

Coping with Unreliable Channels: Efficient Link Estimation for WSNs

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Motivation

- “Wireless sensornets are hard” [Phil Levis 2007]
 - Deployments show poor data retrieval rate:
 - Great Duck Island [Sensys'04] 58%
 - Redwood Tree [Sensys'05] 49%
 - Potato Field [MASS'06] 2%
- Radio channel is the basis
 - What to expect from the underlying radio communication?
 - New packet based radios (2.4 GHz) emerging
- Link estimation prior setting up the topology
 - Select good quality links only
 - Minimize parent switches during operation



Related Work

- Many studies have been published on the performance of the wireless channel; but:
 - Artificial topologies (grid, line)
 - Bit stream based radios in the 868 MHz band
 - [Zhao03, Woo03, Reijers04, Cerpa05, Willig06]

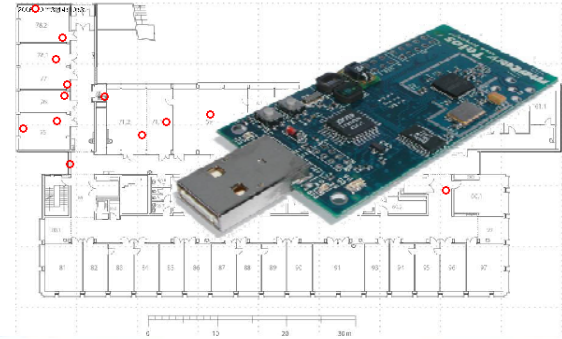
Missing: (1) Real topologies, (2) packet based radios

- Thorough link estimation widely neglected in the sensor network community
 - Links are usually estimated on the fly [Woo03]

Structure

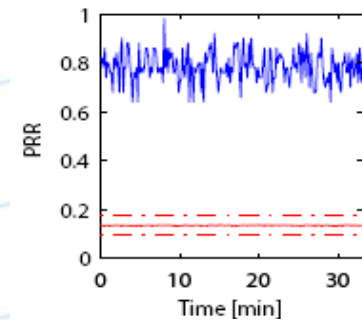
1. Measure Links

- Real indoor deployments, packet based radio



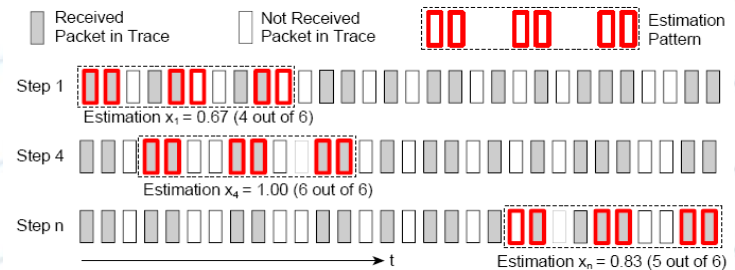
2. Analyze Links

- Detailing the characteristics of wireless links



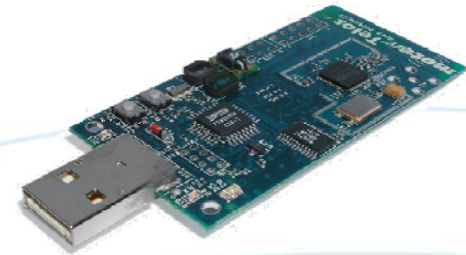
3. Estimate Links

- Efficiently estimate the link quality



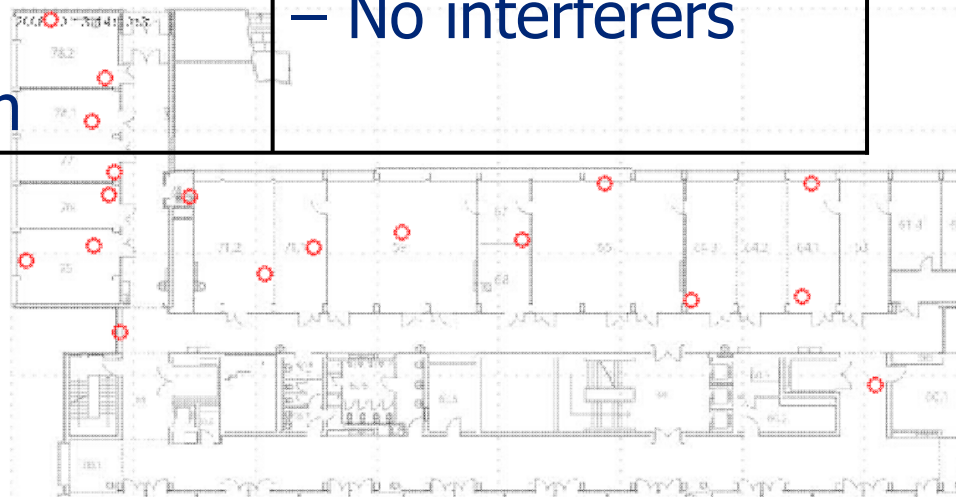
Link Measurements - Test Procedure

- Tmote Sky
 - CC2420, 2.4 GHz
- One sender (no interference)
 - Packet stream, 10'000 packets, 5 Hz
- Multiple receivers
 - Trace received packets:
Sequence number, RSSI, LQI
- Observe all links
 - Rotate sender


