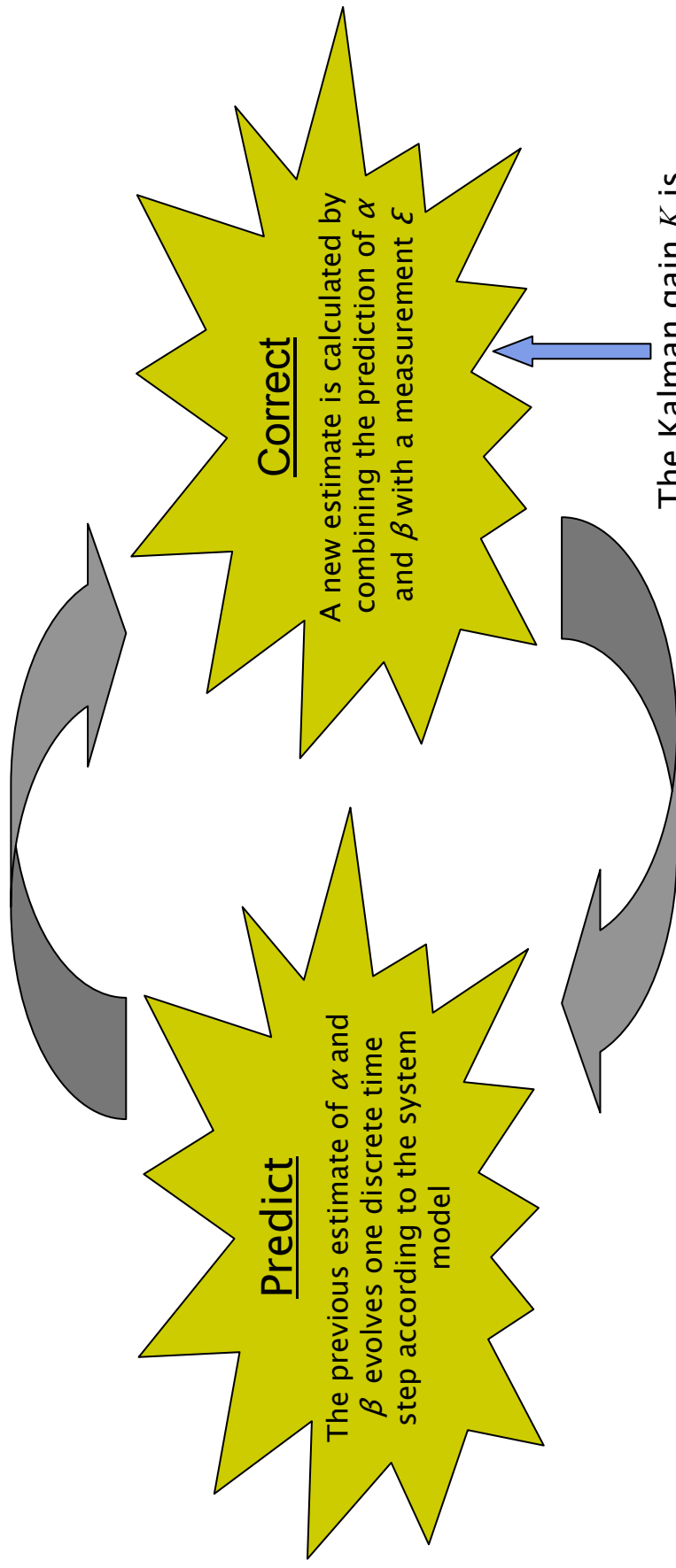


BART – Bandwidth Available in Real-Time

- Characteristics of BART
 - Active probing
 - Kalman filtering
 - Real-time estimation
 - Tuning possibilities



