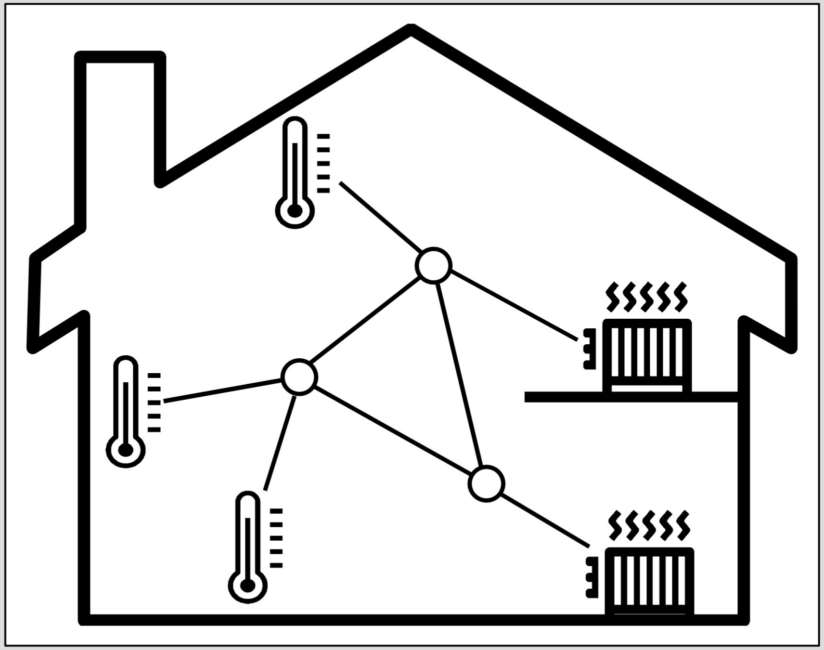
Source-Node Selection to Increase the Reliability of Sensor Networks for Building Automation

Atis Elsts
SICS Swedish ICT

Application area

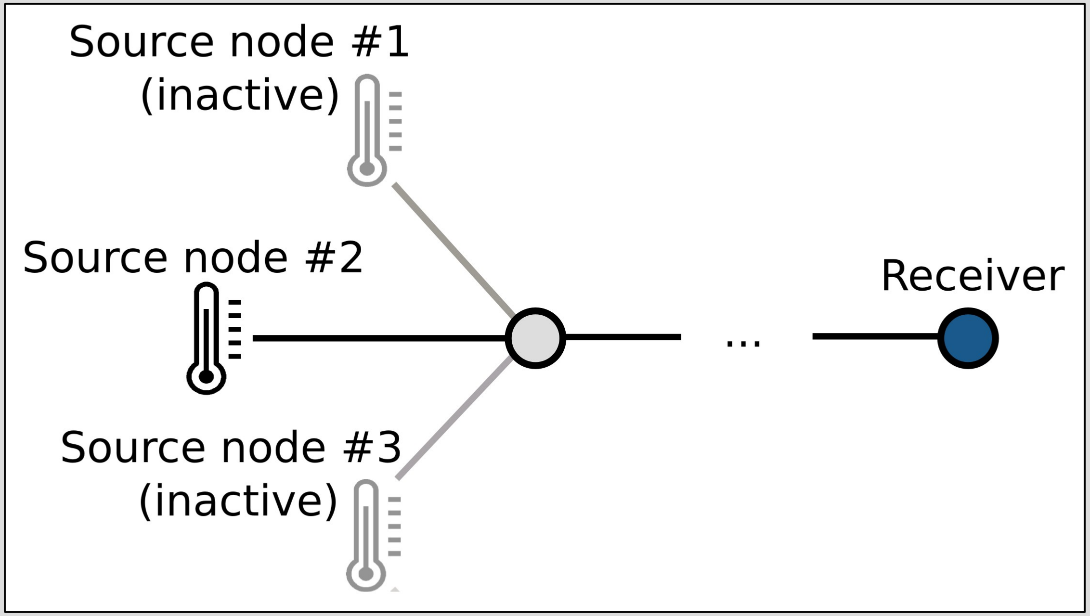
- Smart buildings: monitoring + control for HVAC
- Low-power wireless networks:
  - Can be easier to setup than wired ones
  - More vulnerabe to communication problems & component failures
- Maintenance is expensive!