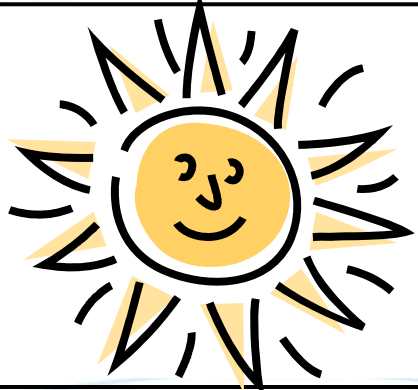


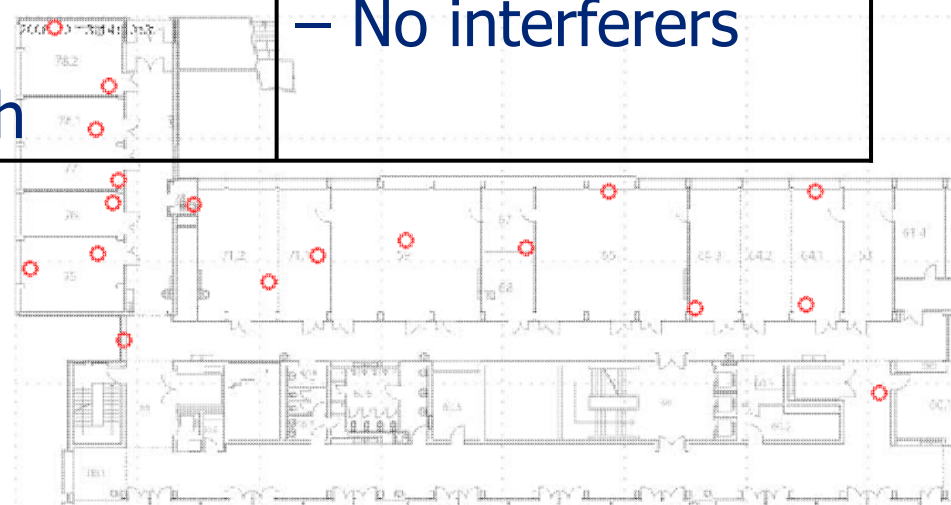
Link Measurements – Two Test Sites

| Network | A: Office Scenario | B: Indoor, Calm |
|------------------|--|--|
| Number of Nodes | 18 | 24 |
| Received Packets | 7'936'690 | 7'171'839 |
| Traced Packets | 10'430'000 | 8'280'000 |
| Average PRR | 76.1% | 86.6% |
| Characteristics | <ul style="list-style-type: none"> – People Moving – Doors open/close – 802.11 – Bluetooth | <ul style="list-style-type: none"> – Machinery – Pipes – No interferers |



Link Measurements – Two Test Sites

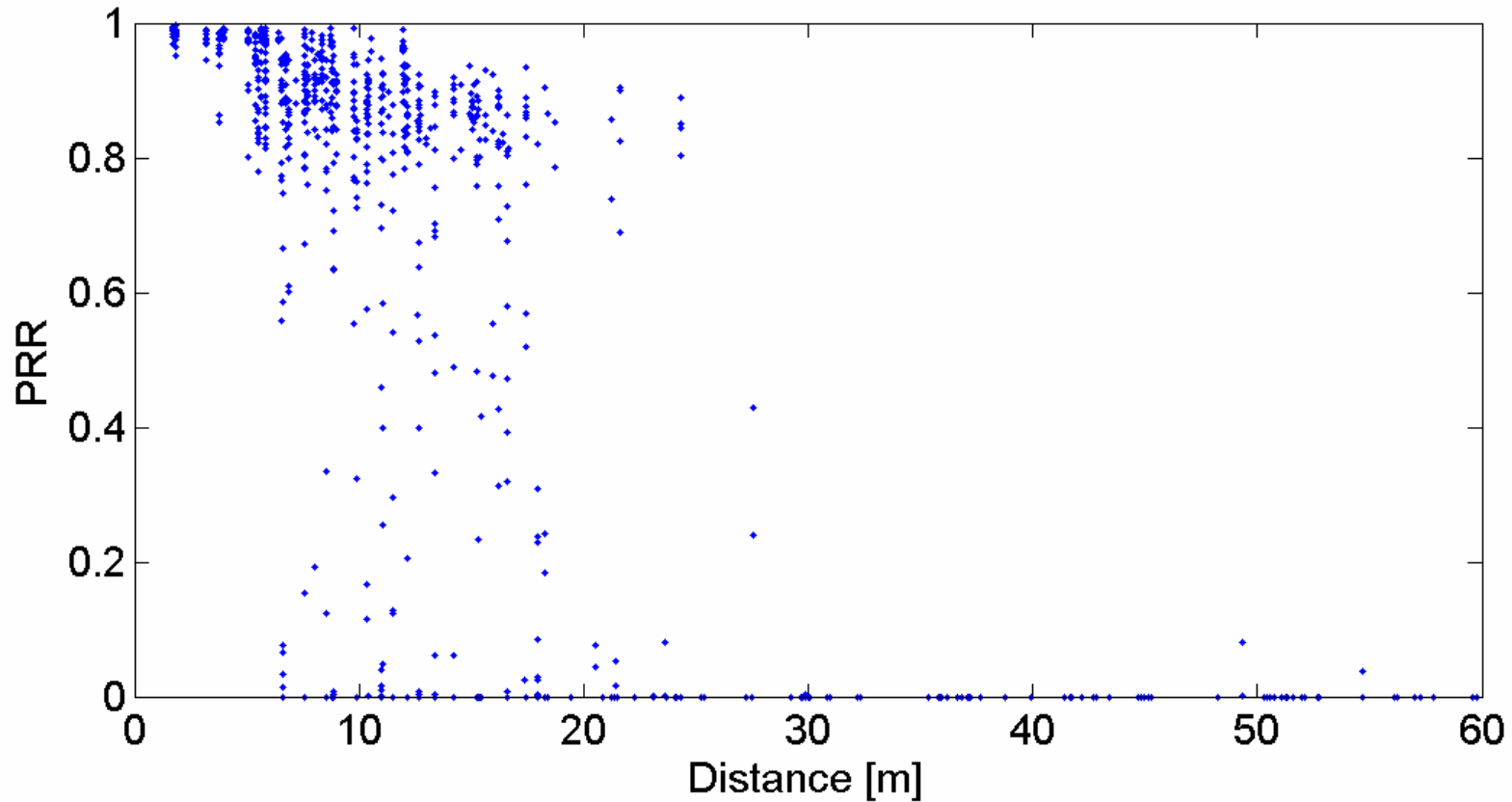
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Link Analysis – Link Quality Distribution



