Holistic Packet Statistics for Neighborhood Management in Sensor Networks

Sebastian Ernst, Christian Renner, Christoph Weyer, Volker Turau

Fachgespräch "Drahtlose Sensornetze", Würzburg

16th September, 2010

Institute of Telematics
Hamburg University of Technology
TUHH

1

Introduction

Knowing Your Neighbors

Reasons

- Clustering
- Collaborative node tasks
- Routing
- Self-$*$ algorithms

Problems & Challenges

- Addition or failure of nodes
- Temporal changes of wireless channel
- Comparison and prediction of links

Simply track your neighbors and associated link qualities!

Simply?

Simply track your neighbors and associated link qualities!

Simply?

Link Assessment Options

Physical Measures

- Signal-to-Noise Ratio (SNR)
- Link Quality Indicator (LQI)
- ...

+ Provided by hardware

- Hardware-dependent, Requires actual packet reception, Difficult-to-compensate effects

Logical Measures

- Packet History
  e.g., Packet Success Rate (PSR)
- State of known nodes
- ...

+ Reflects application-centric link quality

- Requires packet transmission

Link Assessment Options

Physical Measures

- Signal-to-Noise Ratio (SNR)
- Link Quality Indicator (LQI)
- ...

+ Provided by hardware
- Hardware-dependent, Requires actual packet reception, Difficult-to-compensate effects

Logical Measures

- Packet History
  e.g., Packet Success Rate (PSR)
- State of known nodes
- ...

+ Reflects application-centric link quality
- Requires packet transmission

Link Assessment Options

Physical Measures

- Signal-to-Noise Ratio (SNR)
- Link Quality Indicator (LQI)
- ...

+ Provided by hardware

- Hardware-dependent, Requires actual packet reception, Difficult-to-compensate effects

Logical Measures

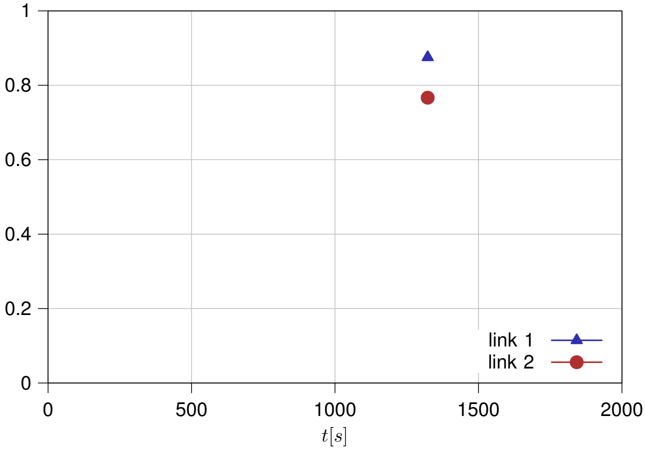
- Packet History
  e.g., Packet Success Rate (PSR)
- State of known nodes
- ...

