

# Tuning the Temporal Characteristics of a Kalman-Filter Method for End-to-End Bandwidth Estimation

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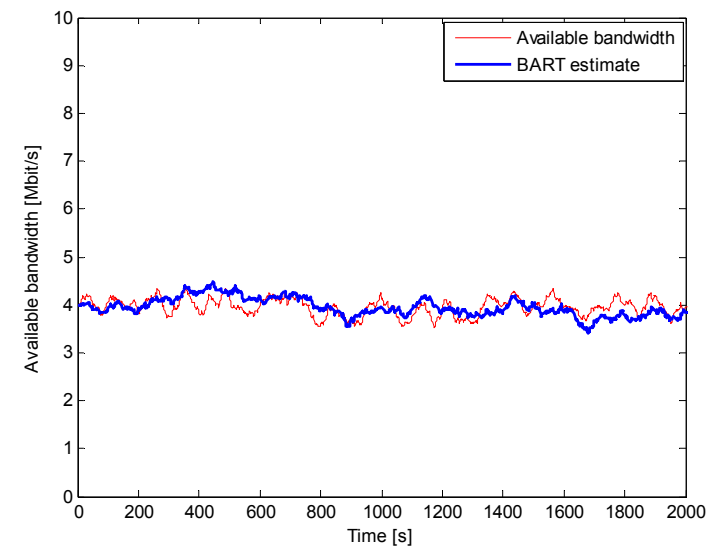
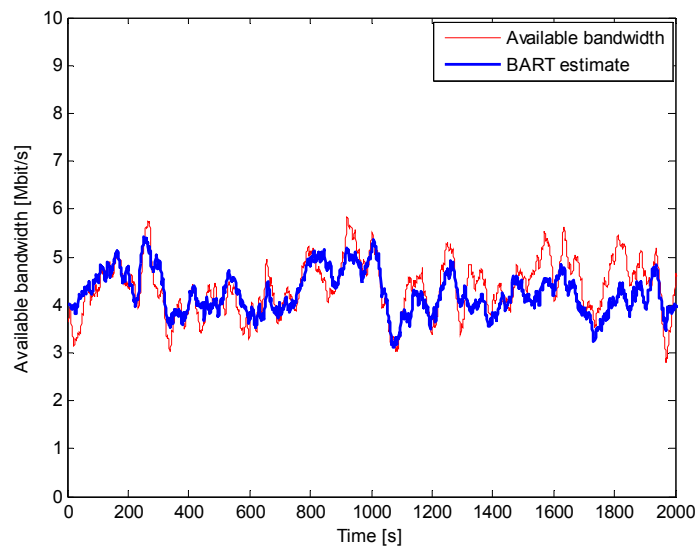