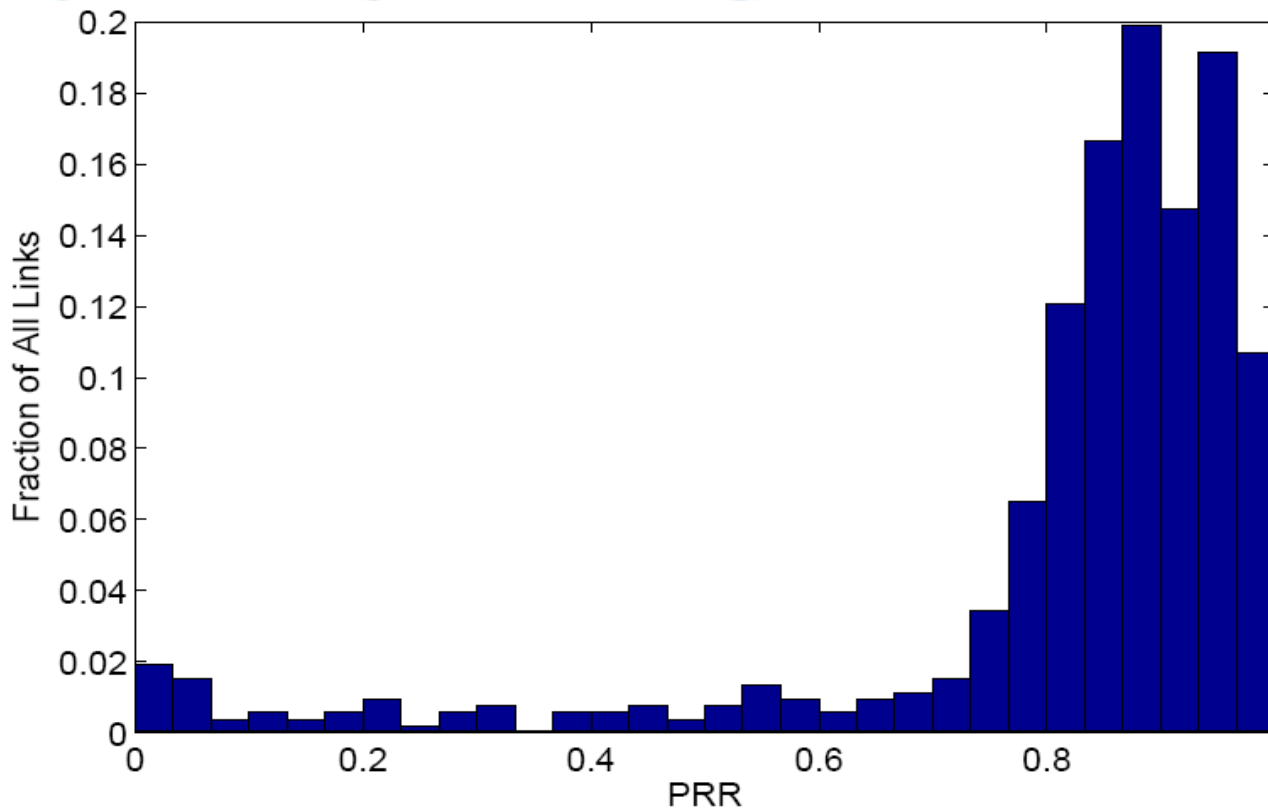
Links are not just available or not



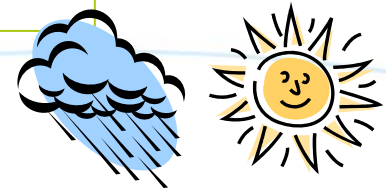
Link Analysis – Sensitivity



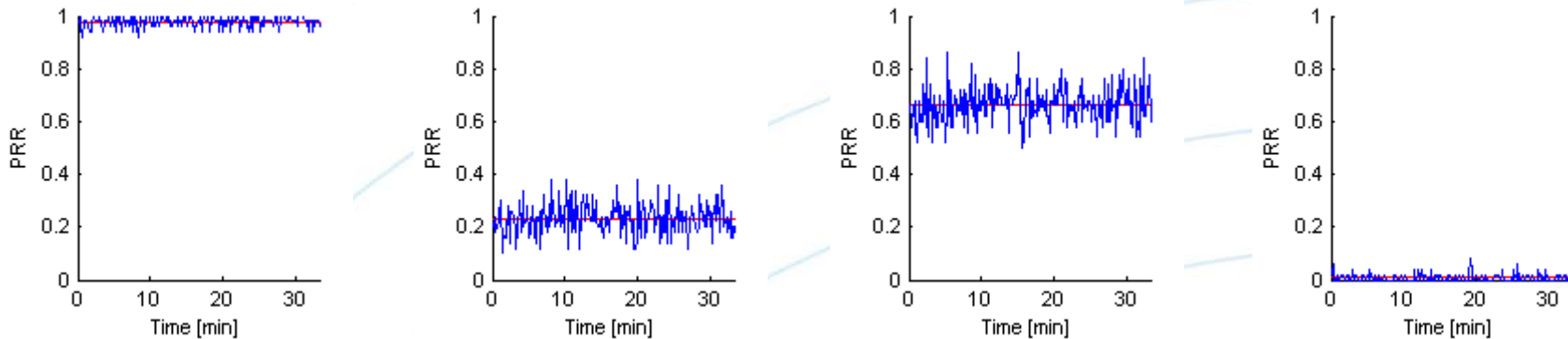
- Select good links is essential
 - A PRR=95% is much more efficient than a PRR=80%