SWEDISH ICT SICS

The idea

- Adaptively activate the minimally required number of source nodes
- Assumption: highly correlated measurements within each region
- Benefits:
  - From redundancy – better reliability
  - From adaptivity – longer lifetime:
    - Lower total energy consumption
    - Less likely to have network congestion



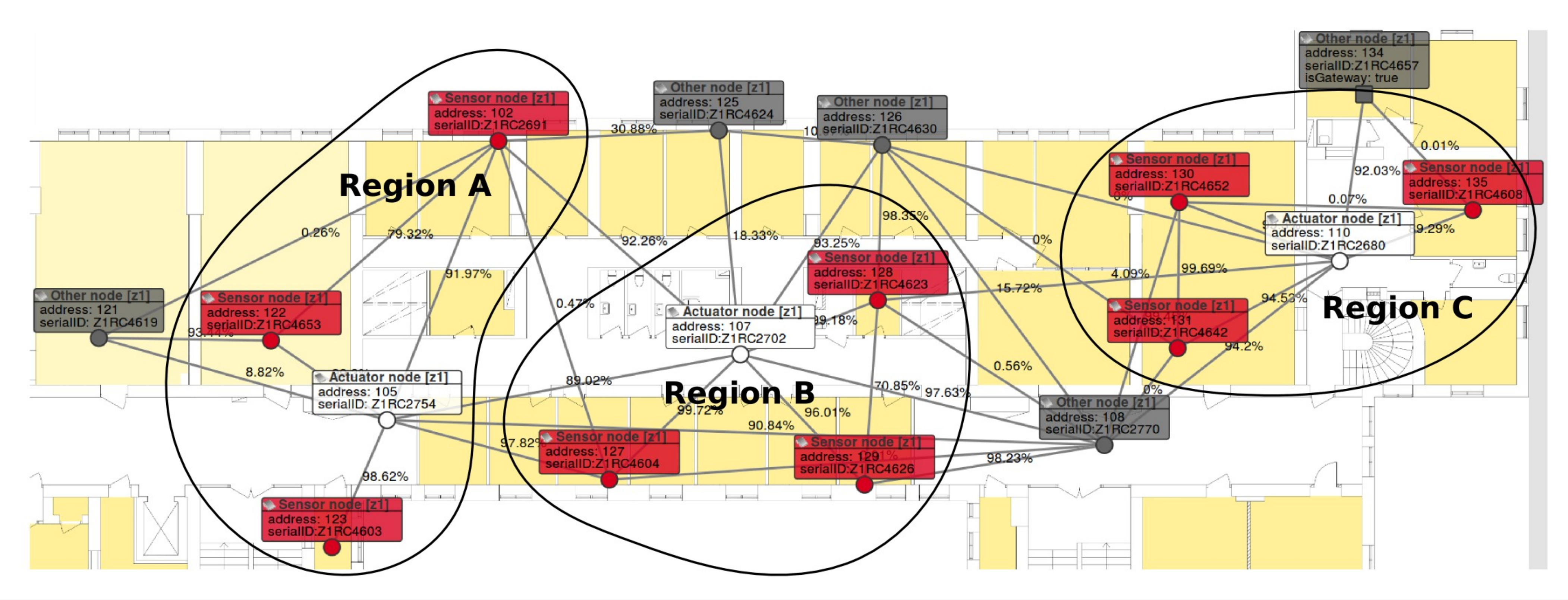
SWEDISH ICT SICS

Existing approaches

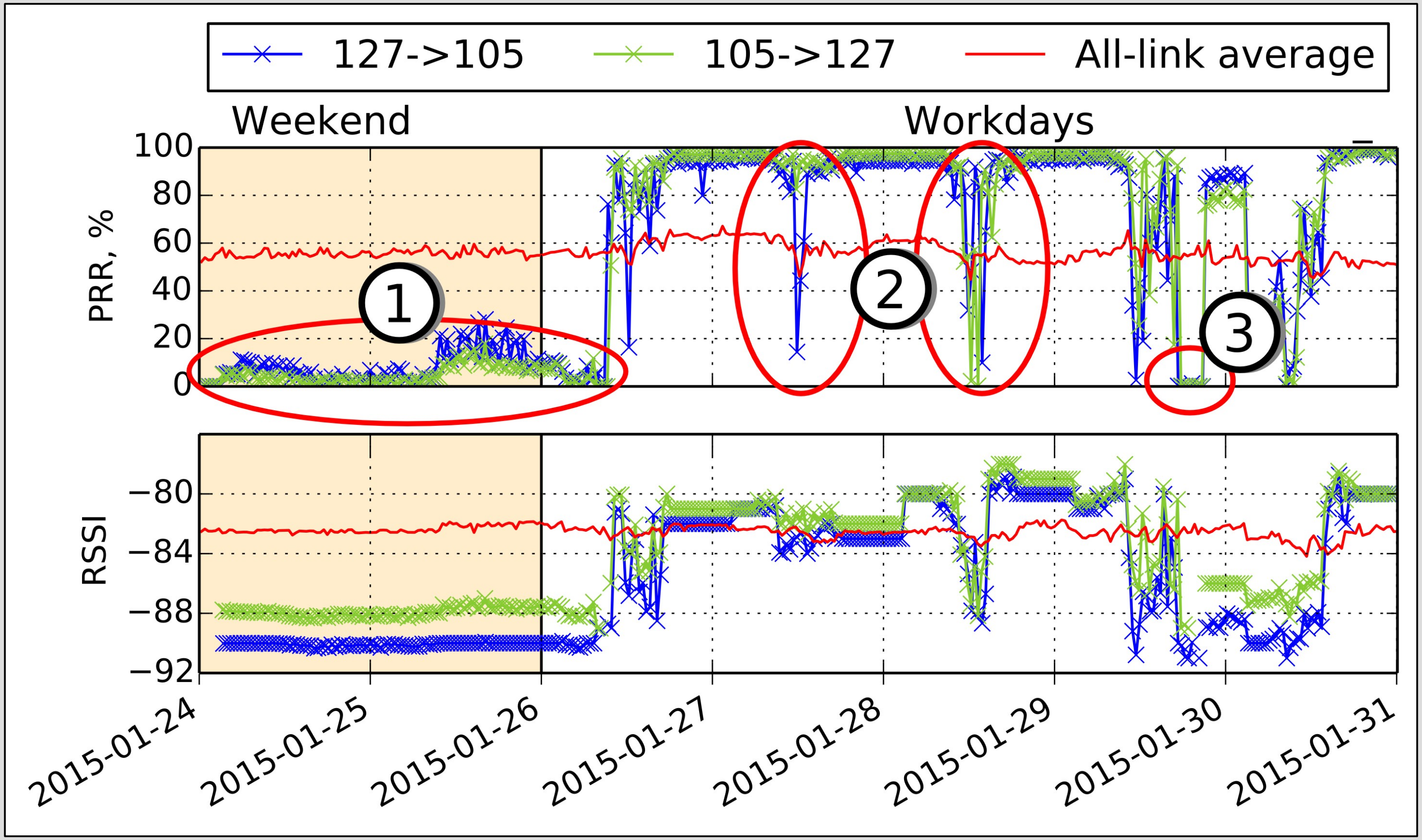
- Methods to increase network reliability:
  - Multichannel communication
  - Multipath & opportunistic routing
  - Network flooding
  - Forward error correction and network coding
- Limits:
  - Limited help when the **source node** breaks down or becomes disconnected

Preliminary measurements

- Low-power wireless network (17 Z1 nodes) in an office building
- Measure four IEEE 802.15.4 channels (12, 15, 18, and 21)
- Measure in several periods (January, April and September, 2015)
- http://rabbit.it.uu.se:12000/profun/ - test network (@ “Network” tab)