+ Reflects application-centric link quality

- Requires packet transmission

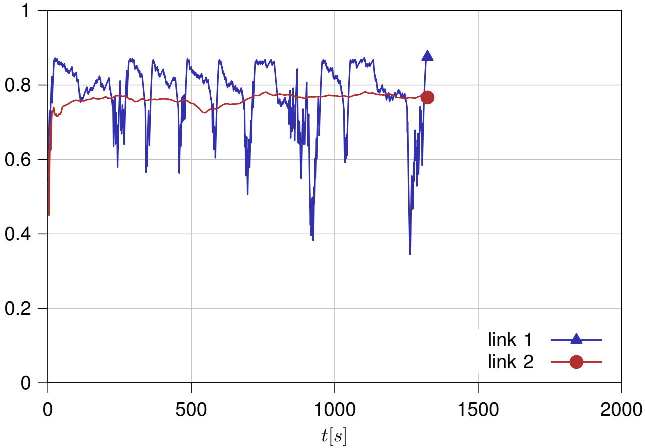
The Swiss Army Knife Problem

or the tale of describing a link with a single value



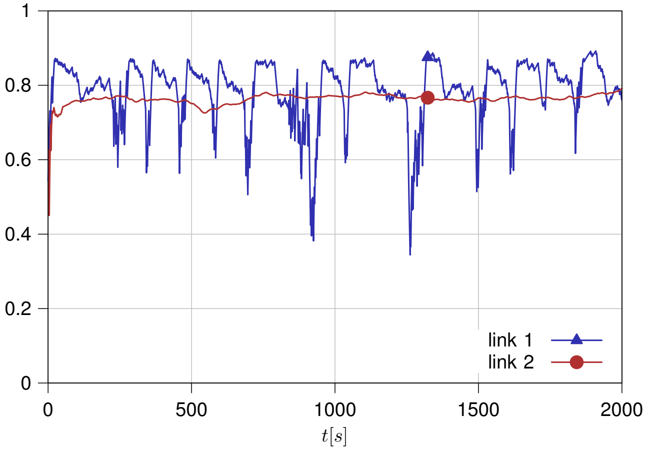
The Swiss Army Knife Problem

or the tale of describing a link with a single value



The Swiss Army Knife Problem

or the tale of describing a link with a single value

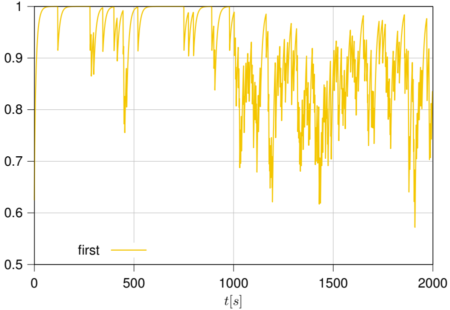


2

Holistic Packet Statistics - HoPS

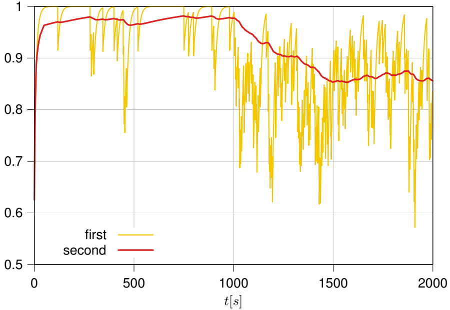
Holistic Packet Statistics - HoPS

1. Short-term analysis
   - ▷ first-order smoothing
2. Long-term analysis
   - ▷ second-order smoothing
3. Oscillation
   - ▷ absolute average deviaton
4. Trend
   - ▷ estimation error



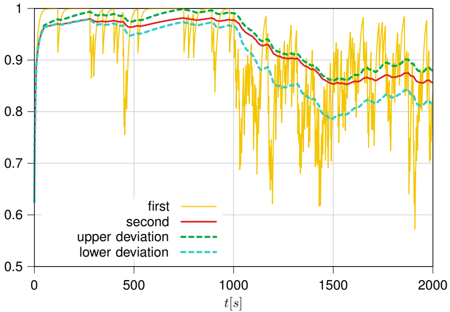
Holistic Packet Statistics - HoPS

1. Short-term analysis
   - ▷ first-order smoothing
2. Long-term analysis
   - ▷ second-order smoothing
3. Oscillation
   - ▷ absolute average deviaton
4. Trend
   - ▷ estimation error



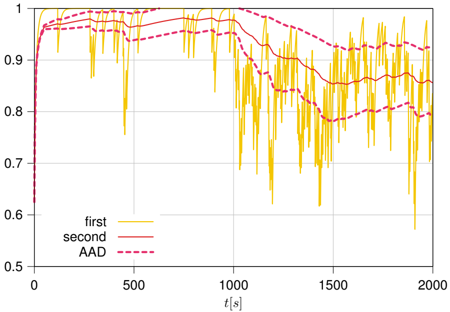
Holistic Packet Statistics - HoPS

1. Short-term analysis
   - ▷ first-order smoothing
2. Long-term analysis
   - ▷ second-order smoothing
3. Oscillation
   - ▷ absolute average deviaton
4. Trend
   - ▷ estimation error