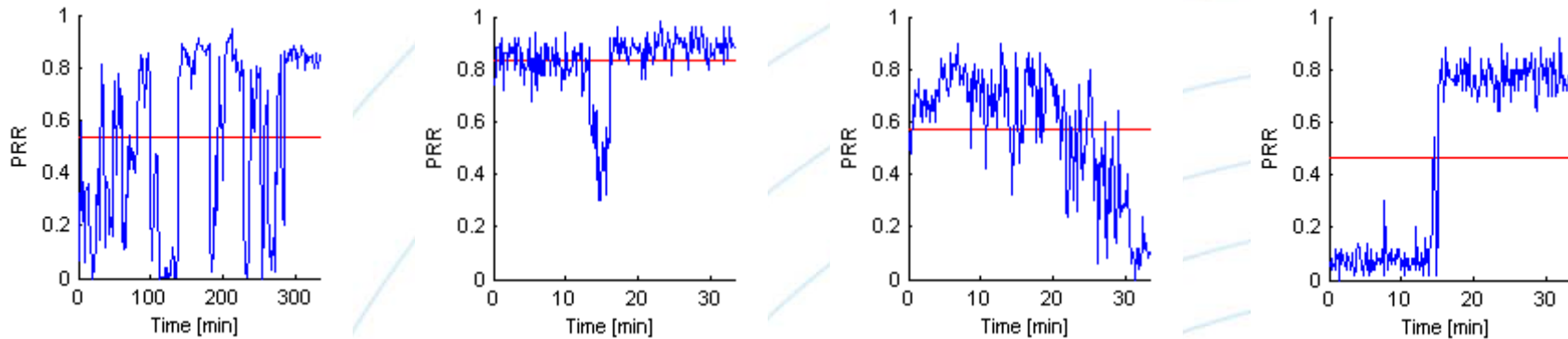
Link Analysis – Time vs. PRR (Link Stability)



- Stable links...



- ... but instabilities can occur at random times



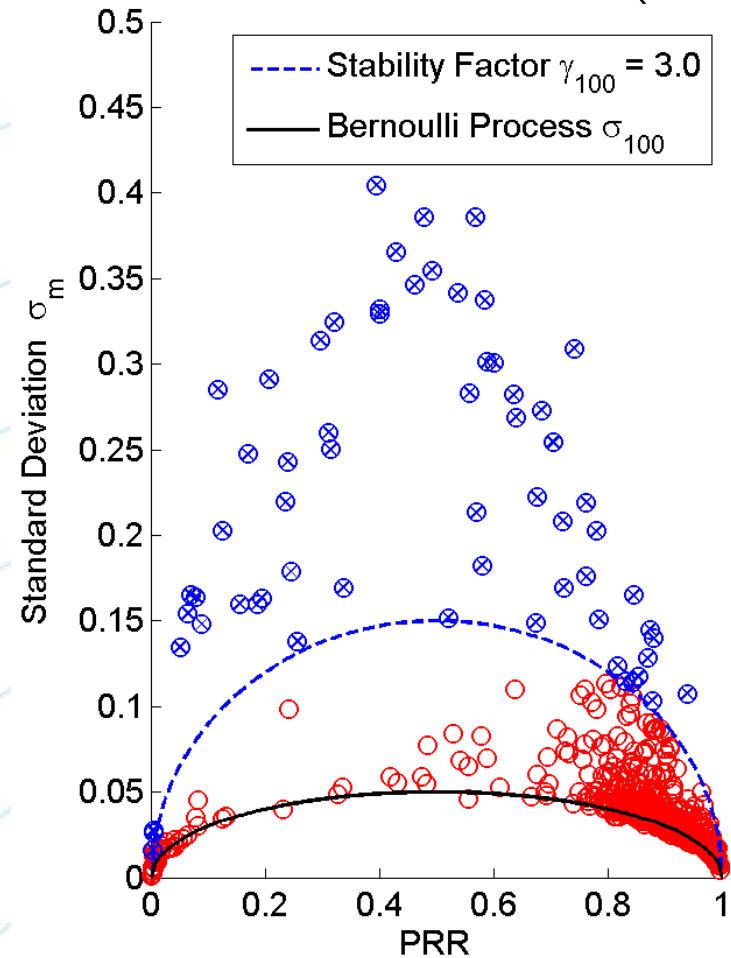
Link Stability – σ_m Metric

- Variance σ_m represents link stability
 - Aggregate m packets and calculate the temporal PRR
- Compare with variance of a stochastic process:
 - Small m for short, large m for long term instabilities