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# Outline

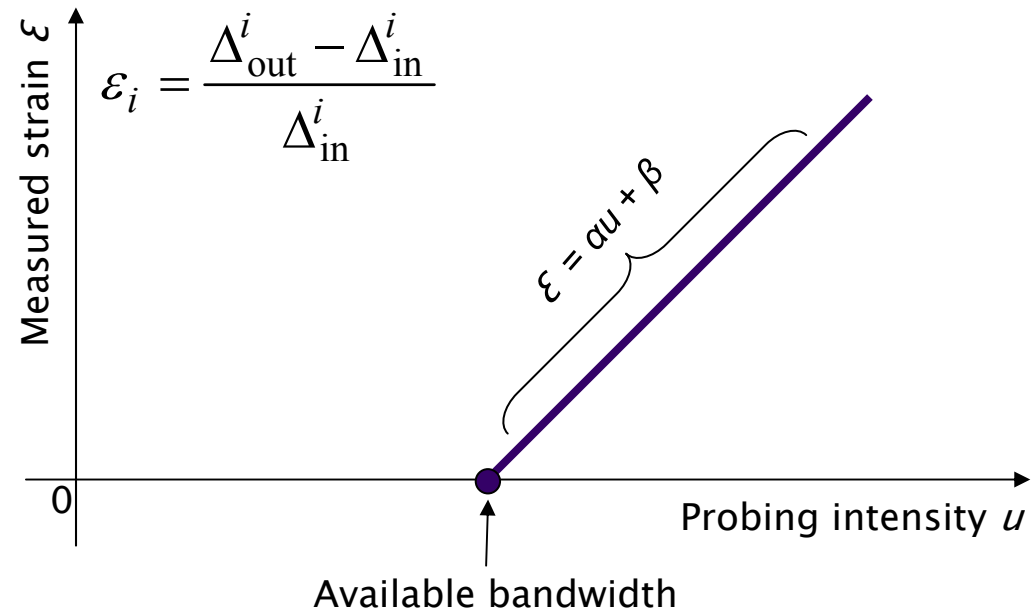
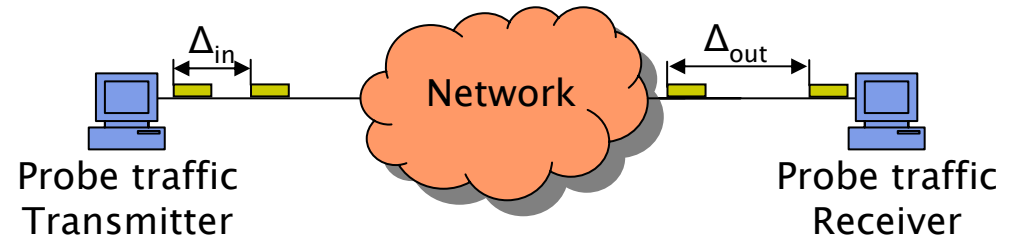
- BART – Bandwidth Available in Real-Time
- Tuning a Kalman-filter parameter
- Experiments