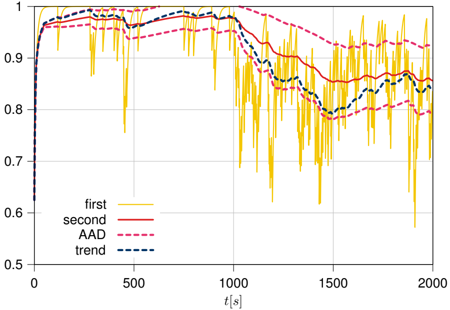
Holistic Packet Statistics - HoPS

1. Short-term analysis
   - ▷ first-order smoothing
2. Long-term analysis
   - ▷ second-order smoothing
3. Oscillation
   - ▷ absolute average deviaton
4. Trend
   - ▷ estimation error



Holistic Packet Statistics - HoPS

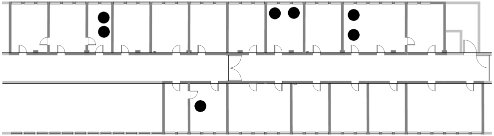
1. Short-term analysis
   ▷ first-order smoothing
2. Long-term analysis
   ▷ second-order smoothing
3. Oscillation
   ▷ absolute average deviaton
4. Trend
   ▷ estimation error



3

A Case Study

Setup



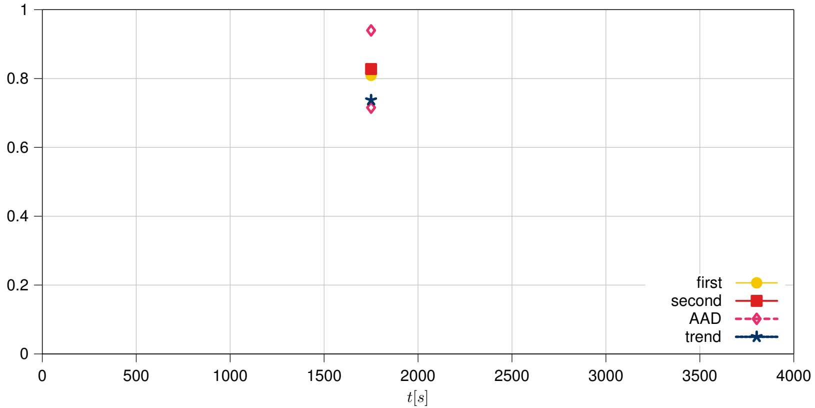
Link Traces

- Real-world office experiment with IRIS nodes
- Synthetic links

Evaluation method

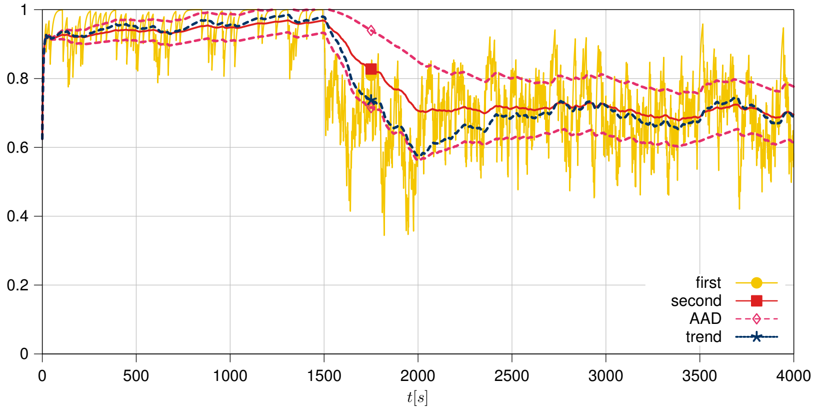
- Java Test Suite
- Simulation of TinyOS implementation (16 bit integers)

Sudden Quality Drop



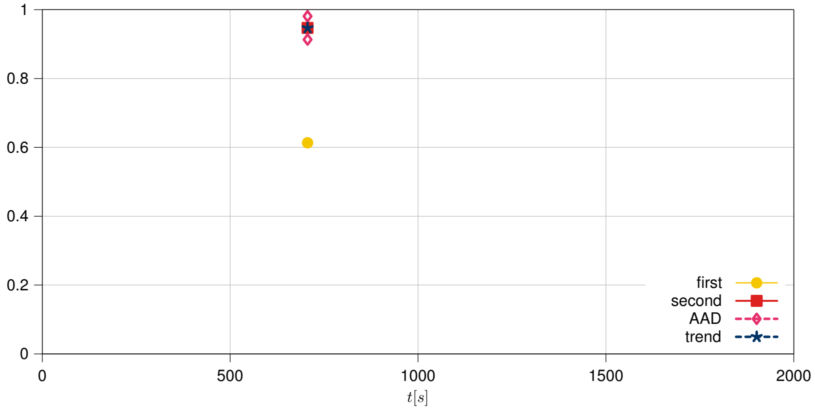
- first and second order smoothing close together
- clearly negative trend