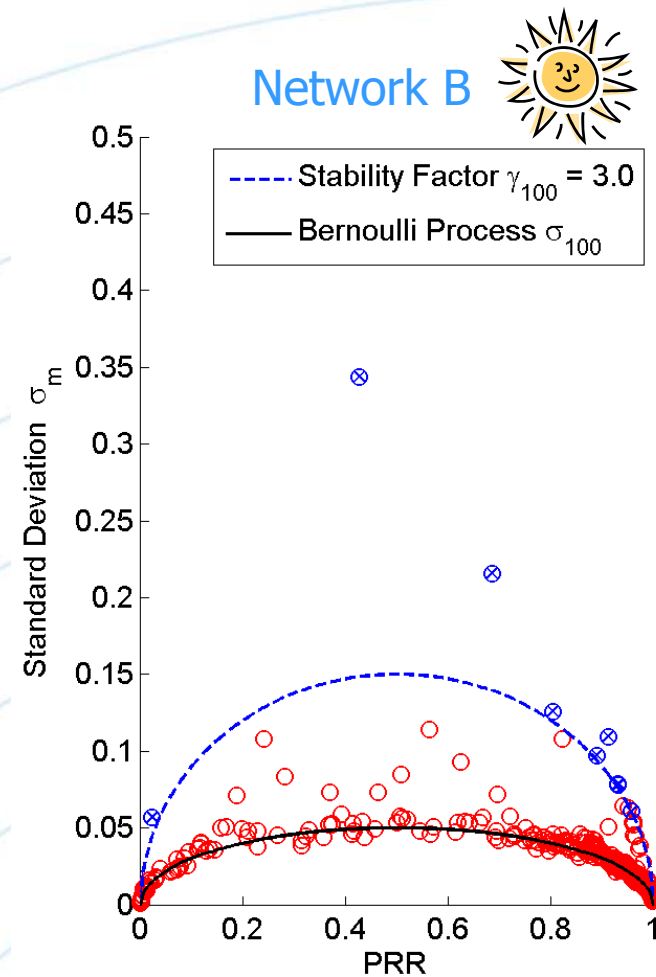
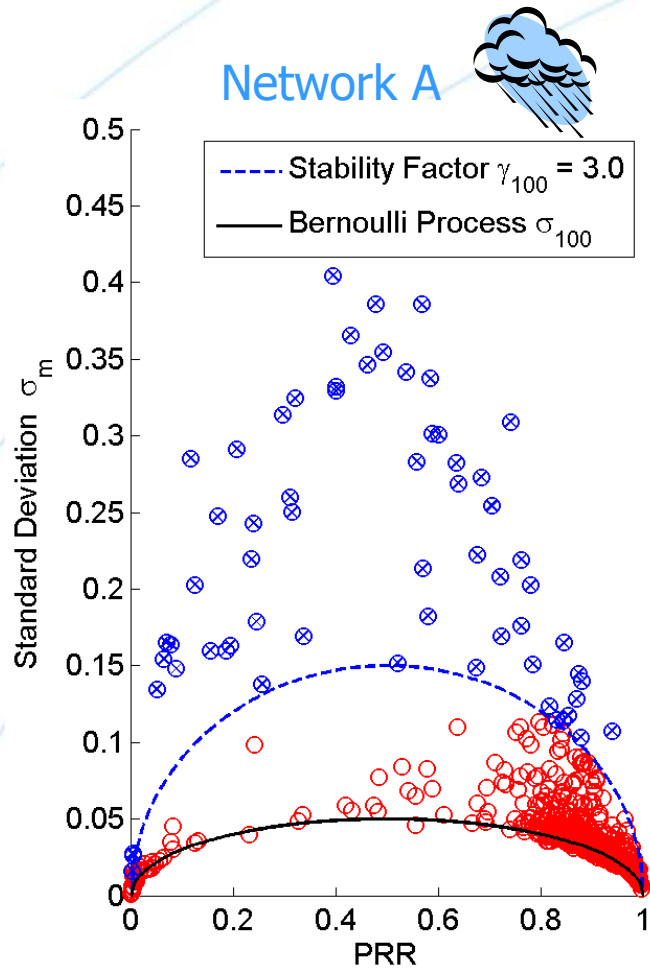
$$\gamma_m = \sqrt{\text{Var}(\text{link}) \frac{P_r(\text{link})(1 - P_r(\text{link}))}{m}}$$

