Software Systems Research – Portfolio Review

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Outline of the Talk – Revisited

- **Background [10%]**
- **Computer-Supported Collaboration [25%]**
- **Dynamically Customized Web Touring [25%]**
- **Multimedia Computing Networking [35%]**
  - **Building Robust Network Performance Indicator**
  - Distributed Resource Management for Multimedia
- **Wrap-Up [5%]**

Network Superheterodyne

"Building Robust Network Performance Indicators"

Work at IBM Thomas J. Watson Research Center

"Applying Statistical Process Control to the Adaptive Rate Control Problem", by Manohar, Nelson R.; Willebeek-Lemair, Marc H.; Prakash, Atul, in Proceedings of Multimedia Computing and Networking Conference, pp. 45-60, San Jose, CA, January 1998.

Motivation

- **Multimedia Computing Networking**
  - **handling the impact of multimedia over the network**
    - e.g., session-oriented, multimedia flows, end-to-end QoS reqs., resource management, value-asset model, etc.
  - **handling of the "impedance mismatch" that exists**
    - between multimedia applications
    - and (to-be provisioning, present or future) networks
  - **we would like the resulting mechanisms or building blocks**
    - to be robust
    - easy to implement
    - low (signaling and tracking) overheads

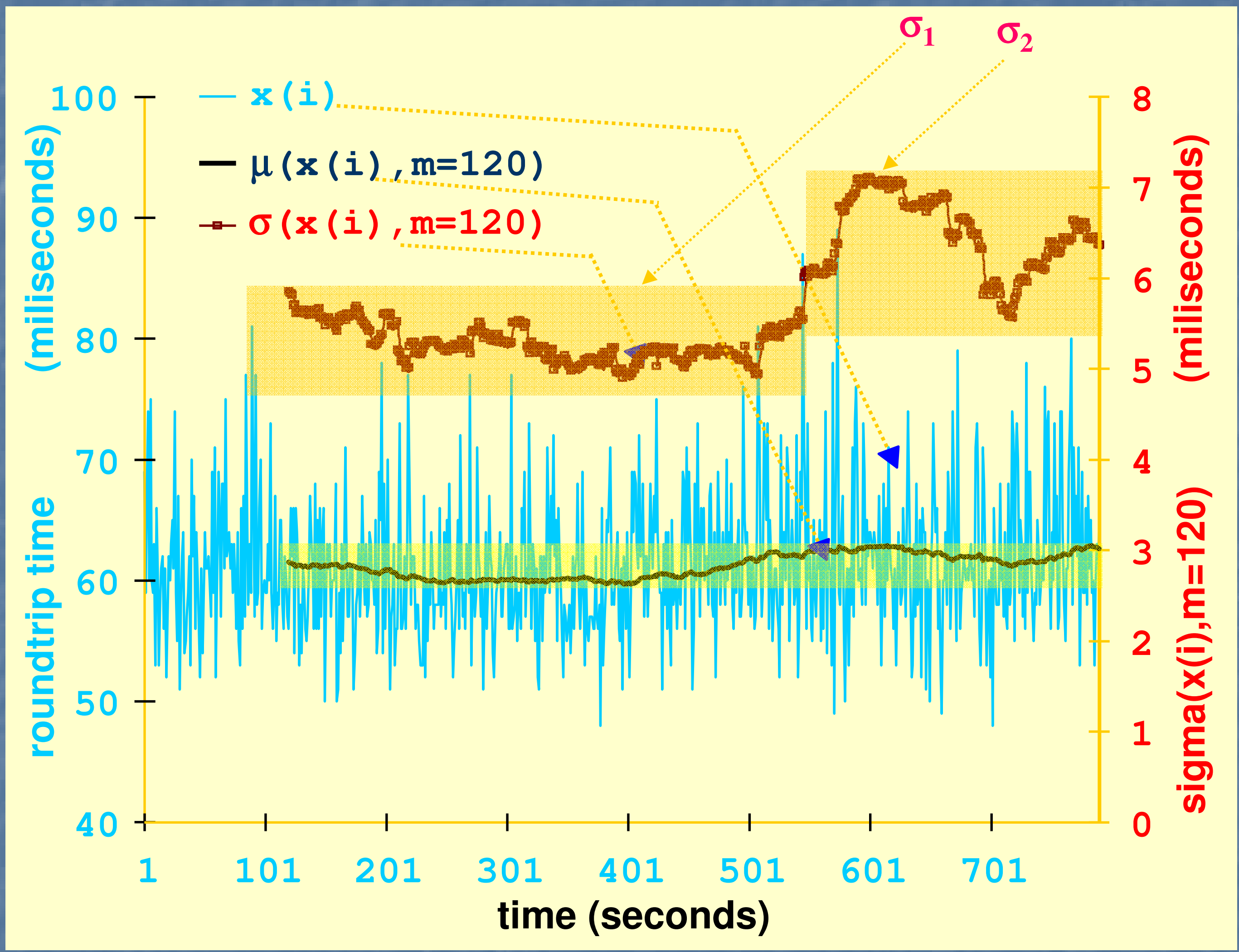
Related Work

- **mechanisms to handle "impedance mismatch"**
  - **(traditionally) from applications to the network:**
    - inducing multimedia application reqs. into networking middleware
      - for example, diffserv (TCP), multicast (routing), etc.
  - **(but also) from network to multimedia infrastructure:**
    - enhancing network capacity (internet2, vBNS, etc.)
    - **enhancing the intelligence of multimedia infrastructure to adapt to the network state (RSVP, QoS, etc.)**
- **network state measurements**
  - **(active) network probing**
    - probe-and-adapt: short-term fluctuations, unnecessary adjustments
  - **(passive) network and web traffic characterization**
    - (web) spatial/temporal stability: different time-scale components
    - ethernet/web traffic fractal: similar shape regardless of timescale

Network Performance Envelope:

Factoring Process Variability on Sessions

- From:
  - probe-and-adapt
    - fast indicators
    - very low setup cost
  - no confidence
- To:
  - process state
    - forecast-strength
    - some setup cost
  - confidence analysis

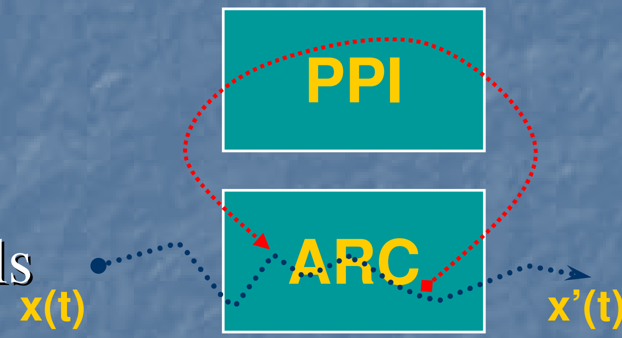


RTT network probe: one apparently stable process mean, but upon examination variability states (i.e., a process shifts).