# BART – Bandwidth Available in Real-Time

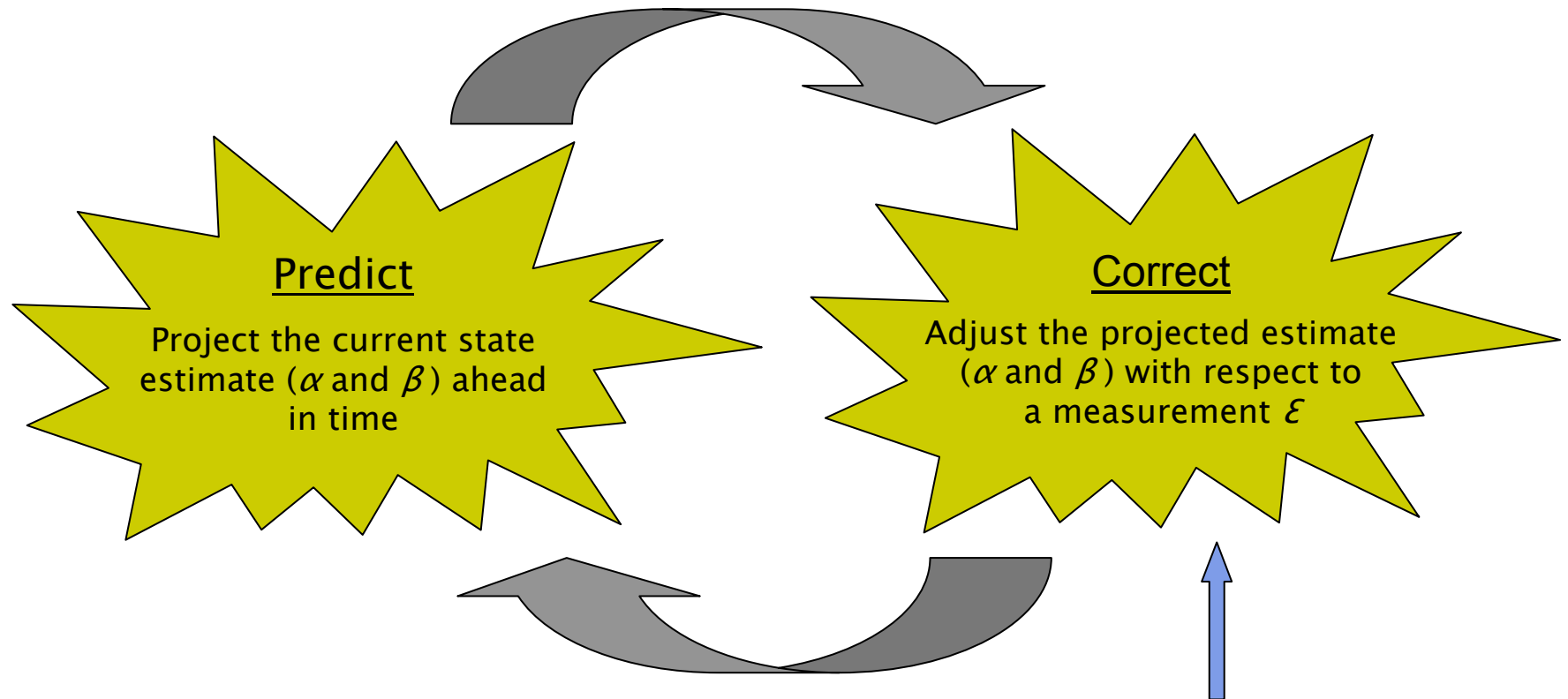
- Characteristics of BART

- Active probing
- Kalman filtering
- Real-time estimation
- Tuning possibilities



# Tuning a Kalman-Filter Parameter

- Kalman filtering – an overview



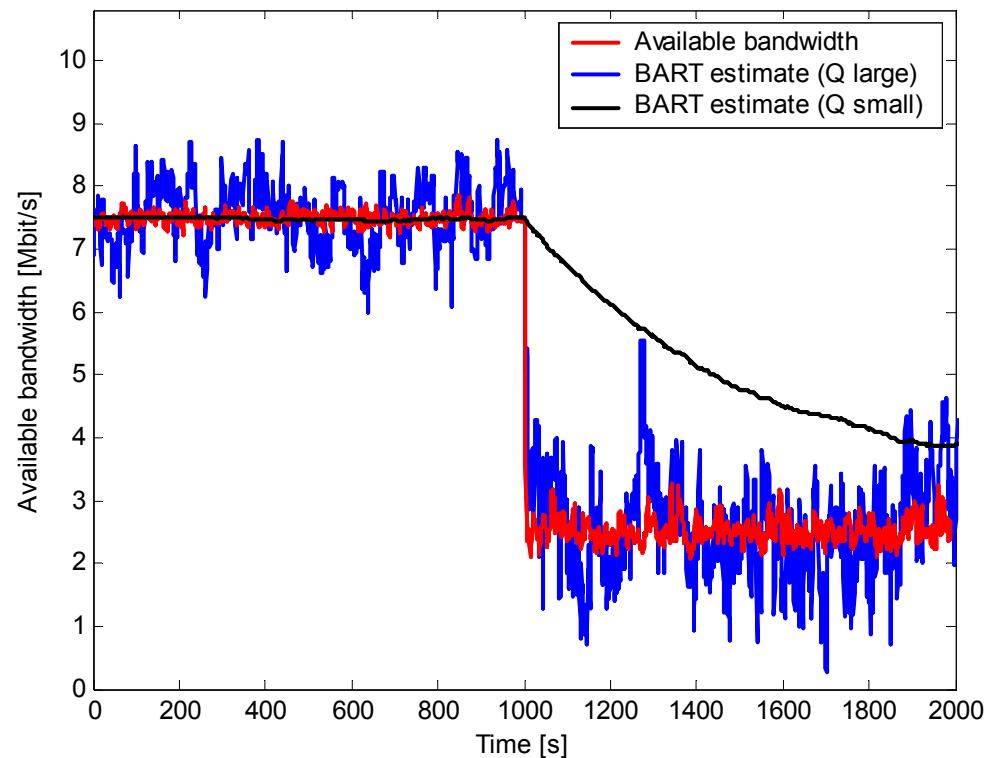
Of great importance:

The precision of the measurement ( $R$ )  
The expected variations in the system ( $Q$ )