- Define stability factor γ_m
 - Based on manual inspection

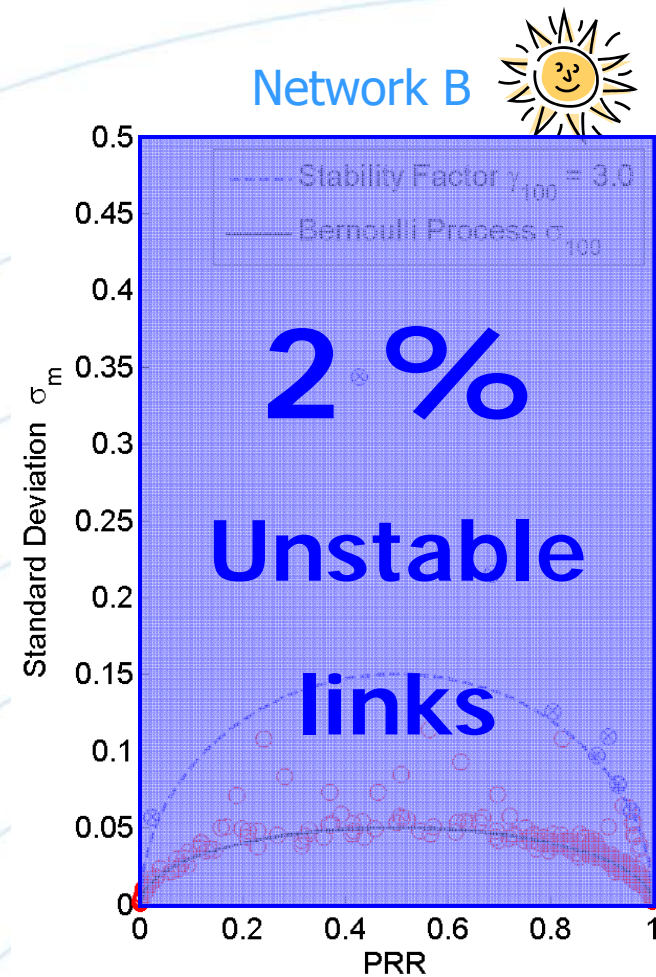
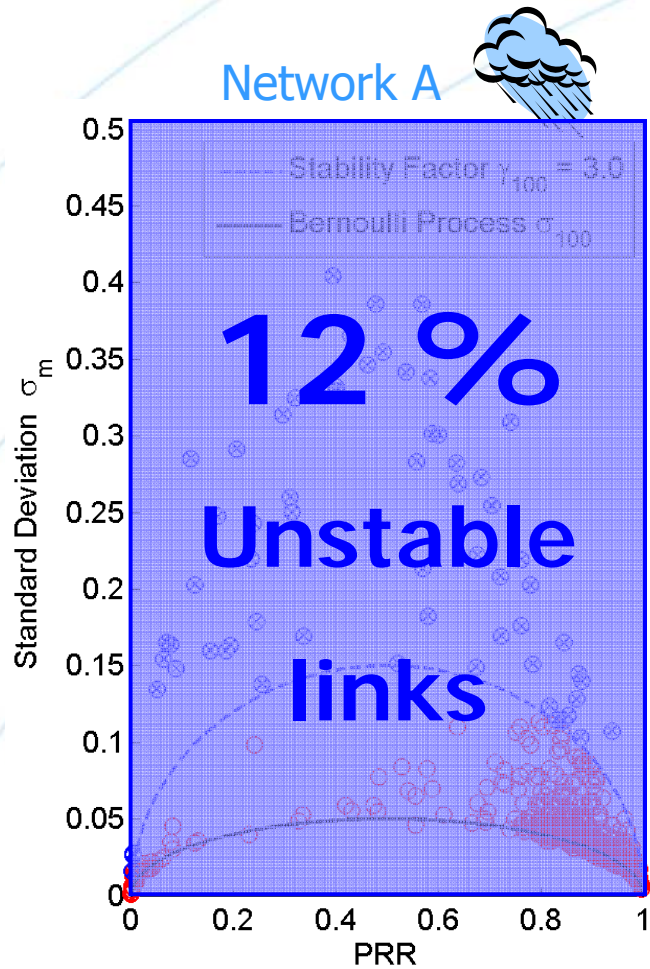
Network A



Link Stability – Comparison



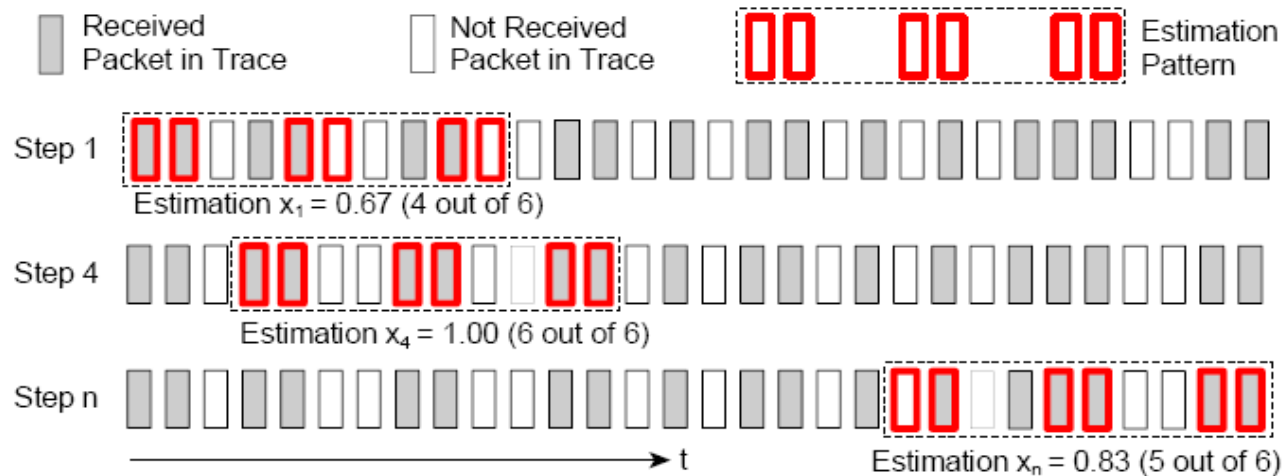
Link Stability – Comparison



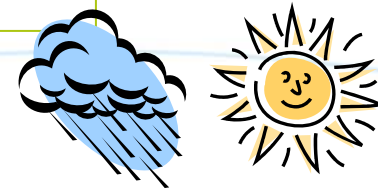
Account for deployment site when designing application