Building Reliable Building Block:

Network Performance Indicator

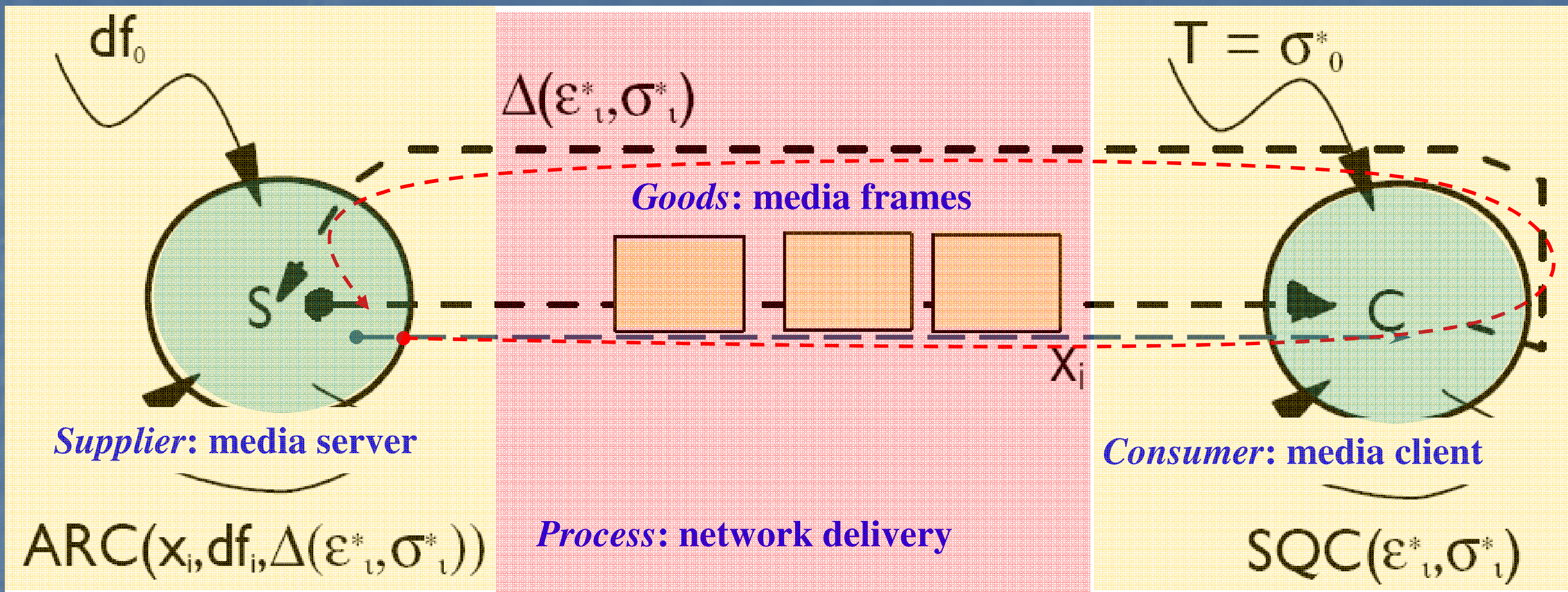
- **Reliable process performance indicators (PPI)?**
  - **robust forecasts**
    - strength of sampling and smoothing
    - capable of associating confidence to forecasts
  - **assimilation of process variability**
    - to recognize significant changes
  - **generation/tracking of process state**
    - to understand where we stand
- **Important to adaptive applications**
  - atop (i.e., guiding) prove-and-adapt protocols
  - such as Adaptive Rate Control (ARC)



- **Statistical Process Control (SPC) as PPI-kernel**
  - typically long-term horizon, industrial processes
    - run-to-run feedback control vs. online-SPC
    - centralized online-SPC vs. <u>distributed</u> online-SPC
  - adapt online-SPC for <u>distributed</u> ARC problem

Network Performance Envelope:

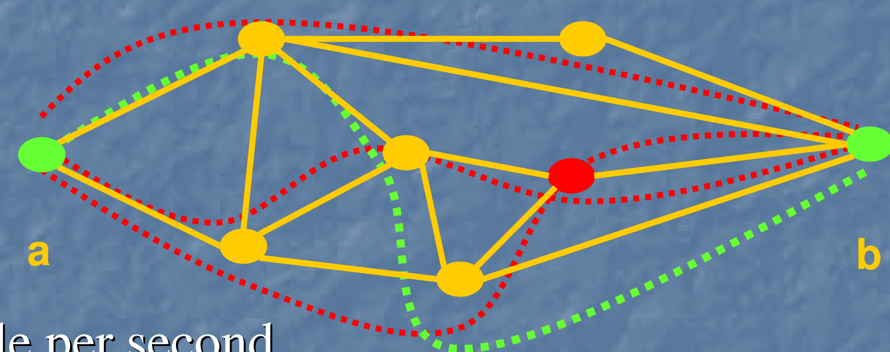
Statistical Process Control Formulation



- **Supplier: adaptive rate control**
  - to match production to delivery
- **Process: network delivery**
  - *goods*: media packets, frames, buffers
- **Consumer: smoothing problem**
  - adapts delivery to presentation
- **SPC: end-to-end process performance**
  - quantizes performance measurements
  - into statistical process state – a quality indicator
  - then drives ARC() w such quality indicato