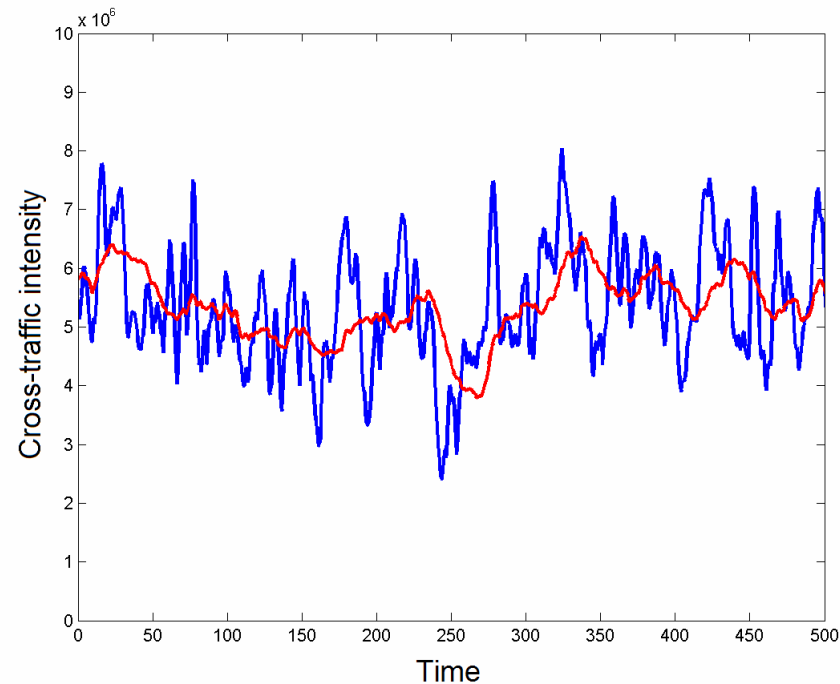
# Tuning a Kalman-Filter Parameter

- The values of  $Q$  affect the characteristics of BART
- Stability can be traded for agility
- Two extreme cases:



# Tuning a Kalman-Filter Parameter

- Stability vs. agility:
  - The choice depends on the variability of the true available bandwidth (i.e. the variability of the cross traffic)

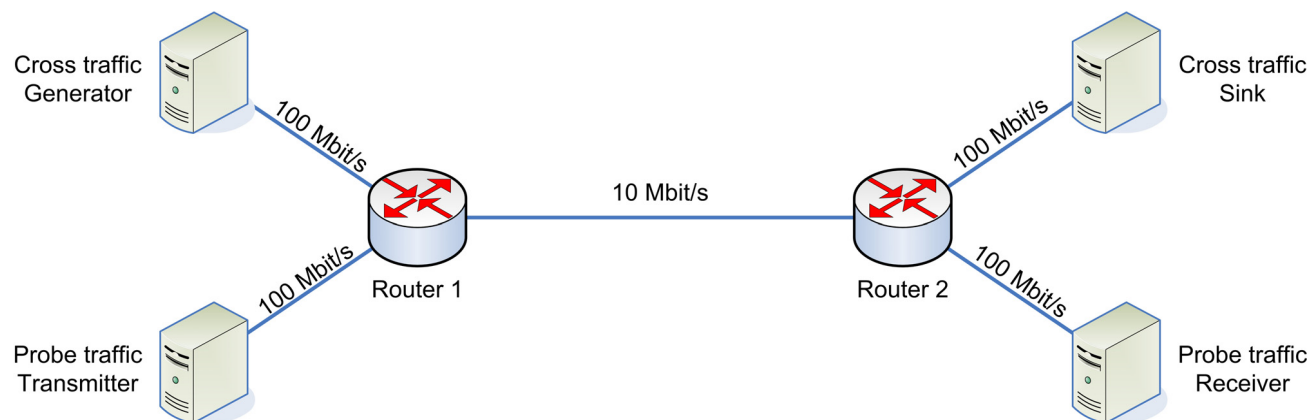


- Two factors affecting the available bandwidth variability:
  - The cross-traffic aggregation and the time resolution ( $\tau$ )