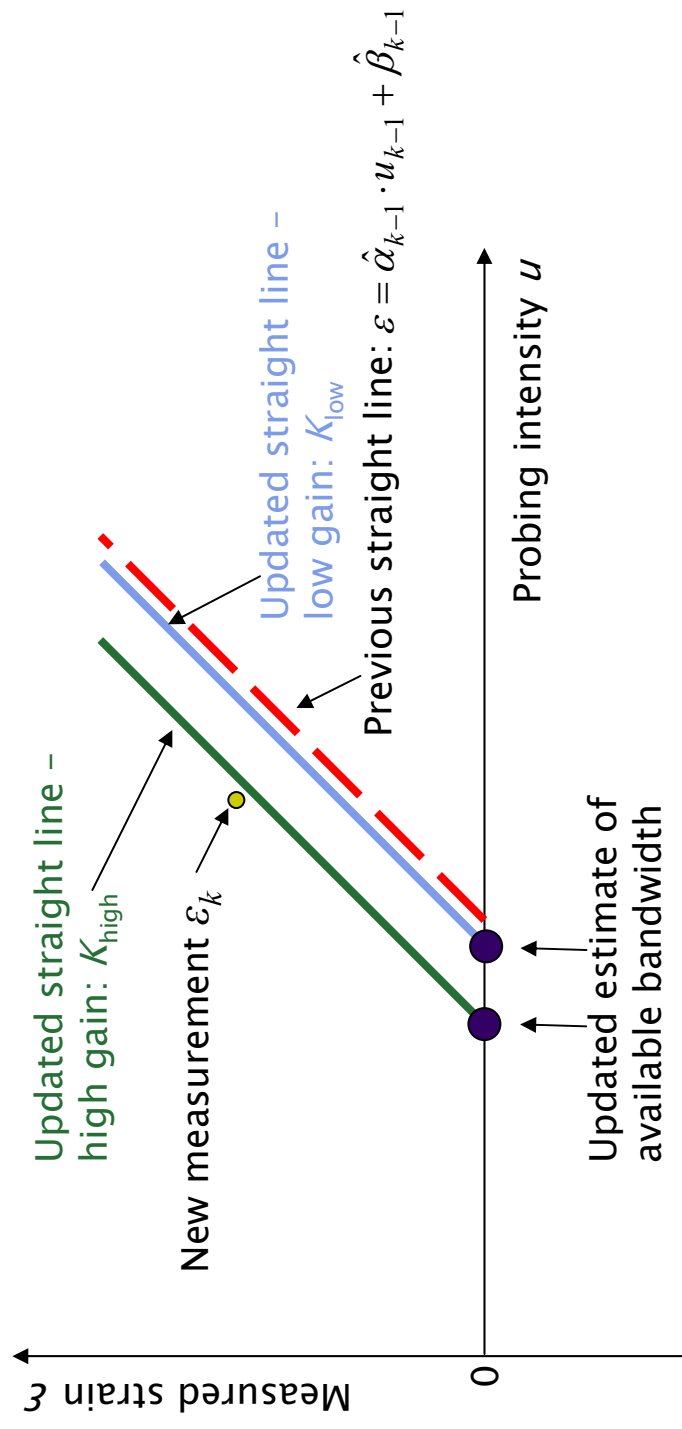
Kalman Filtering



$$\begin{bmatrix} \hat{\alpha}_k \\ \hat{\beta}_k \end{bmatrix} = \begin{bmatrix} \hat{\alpha}_{k-1} \\ \hat{\beta}_{k-1} \end{bmatrix} + K_k \gamma_k$$

Kalman Filtering

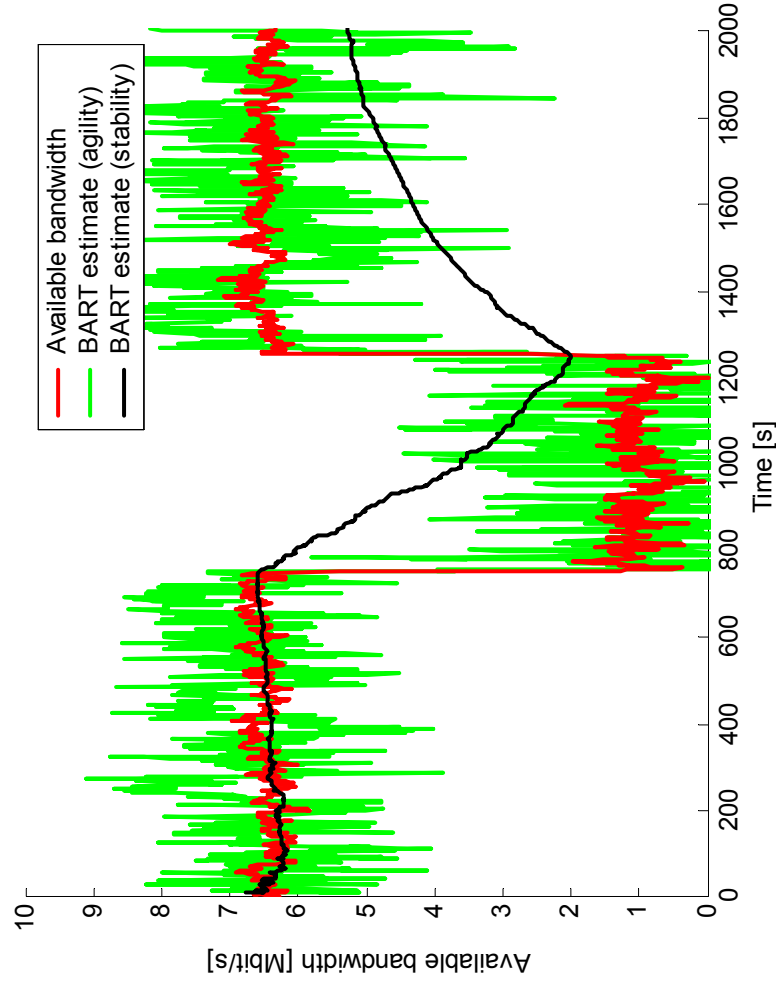
- The Kalman gain K is important since it describes the relative weight given to the new measurement