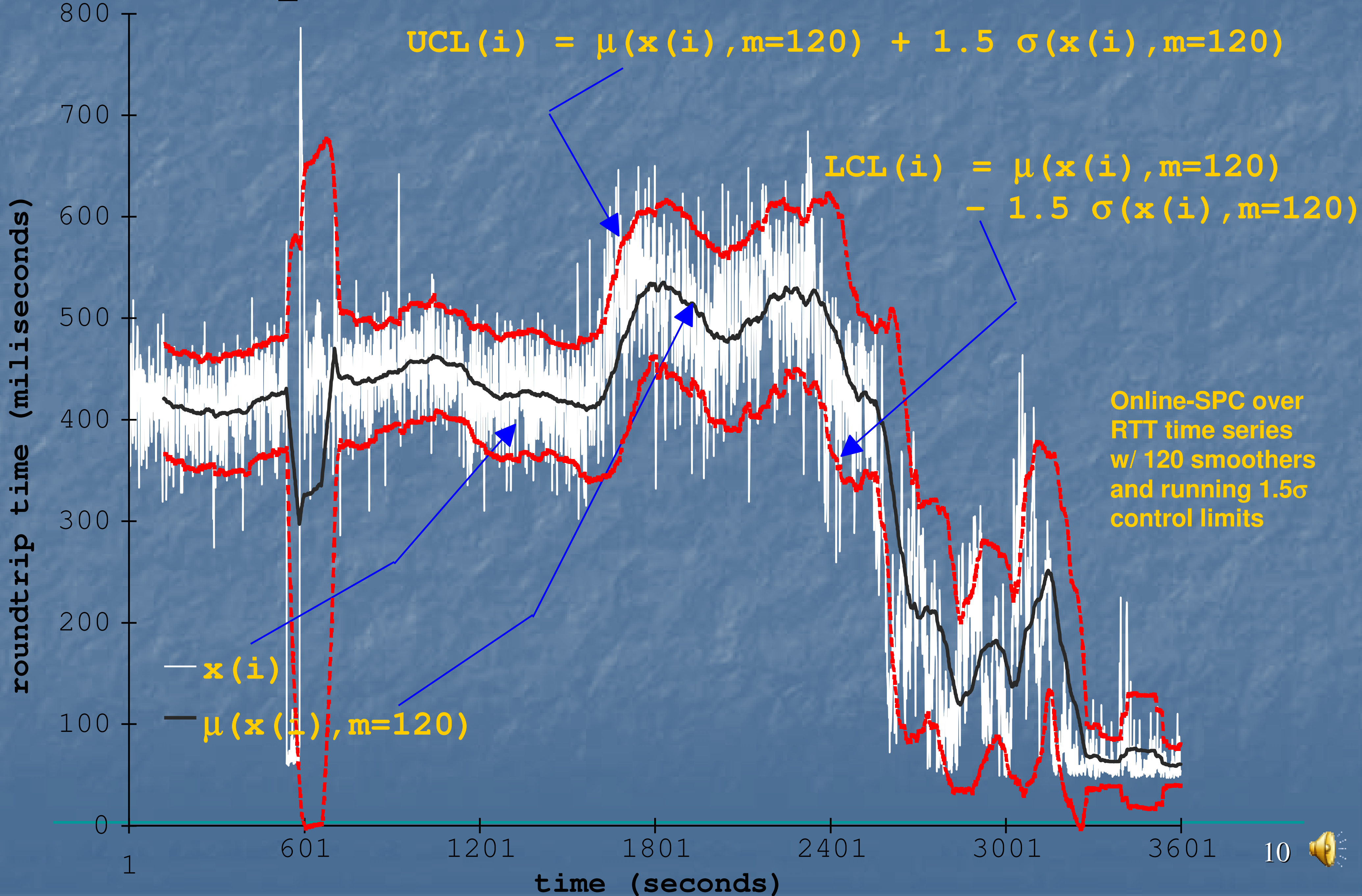
Network Measurements – Setup

- **(active) network probing and monitoring**
  - **network indicator**: RTT roundtrip delay (measure of congestion along path)
  - e.g., available bandwidth, **network congestion, stability, jitter**
- **probing methodology (time series acquisition)**
  - **end nodes**: (Univ. Michigan at A2) - (Univ. North Carolina – CH)
  - **network probe**: ping (ICMP)
  - **test duration**: 3600 seconds
  - **timescale**: seconds to minutes
  - **smoother**: 120/30 UWMA smoother
  - **sampling frequency**: 1 random sample per second
  - **sampling load**: negligible (40ms to 400ms) with respect to sampling frequency (1 second) with respect to available network bandwidth
  - **sampled distribution**: no constraining assumption due to law of large numbers, random sampling, temporal/spatial stability, and network fractality



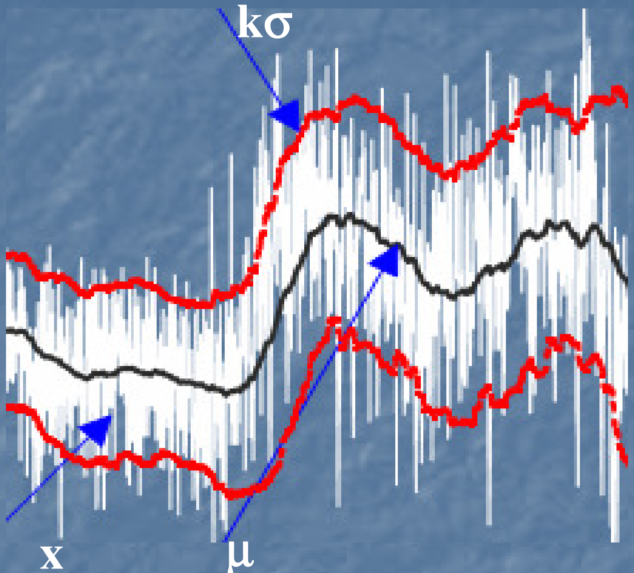
- **bottleneck spots, router instability, underlying distr.**
  - timescale leads to aggregation effect on multiple path routing and corresponding random sampling of underlying distribution(s) across *i-th* samples

Online-SPC Floating Performance Envelope

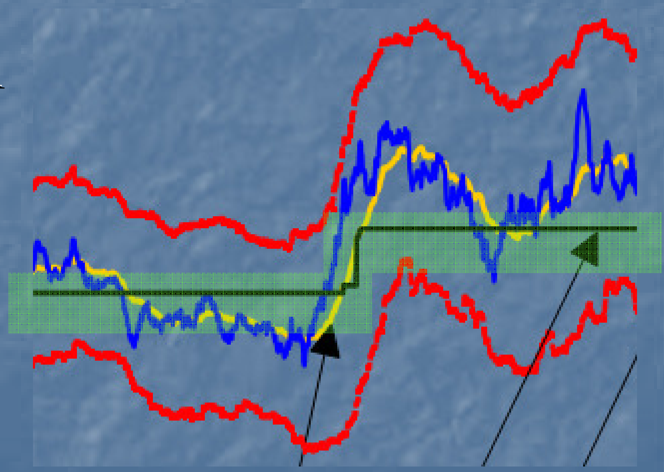


Process State – Basic Idea

- **floating performance envelope**
  - tracking window over process state (μ, σ)
  - under associated statistical confidence region (kσ)
  - reacts to statistically significant changes
- **process stability indicator**
  - quantizes performance into statistical process state
- **providing context for state changes**
  - between fast (fractional process state) signal
  - *wrt* slow (full process state) signal
- **compare fast against stable signal**
  - approx. same versus significantly different
  - two types of **piece-wise linear** segments
    - **horizontal** segments (process state)
    - linear **slopes** (process changes)
  - building block for adaptive infrastructures