# Experiments

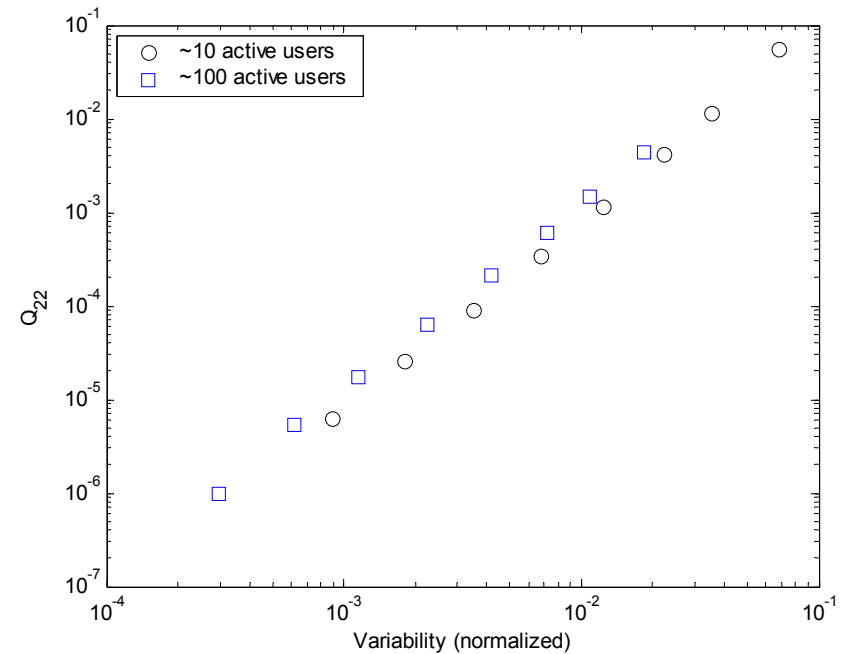
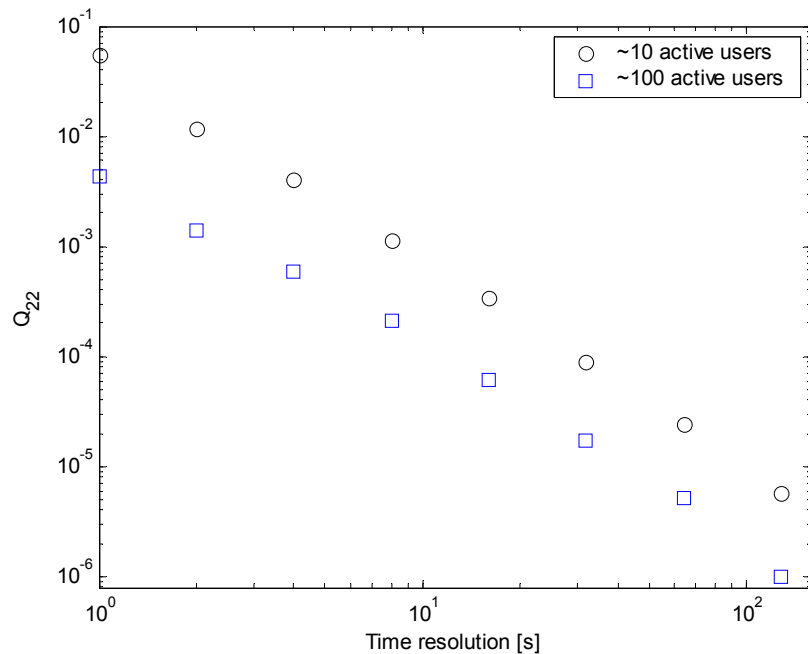
- Optimization of  $Q$  with respect to variability for different time resolution and cross-traffic aggregation



- True available bandwidth:
  - Averaging time scale  $\tau = 1, 2, 4, 8, 16, 32, 64, 128$  seconds
- Traffic cases:
  - Synthetic cross traffic: approximately 10 and 100 active users