- The Kalman gain is affected by the precision of the system model prediction, and the precision of the measurement

Kalman Filtering

- The Kalman gain K affects the tracking ability of BART
- Stability is obtained if K is small
- Agility is obtained if K is large

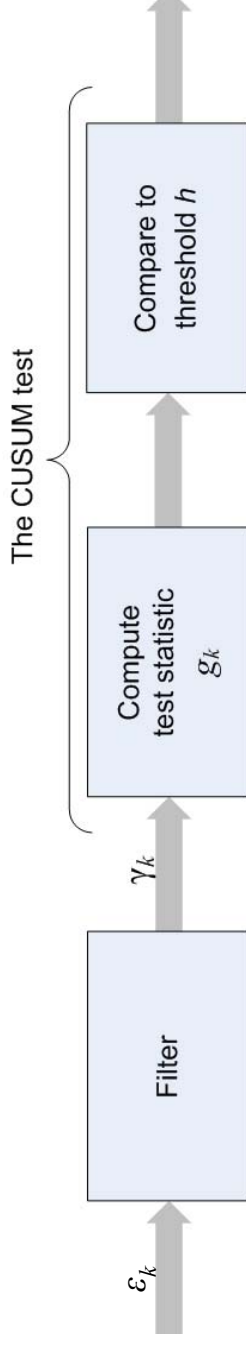


Change Detection

- Filter residuals are valuable in change detection:
 - A filter residual γ is defined as the difference between the measured quantity and the filter's prediction of this measurement
 - By investigating the characteristics of filter residuals, it is possible to get indications of whether the filter is "off track"
 - When there is no abrupt change in the system state, filter residuals can be interpreted as independent stochastic variables with zero mean
 - After an abrupt change, the distribution of the residuals changes
- In change detection, the challenge is to detect variations in the characteristics of the filter residuals

Change Detection

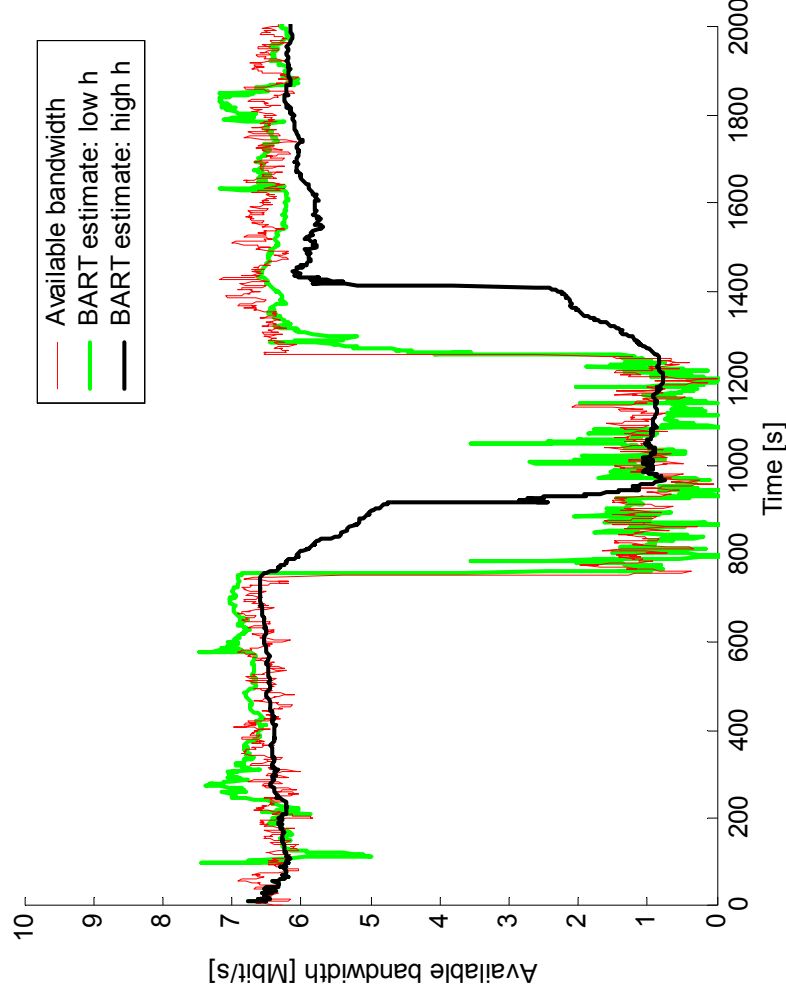
- The Cumulative Sum (CUSUM) change–detection test:
 - The filter residuals γ are used to build up the CUSUM test statistic:
 - Test statistic at time k : $g_k = \max(g_{k-1} + \gamma_k - \nu, 0)$
 - The drift parameter ν allows for a slowly varying system state
 - The test statistic is compared to a threshold h