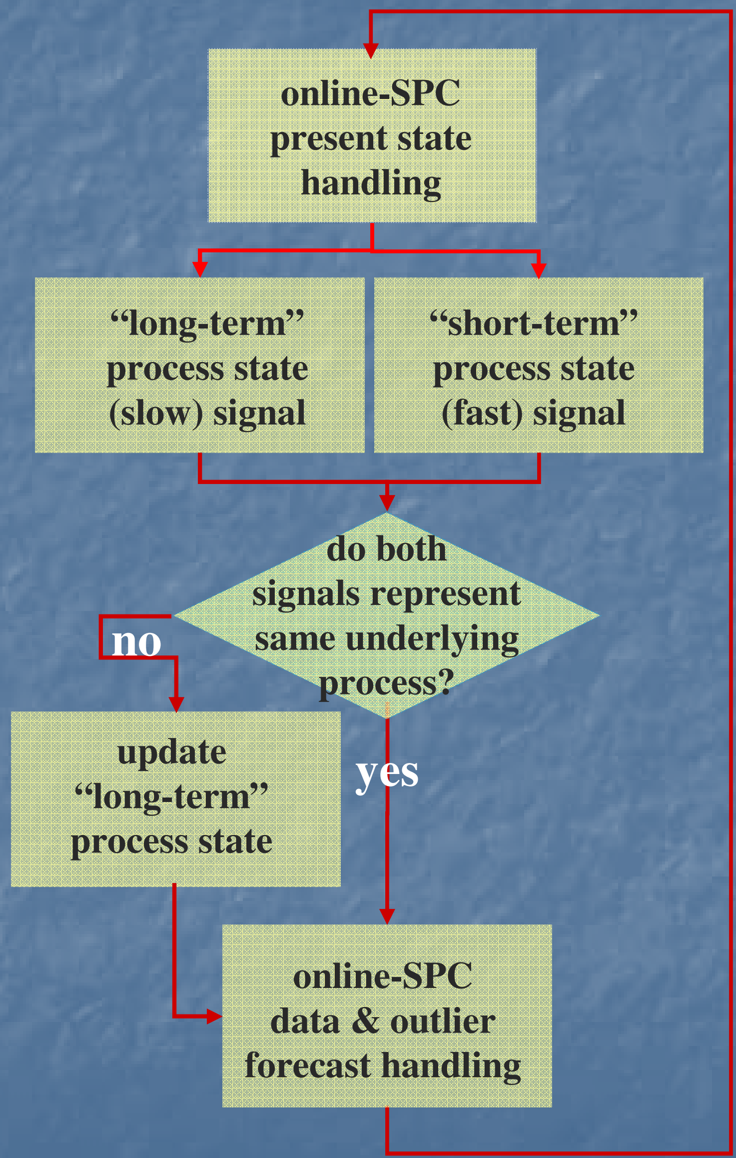
that is, just with online-SPC, but now three signals!



Network Performance Envelope:

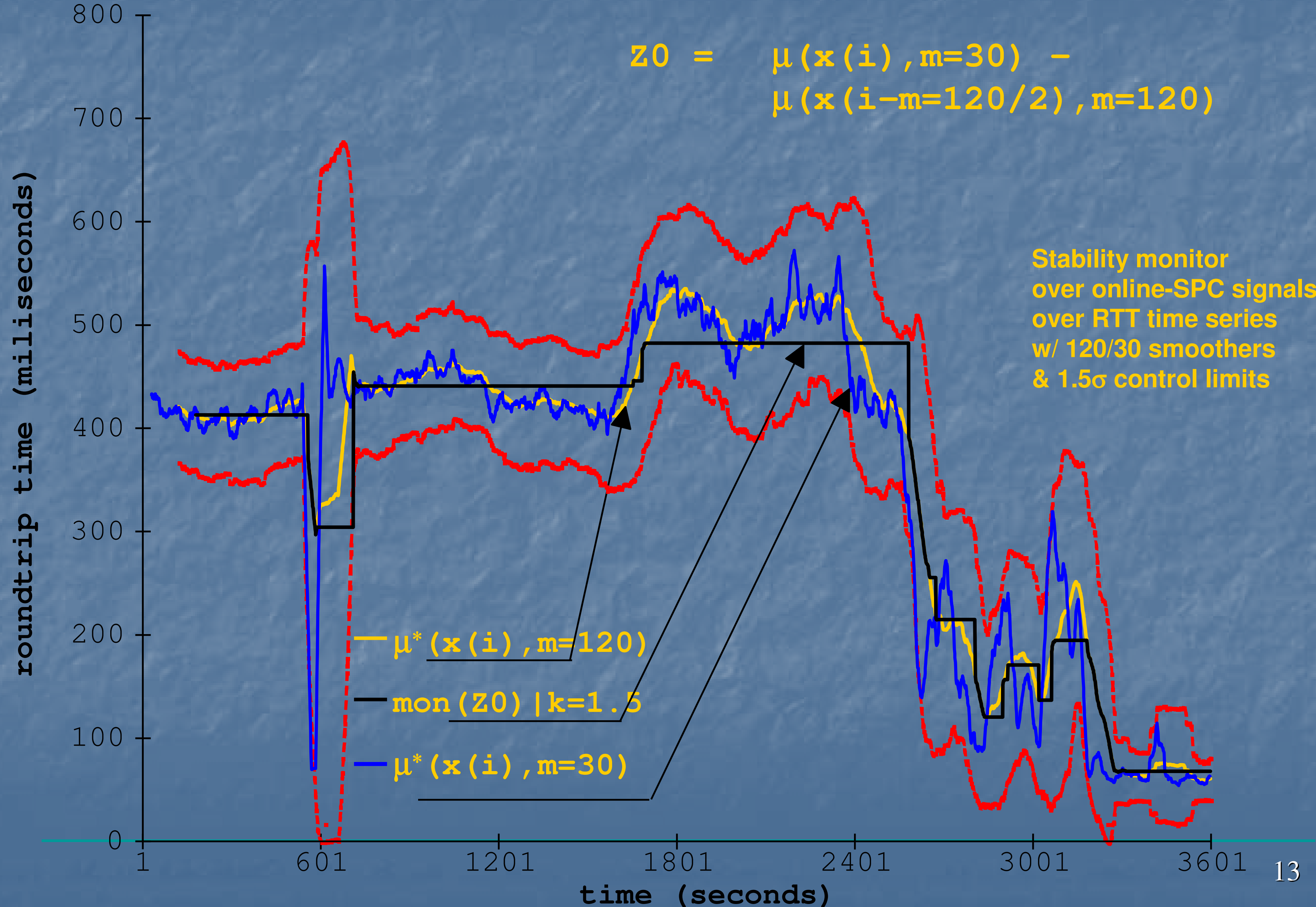
Online-SPC Process State Tracking Kernel