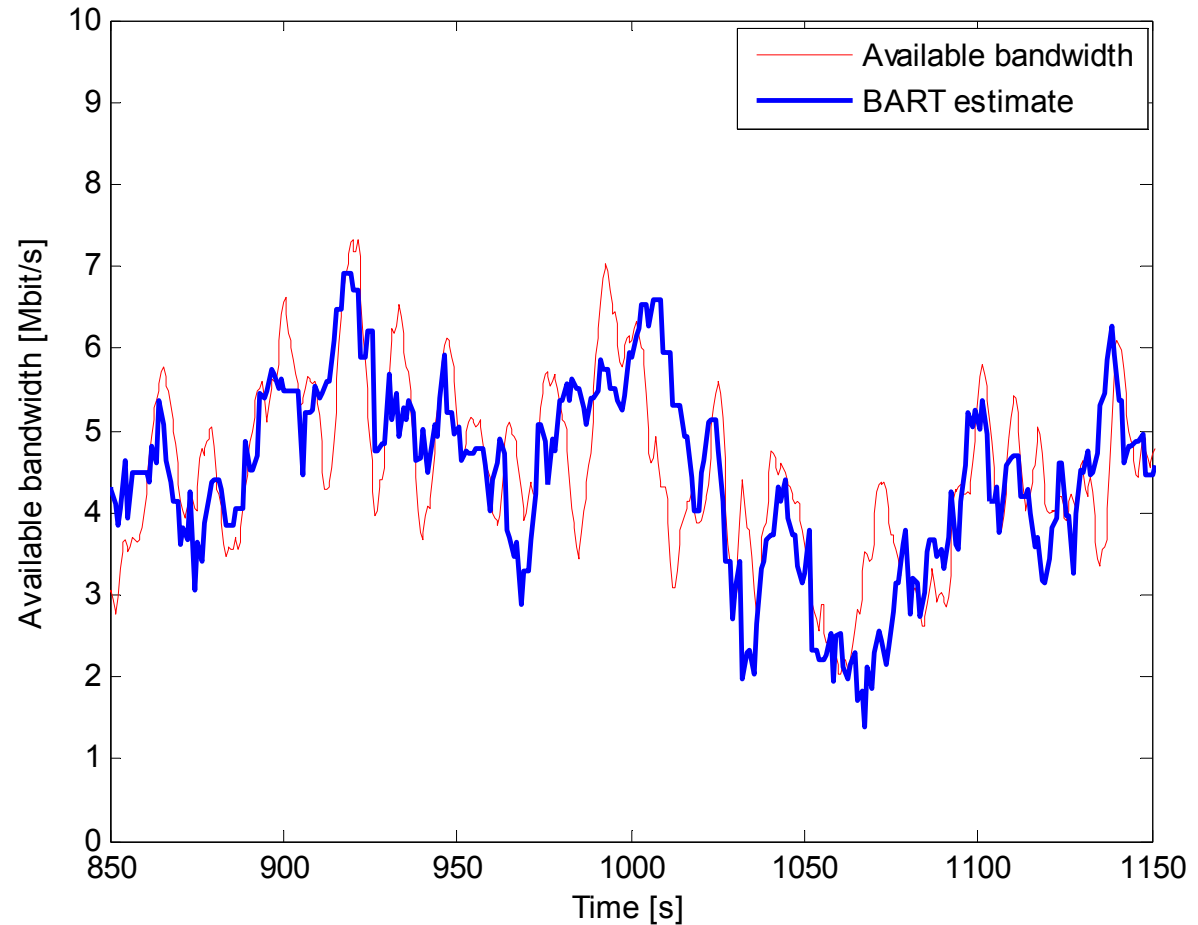
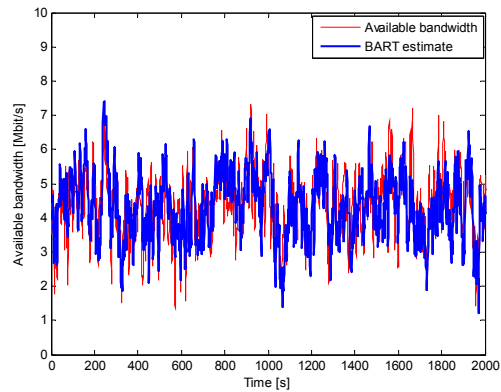
# Experiments

- $Q_{22}$  is the crucial element:  $Q = \begin{bmatrix} Q_{11} & Q_{12} \\ Q_{21} & Q_{22} \end{bmatrix} = \begin{bmatrix} V(\Delta\alpha) & C(\Delta\alpha, \Delta\beta) \\ C(\Delta\alpha, \Delta\beta) & V(\Delta\beta) \end{bmatrix}$ 
  - Optimal  $Q_{22}$  vs. time resolution (left figure)
  - Optimal  $Q_{22}$  vs. cross-traffic variability (right figure)