- In BART, a suitable action is to momentarily increase the Kalman gain K (stability \rightarrow agility) if the test statistic g exceeds the threshold h

Change Detection

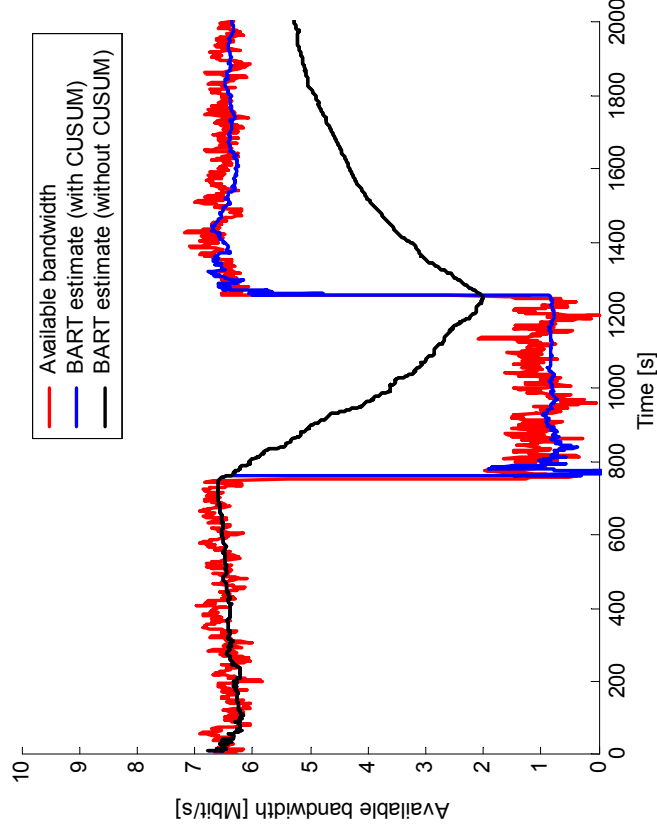
- The threshold value h affects the change-detection performance in terms of false alarm rate and time to detection



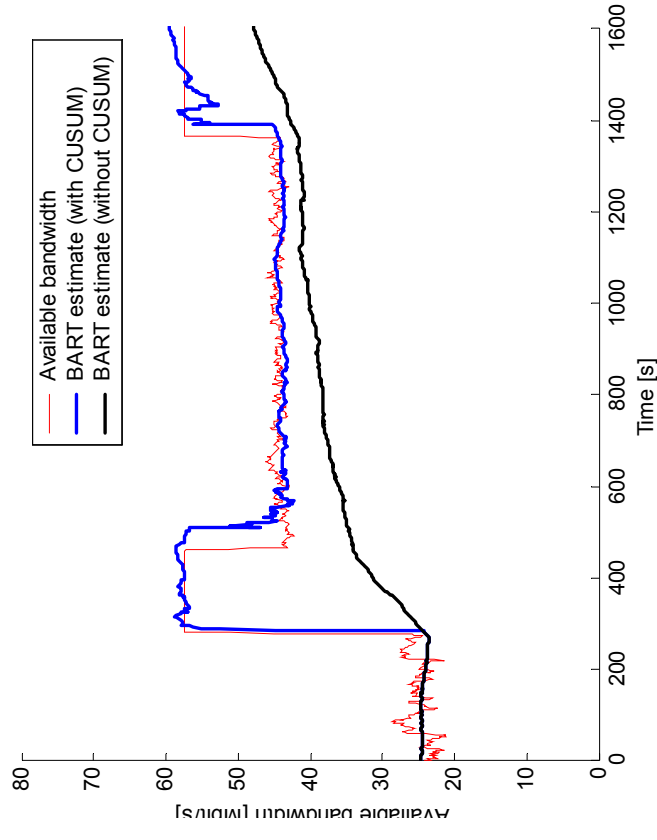
Change Detection

- Testbed and Internet experiments:

Testbed:



Internet:



Summary

- BART – Bandwidth Available in Real-Time
 - Active probing
 - Kalman filtering
 - Real-time estimation
- Kalman Filtering
 - A recursive data processing algorithm (prediction ↔ correction)
 - Estimates the state of a noisy system using noisy measurements
 - Configuration of tracking performance is achievable (stability ↔ agility)
- Change detection
 - Useful for filter-based estimation of systems with abrupt changes
 - Feasible to trade stability for agility “on the fly”
 - The CUSUM test: a light-weight change-detection technique