Link Estimation Based on Packet Traces

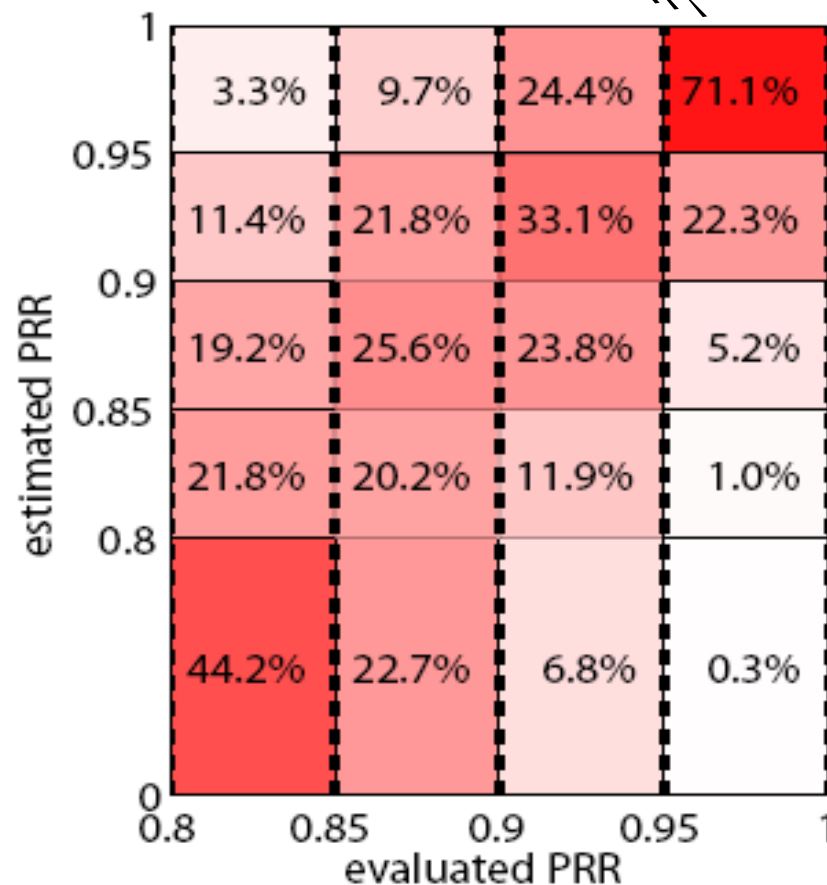
- Perform online on the sensor node
 - Minimize overhead
- Estimation performance depends on
 - Amount of packets received, temporal patterns
 - Additional markers: RSSI/LQI



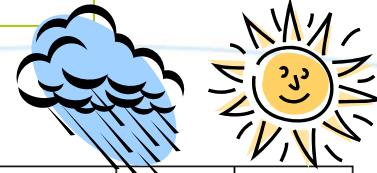
Estimate Link with 20 packets: Baseline



- Send 20 packets with a frequency of 5 Hz.
Estimate link quality according to the PRR.
 - Bad and good links are well distinguished
 - Only 71% of the high quality links (PRR > 0.95) are assessed as such

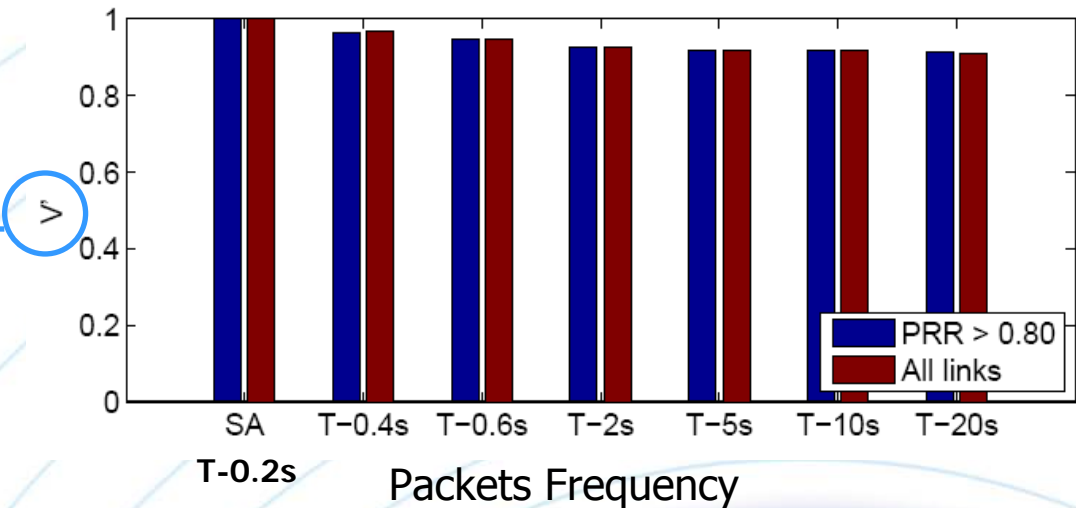
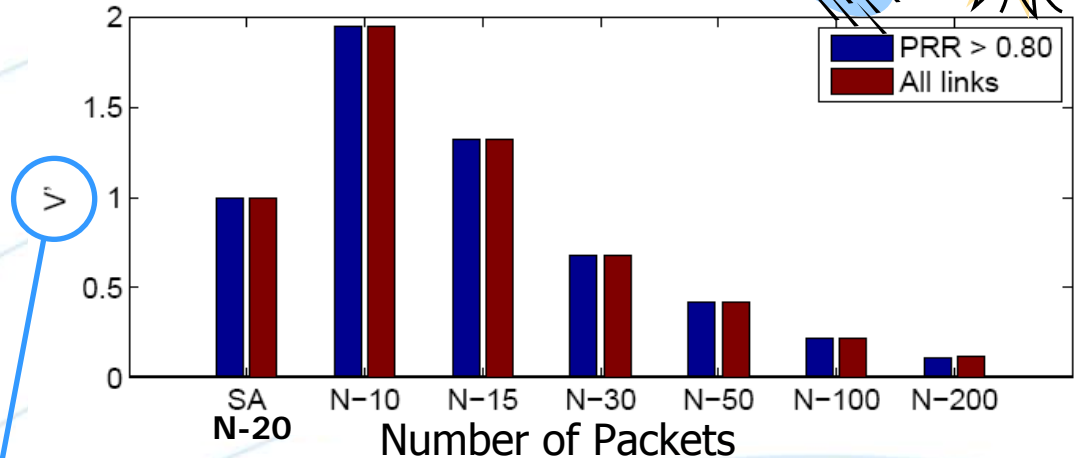