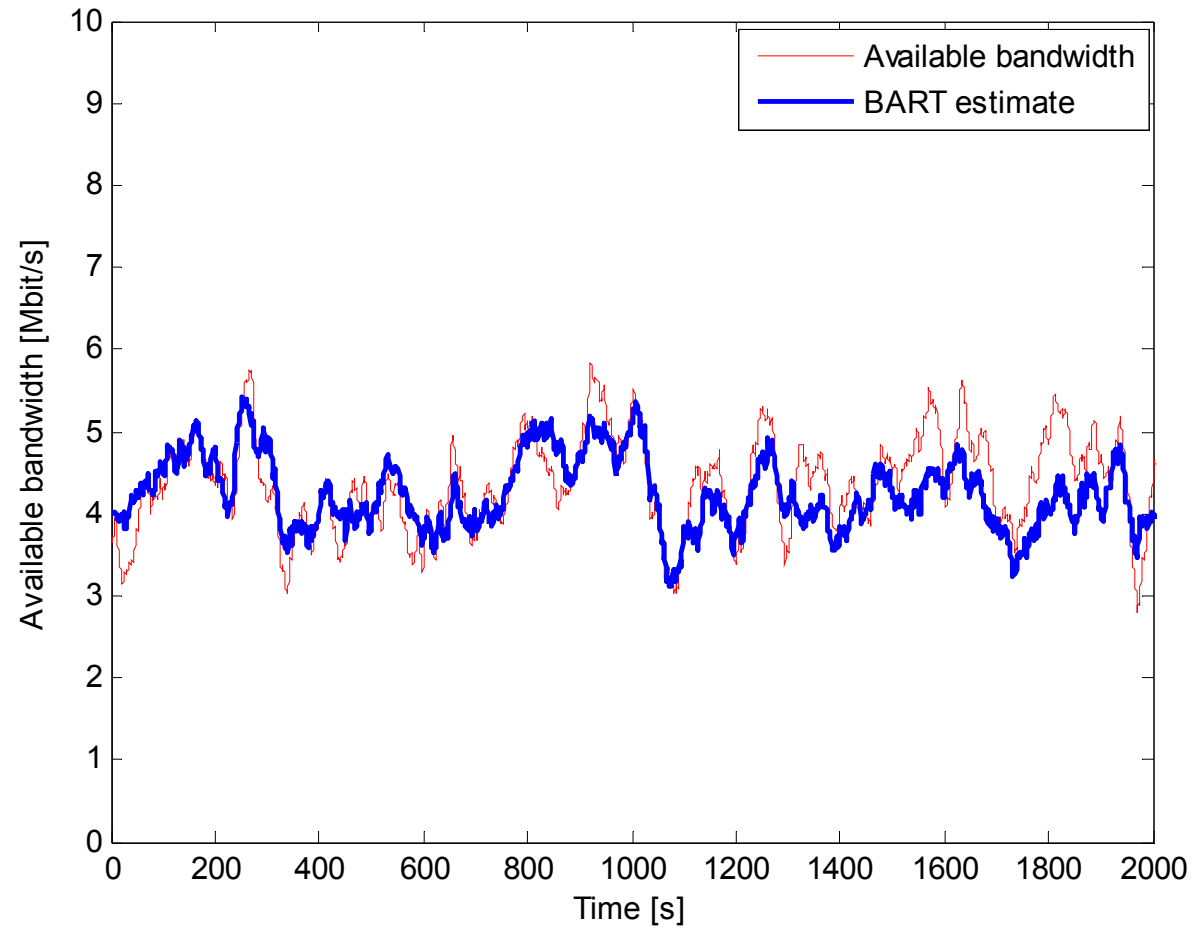
# Experiments

- BART estimation: Approx. 10 active users –  $\tau = 4$  seconds



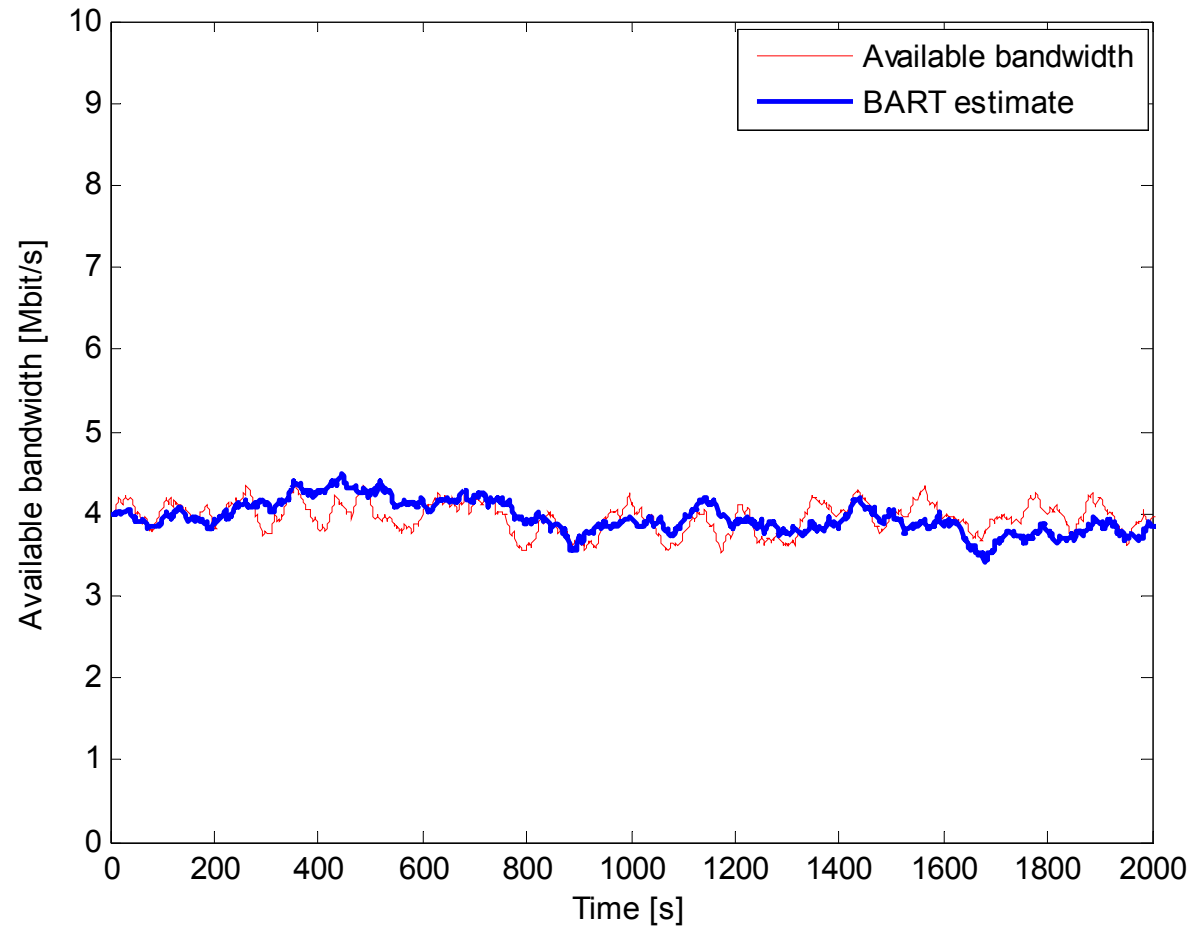
# Experiments

- BART estimation: Approx. 10 active users –  $\tau = 32$  seconds



# Experiments

- BART estimation: Approx. 100 active users –  $\tau = 32$  seconds



# Summary

- BART – Bandwidth Available in Real-Time
  - Active probing
  - Kalman filtering
- Tuning a Kalman-filter parameter
  - The process noise covariance  $Q$
  - Stability vs. agility
- Experiments
  - Tuning  $Q$  for optimizing the tracking for desired temporal characteristics
  - Focus on variability –  $Q_{22}$  is the crucial element
- A more thorough presentation of BART:
  - Tuesday: NOMS – Technical Session 3: Measurements and QoS  
“Real-Time Measurement of End-to-End Available Bandwidth using Kalman Filtering”