- **Running Window Indicators**
  - UWMA(x_i,m) smoothers
  - $\mu(i,m') = \mu(x_i \,..\, x_{m'-i})$
  - $\mu(i,m) = \mu(x_i \,..\, x_{m-i})$
  - $\sigma(i,m) = \sigma(x_i \,..\, x_{m-i})$
- **Hypothesis Testing**
  - H0 : $\mu(i,m') = \mu(i,m)$
  - $Z0 = \mu(i,m') - \mu(i- {}^{m}/_{2}, m)$
- **Process State Generation**
  - if $|Z0| < k * \sigma(i,m)$
  - then $mon_i = mon_{i-1}$
  - else $mon_i = \mu(i,m)$
  - $mon^*_{i+1} = mon_i$
  - $error = mon^*_i - mon_i$



Network Performance Envelope:

Network Stability Monitor



Network Performance Envelope:

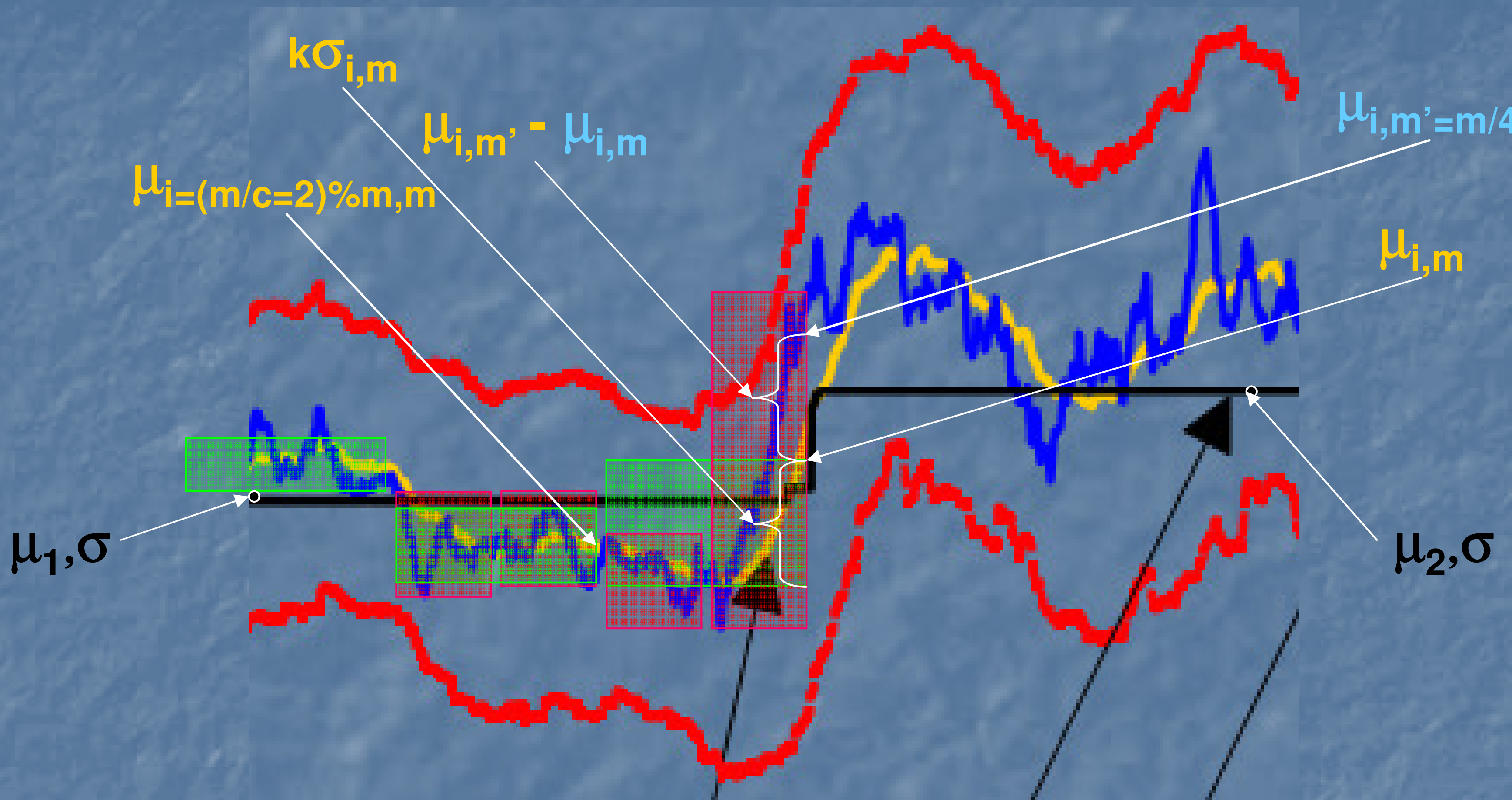
Stationarity Test: Comparison of Sampled Means

$$Z0 = \underbrace{\left\{ \begin{matrix} \mu(i, m' = 30) \\ \text{fast signal (front - end)} \end{matrix} \right\} - \left\{ \begin{matrix} \mu(i - \frac{m}{2}, m = 120) \\ \text{slow signal (~ uncorrelated past)} \end{matrix} \right\}}_{\text{if } (|Z0| < k\,\sigma(i, m=120))}$$

- **Hypothesis tested by comparing two indicators**
  - (a) slow signal and
  - (b) fast signal
- **This resulting in two process states**
  - (a) stationary state or
  - (b) process change
- **Sensitization parameters**
  - m' (fast signal), m (slow signal)
  - k (confidence), m/c (decorrelator)

Network Performance Envelope:

Equality Between Two Population Sampled Means



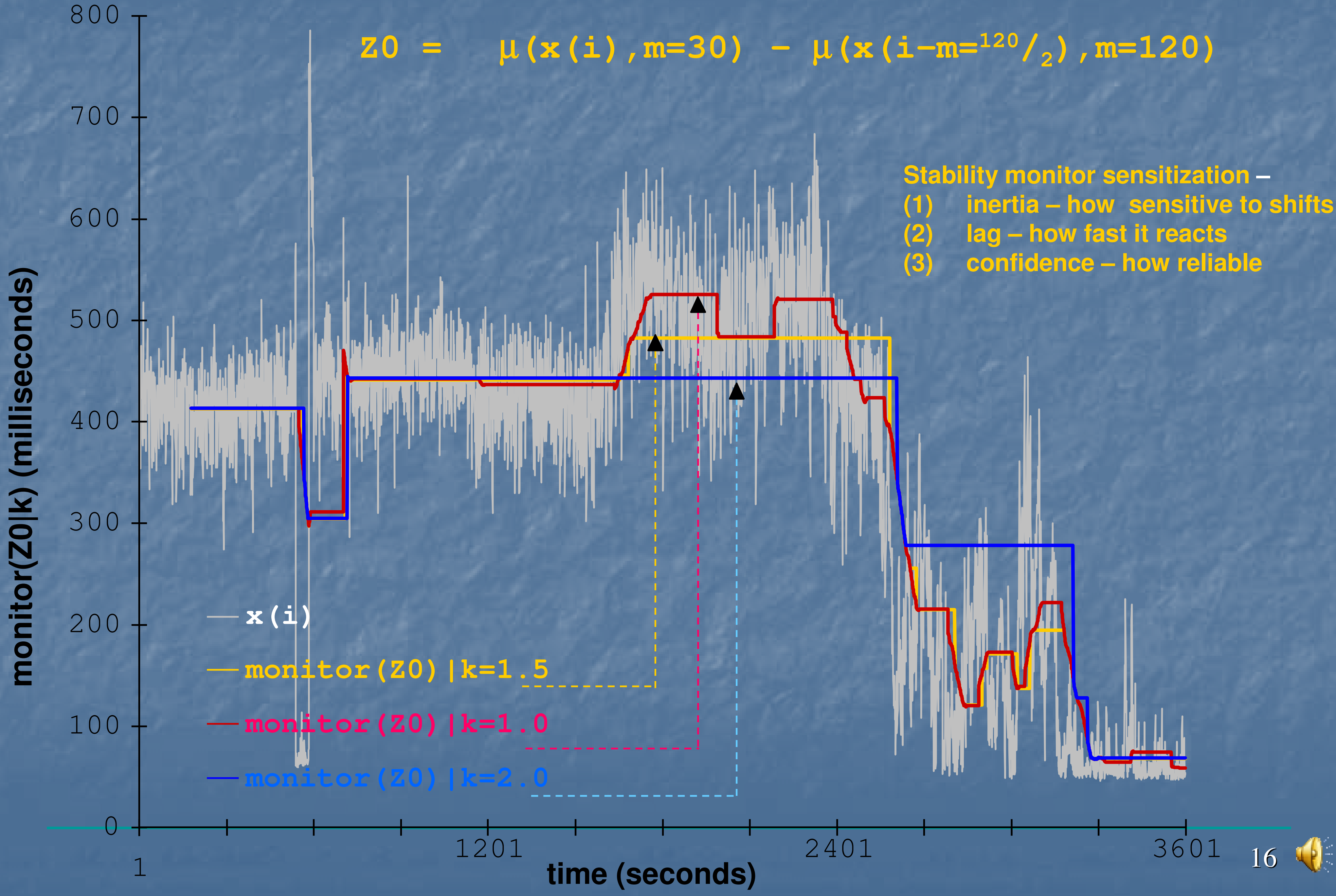
- *t*-test on unknown mean and unknown variance for a ~normal population with test statistic

$$t_0 = \frac{\mu(i,m) - \mu(i-m/2,m)}{\sqrt{\frac{\sigma(i,m)^2 + \sigma(i-m/2,m)^2}{m}}}$$

- at (α=0.5, m=120) → t ≈ 3.3

Network Performance Envelope:

Sensitivity Parametrization



Network Performance Envelope:

Comparative Analysis Test Space

- **Parameters**
  - m – size of the moving window outlook for the slow signal
  - m' – size of the moving window outlook for the fast signal
  - K – number of sigma levels used to clip outliers from the input time series
  - k – approx. number of sigma levels used to recognize as statistical significant the current variability on the state tracking signal (i.e., how sensitive to process state shifts)
  - c – point ($t - {}^{m}/_{c}$) into the recent's past of the slow moving used to decorrelate the windows of the slow signal from the fast signal

- **Constraints**
  - $1 < K \leq 3$
  - $1 < k \leq 3$
  - $m' < m$
  - $c < m$

Network Performance Envelope:

Test Case Structure

- **input time series**
  - approximately normal distributed random variable signal
  - 3600 samples – representing random 1-second-spaced samples
- **three process state shifts (μ,σ)**
  - RTT (μ=80,σ=10) from t=2 to 1201
  - RTT (μ=160,σ=20) from t=1202 to 2401
  - RTT (μ=40,σ=5) from t=2402 to 3601
- **signal recognition setup**
  - state recognition lag test – square wave signal
  - state recognition accuracy test – process state shifts
  - tracking error test – random generated signal

Network Performance Envelope:

Comparison Metrics

- **state monitor's overall accuracy**
  - monitor's sum of error squares
  - $[mon(t|m')-RTT(t)]^2 + [mon(t|m')-mon(t|m)]^2$

- **state monitor's fractality**
  - monitor's number of states
  - monitor's standard deviation

$$\sum_{i=1}^{3}\left[\left|\hat{\mu}\left[mon(t,m')\right] - \mu\left[RTT(t)\right]\right|_{t \in R(i)}\right]^2$$

- **monitor's state tracking accuracy**
  - R1: RTT (μ=80,σ=10) from t=2 to 1201
  - R2: RTT (μ=160,σ=20) from t=1202 to 2401
  - R3: RTT (μ=40,σ=5) from t=2402 to 3601