Estimation Time vs. Amount of Packets

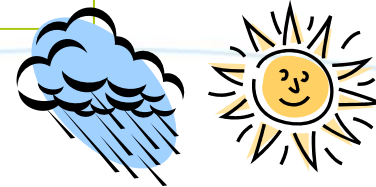


- The number of packets greatly impacts the estimation
- Increasing the packet frequency to up to 2 s (0.5 Hz) for further improvement

Estimation accuracy compared with baseline (SA)
Smaller = better

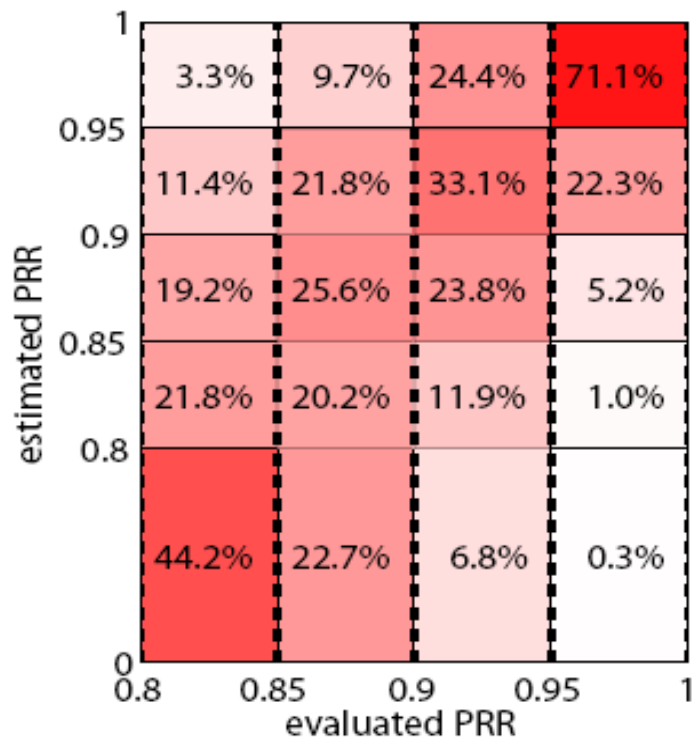


Adaptive Estimation using RSSI

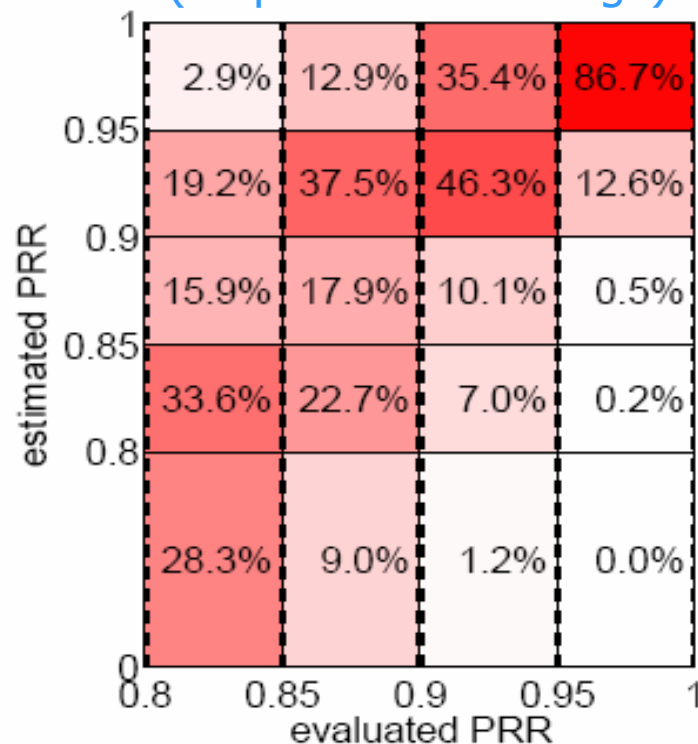


- Adaptive estimation for a substantially increased estimation performance

Baseline with 20 packets

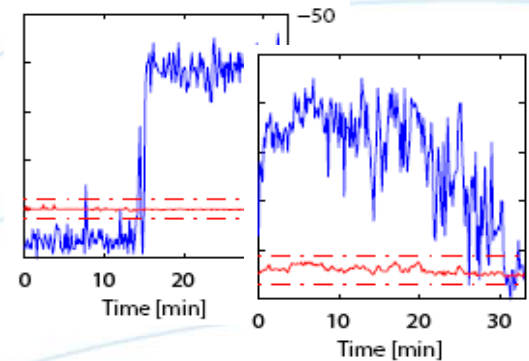


Adaptive approach
(18 packets in average)



Conclusion

- Measurements show:
 - Wireless links are unreliable
- Thorough link estimation allows:
 - Selecting good quality link



| | | | | |
|------|-------|-------|-------|-------|
| 1 | 2.9% | 12.9% | 35.4% | 86.7% |
| 0.95 | 19.2% | 37.5% | 46.3% | 12.6% |
| 0.9 | 15.9% | 17.9% | 10.1% | 0.5% |

Routing in WSN requires to account for communication failures

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