Sudden Quality Drop



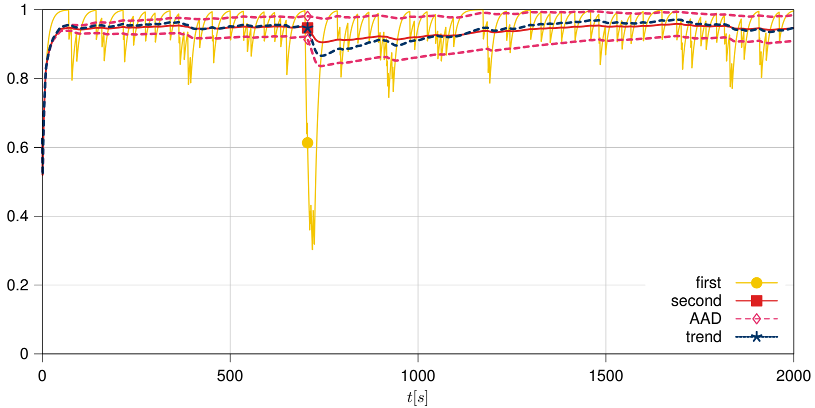
- first and second order smoothing close together
- clearly negative trend

Temporary Disturbance



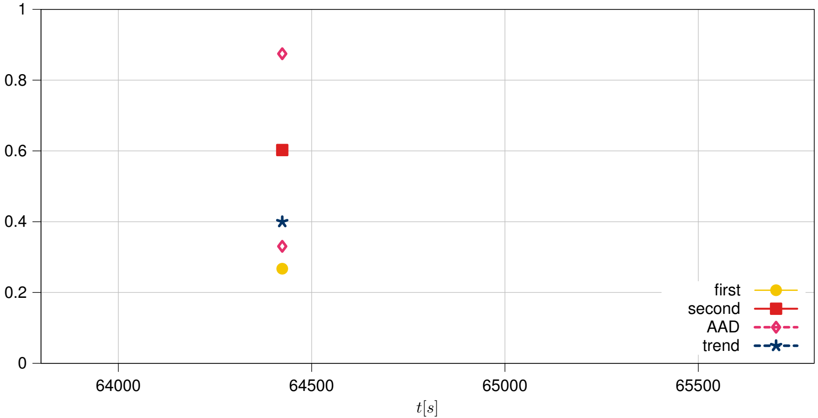
- no discernible trend
- first order smoothing far away from oscillation bounds

Temporary Disturbance



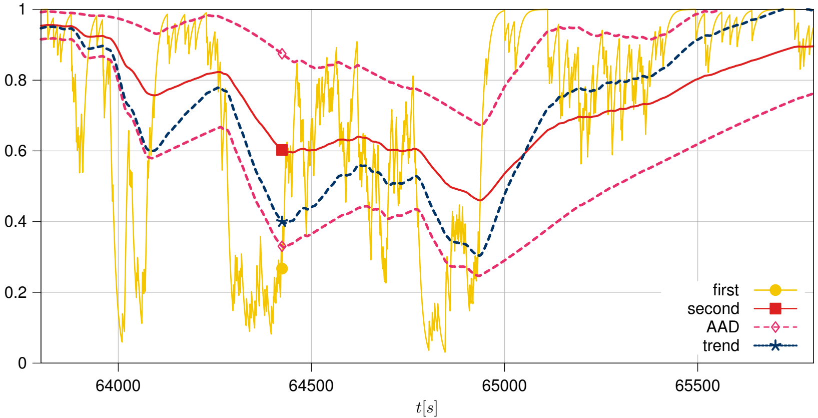
- no discernible trend
- first order smoothing far away from oscillation bounds

Highly Fluctuating Link



- very large oscillation
- clearly negative trend

Highly Fluctuating Link



- very large oscillation
- clearly negative trend

4

Conclusion

Conclusion

The reward ...