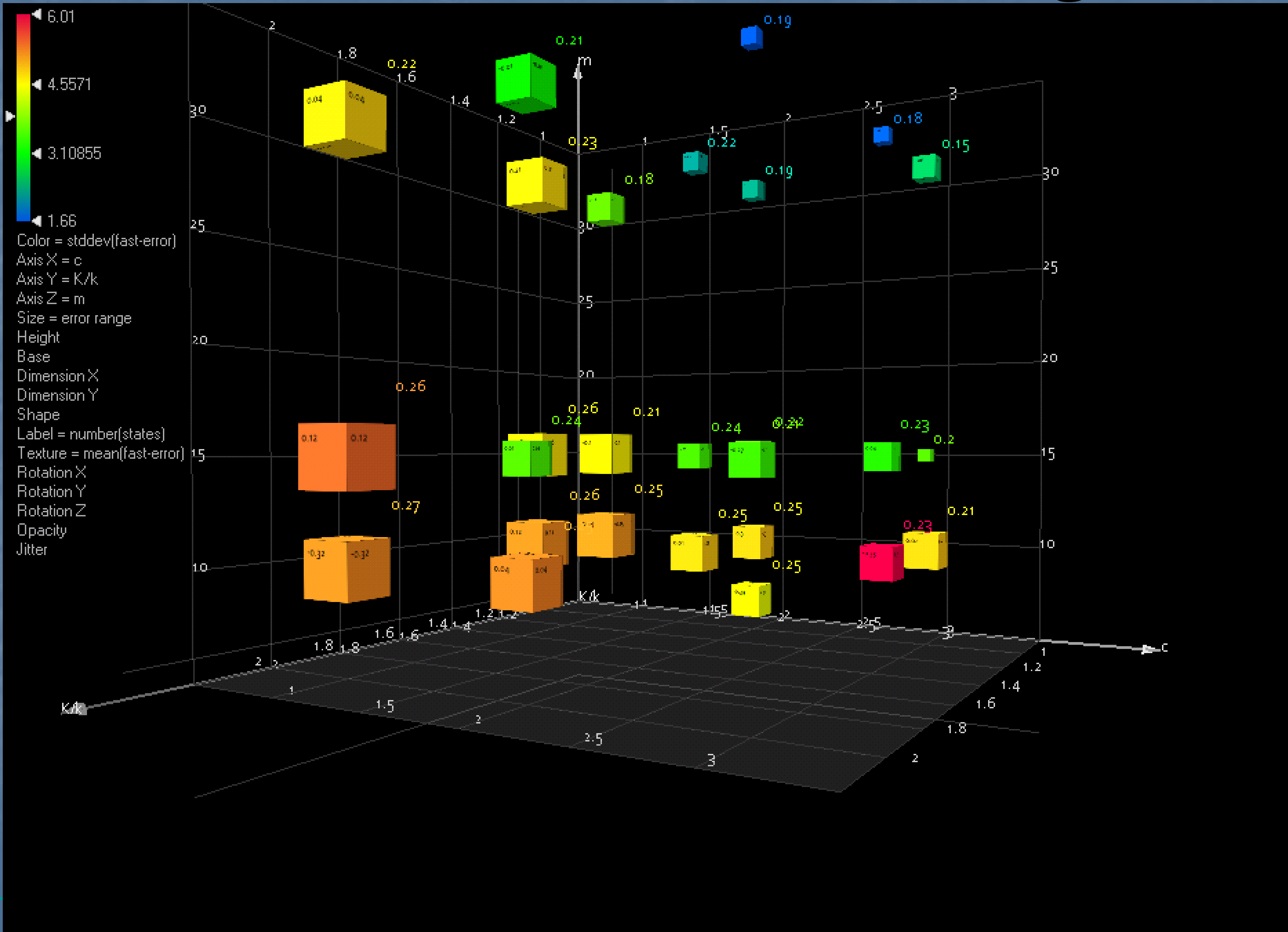
Network Performance Envelope:

Findings (to be updated)

- **Fast vs. Slow Signal Window Size**
  - m, m' ………..
- **Outlier Detection**
  - K, m …………..
- **Decorrelator Point**
  - c, m …………..
- **Error**
  - k, m/m' …………..
- **State Fractality**
  - k …………..

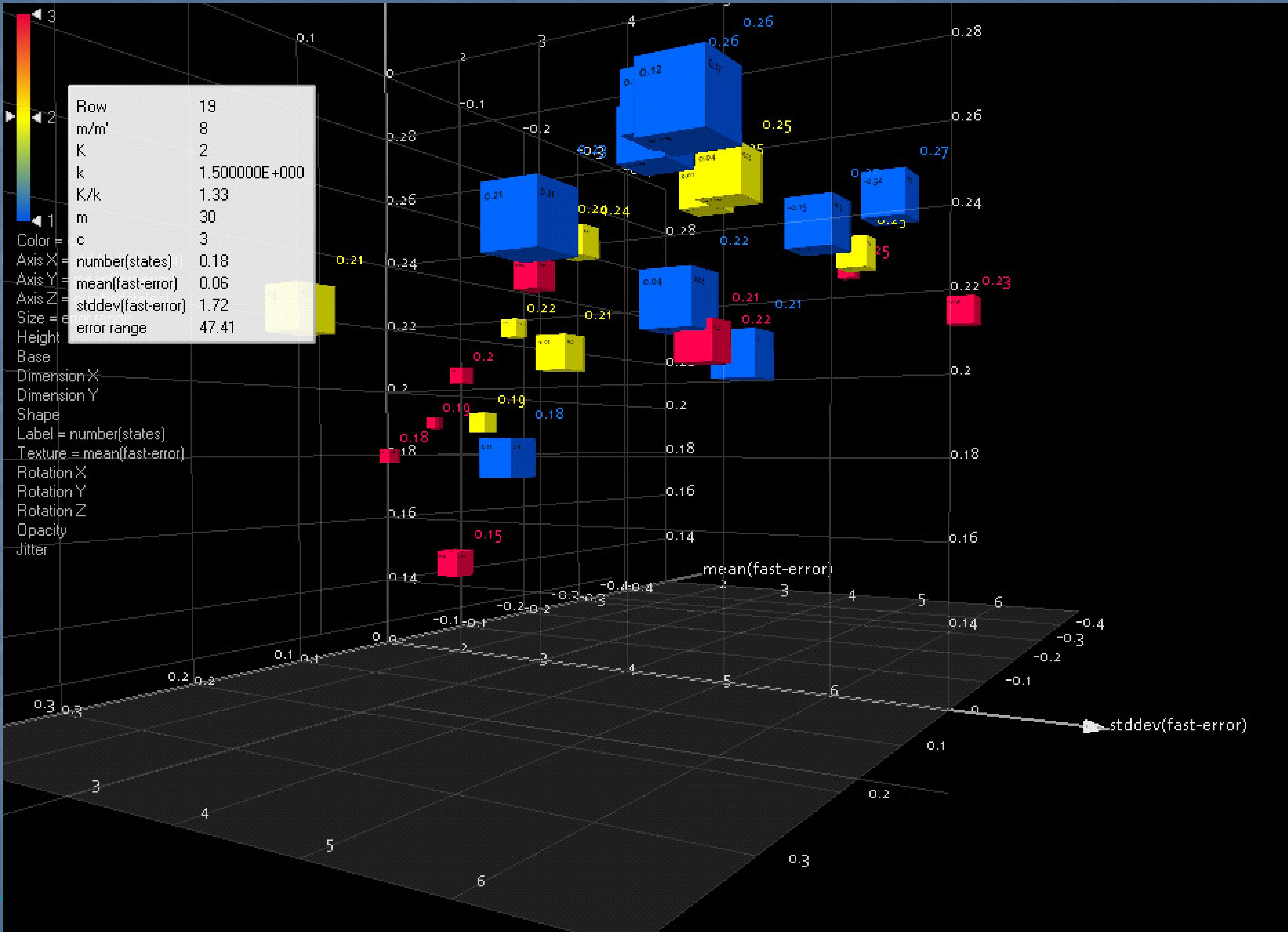
Network Performance Indicator Comparative Analysis