- Short- and long-term analysis of link quality
- Oscillation and trend indicators
- Sophisticated link assessment and behavior prediction
- Fulfillment of application-specific demands
- Same speed as single EWMA estimation

and the prize

- Interpretation and comparability is more complex
- Higher usage of memory and computation power
  8 byte, 4 multiplications (EWMA)

Work in Progress

- Comparison with other link quality estimators
- Analysis of relation with hardware metrics (SNR, LQI)
- Assessment of link-quality prediction
- Integration into Mahalle neighborhood protocol
- Handling of non-uniform packet reception patterns

Holistic Packet Statistics for Neighborhood Management in Sensor Networks

Sebastian Ernst, Christian Renner, Christoph Weyer, Volker Turau

Fachgespräch "Drahtlose Sensornetze", Würzburg

16th September, 2010

Institute of Telematics
Hamburg University of Technology
TUHH

First- and Second-Order Smoothing

First-order Smoothing

$$\xi_t = \alpha \cdot \xi_{t-1} + (1-\alpha) \cdot P_t \,, \quad P_t = \begin{cases} 1 & , \quad t^{th} \text{ packet received} \\ 0 & , \quad t^{th} \text{ packet missed} \end{cases} \tag{1}$$

$$\xi_t = (1-\alpha) \cdot \sum_{i=0}^{n} \alpha^i \cdot P_{t-i} + \alpha^{n+1} \cdot \xi_{t-(n+1)} \tag{2}$$

Second-order Smoothing

$$\nu_t = \beta \cdot \nu_{t-1} + (1-\beta) \cdot \xi_t \tag{3}$$

▷ Back

Upper and Lower Deviation

Estimated mean $\tilde{\mu} = \mu + \Delta\mu$ of X with estimation error $\Delta\mu$ and

$$\mu = E\{X\}, \quad X^+ = \{x \in X | x > \tilde{\mu}\}, \quad X^- = X \setminus X^+, n = |X|$$

Upper and Lower deviation

$$\delta^- := \frac{1}{n} \sum_{x^- \in X^-} (\tilde{\mu} - x^-), \qquad \delta^+ := \frac{1}{n} \sum_{x^+ \in X^+} (x^+ - \tilde{\mu}) \tag{4}$$

Practical calculation

$$\delta_t^+ = \gamma \cdot \delta_{t-1}^+ + (1 - \gamma) \cdot \varphi(\xi_t, \nu_t) \tag{5}$$

$$\delta_t^- = \gamma \cdot \delta_{t-1}^- + (1 - \gamma) \cdot \varphi(\nu_t, \xi_t) \tag{6}$$

$$\varphi(a, b) = \begin{cases} a - b & , \quad \text{if } a > b \\ 0 & , \quad \text{else} \end{cases} \tag{7}$$

Oscillation

$$\begin{aligned}
\delta^{+} + \delta^{-} &= \frac{1}{n}\left(\sum_{x\in X^{+}}(x-\tilde{\mu}) + \sum_{x\in X^{-}}(\tilde{\mu}-x)\right) \qquad (8)\\
&= \frac{1}{n}\sum_{x\in X^{+}}(x-\mu) - \Delta\mu + \frac{1}{n}\sum_{x\in X^{-}}(\mu-x) + \Delta\mu\\
&= \frac{1}{n}\sum_{x\in X}|x-\mu|
\end{aligned}$$

▷ Back

Trend

$$\delta^+ - \delta^- \stackrel{(4)}{=} \frac{1}{n}\sum_{x\in X}(\tilde{\mu} - x) = \frac{1}{n}\sum_{x\in X}(\mu + \Delta\mu - x) \tag{9}$$

$$= \underbrace{\frac{1}{n}\sum_{x\in X}(\mu - x)}_{=0} + \frac{1}{n}\sum_{x\in X}\Delta\mu = \Delta\mu$$

▷ Back