c, K/k, m → stdev, numstates,range



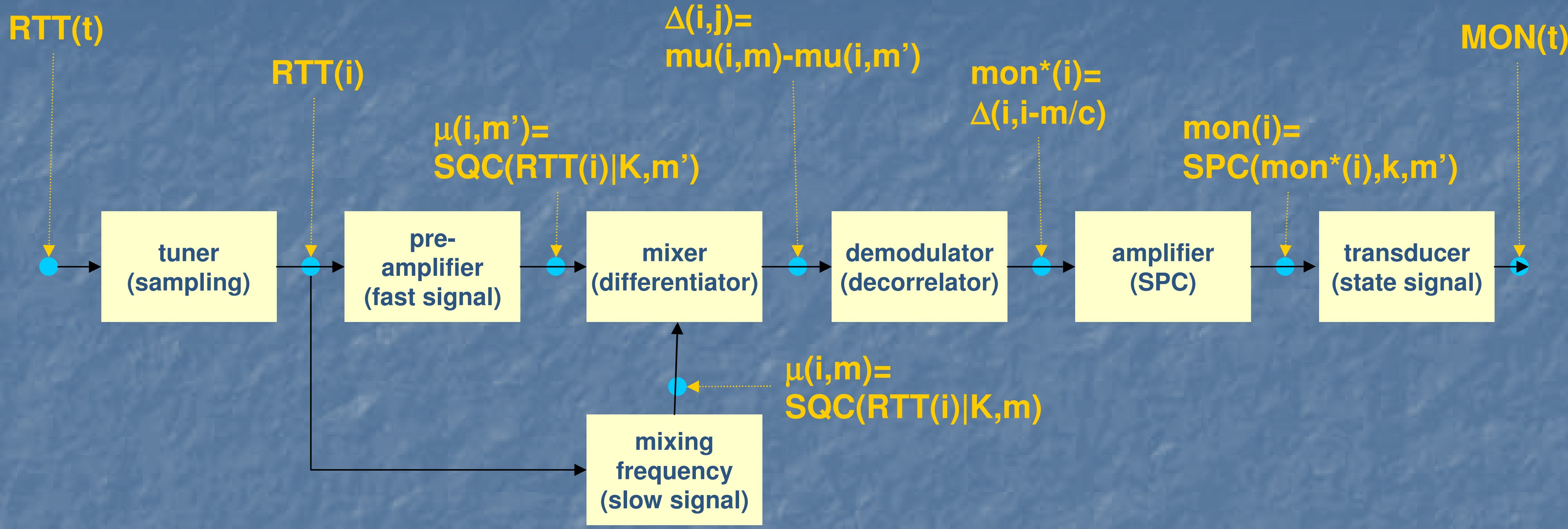
Network Performance Envelope Comparative Analysis

mean,stdev,sum → numstates, ….



Network Performance Envelope:

Network Superheterodyne (Armstrong)

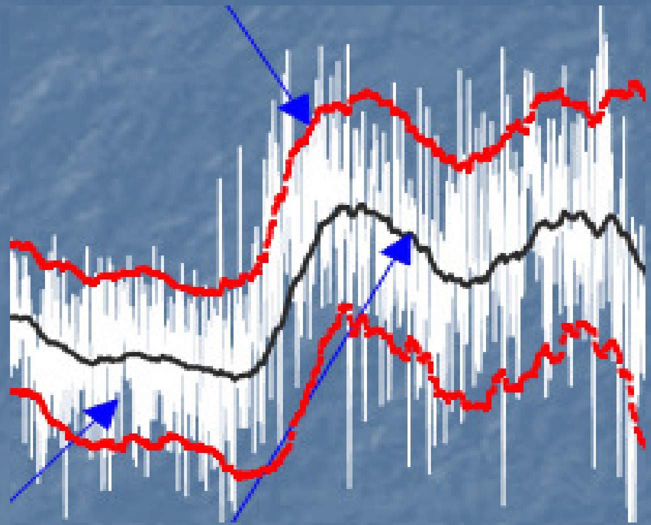


- www.answers.com, www.fas.org/man/dod-101/navy/docs/es310/
  - Of, relating to, or being a form of radio reception
  - in which the frequency of an incoming radio signal
  - is mixed with a locally generated signal
  - and converted to an intermediate frequency
  - in order to facilitate amplification and the rejection of unwanted signals
  - superheterodyne receivers have better performance because the components can be optimized to work a single intermediate frequency

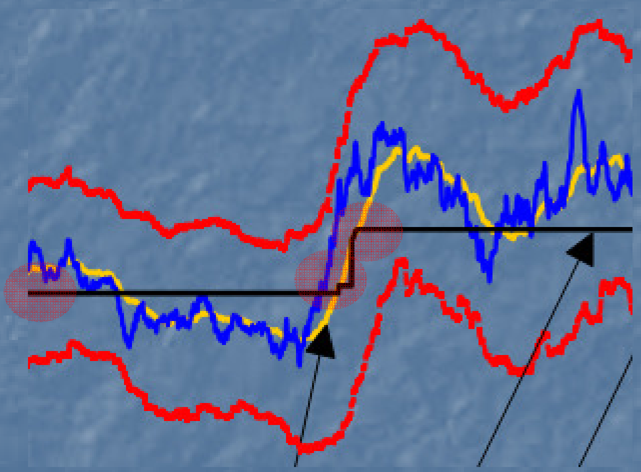
Network Performance Envelope:

Network Stability Monitor Requirements

- **robust process state tracking**
  - quantifiable confidence interval
  - forecast confidence



- **low tracking overhead**
  - moving window kernels have straightforward O(1) complexity
- **easy to implement**
  - moving window process state and control rules are simple (see flowchart)



- **low signaling overhead**
  - process state communicated only when necessary, that is, when it changes (i.e., only when statistically significant)

Research Contributions

- **online generation of a robust floating envelope**
  - showed the particular relevance of online-SPC - despite its simplicity
  - used to track the process performance associated with an indicator
  - shown for RTT – indicator for network congestion and flow management
- **formulated online SPC-based monitor of network state**
  - detection of stationary conditions (temporal stability, **process state**)
  - detection of piece-wise linear (**process changes**)
  - fast, robust, reliable , and low overhead
  - some setup vs. parametrizable statistical performance
- **robust state tracking building block**
  - near-stationarity conditions used to distinguish between process state and process changes
  - timescale and robustness targeted for process-performance

Future Work

- **simulations of SPC+ARC()**
  - further sensitivity analysis of SPC+ARC kernels
    - lag (m, m’), confidence (kσ), smoothing (m), smoother/sampling (UWMA, EWMA, etc.), adaptation (ω) and adaptation strategy (linear, multiplicative, constant), quantization process (mon), outlier recognition (kσ), fitness/residual analysis (err*), etc.
  - further performance g and optimality
    - comparative performance of SPC+ARC()
    - statistical performance (alpha errors, beta errors, etc.)
- **implementation of applications of SPC+ARC()**
  - multimedia networking performance
  - other distributed online process control (see next segment)