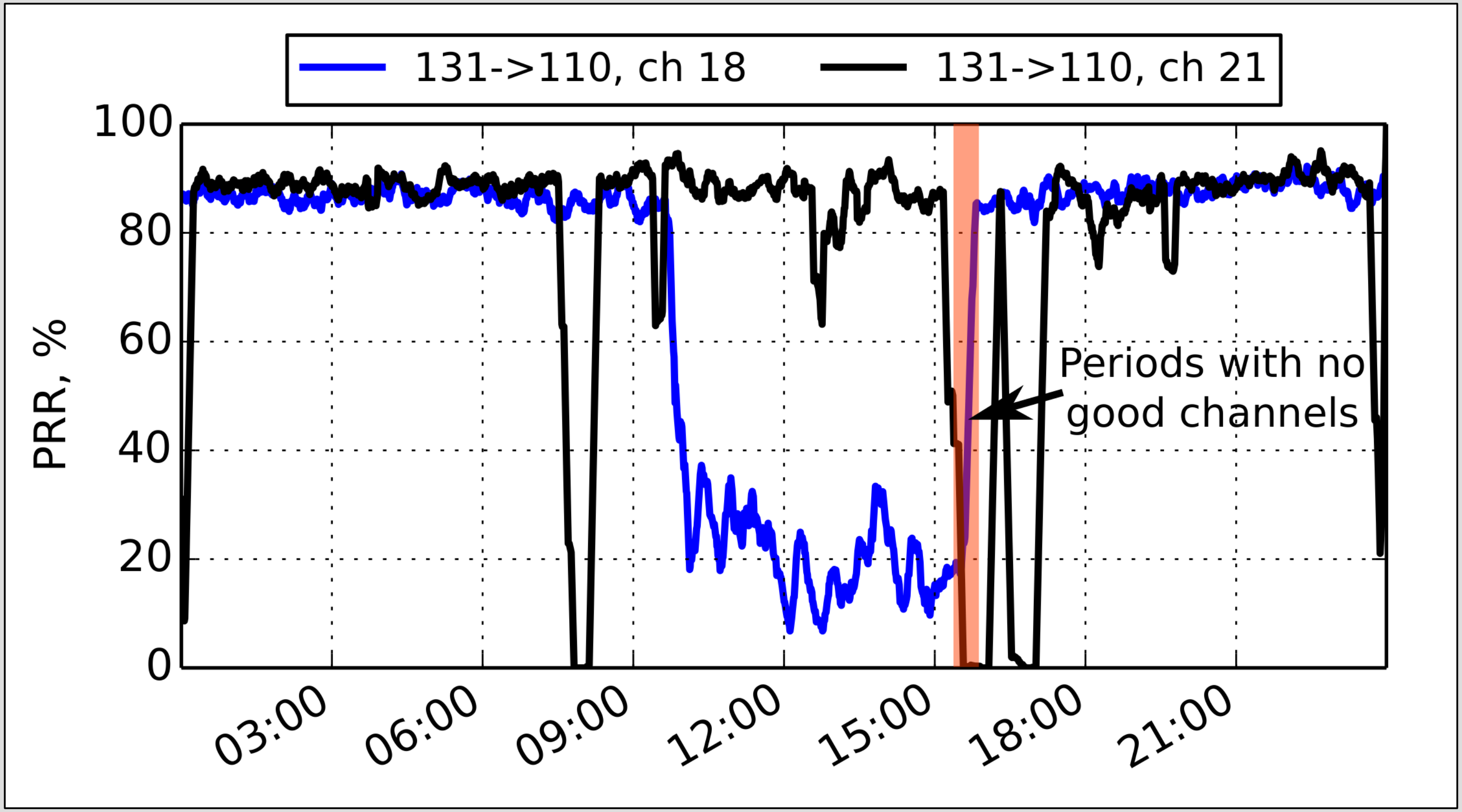
Multiple causes of bad performance



- Causes: (1) weak links; (2) WiFi interference
- (3) shows long (minutes to hours) periods with very low performance

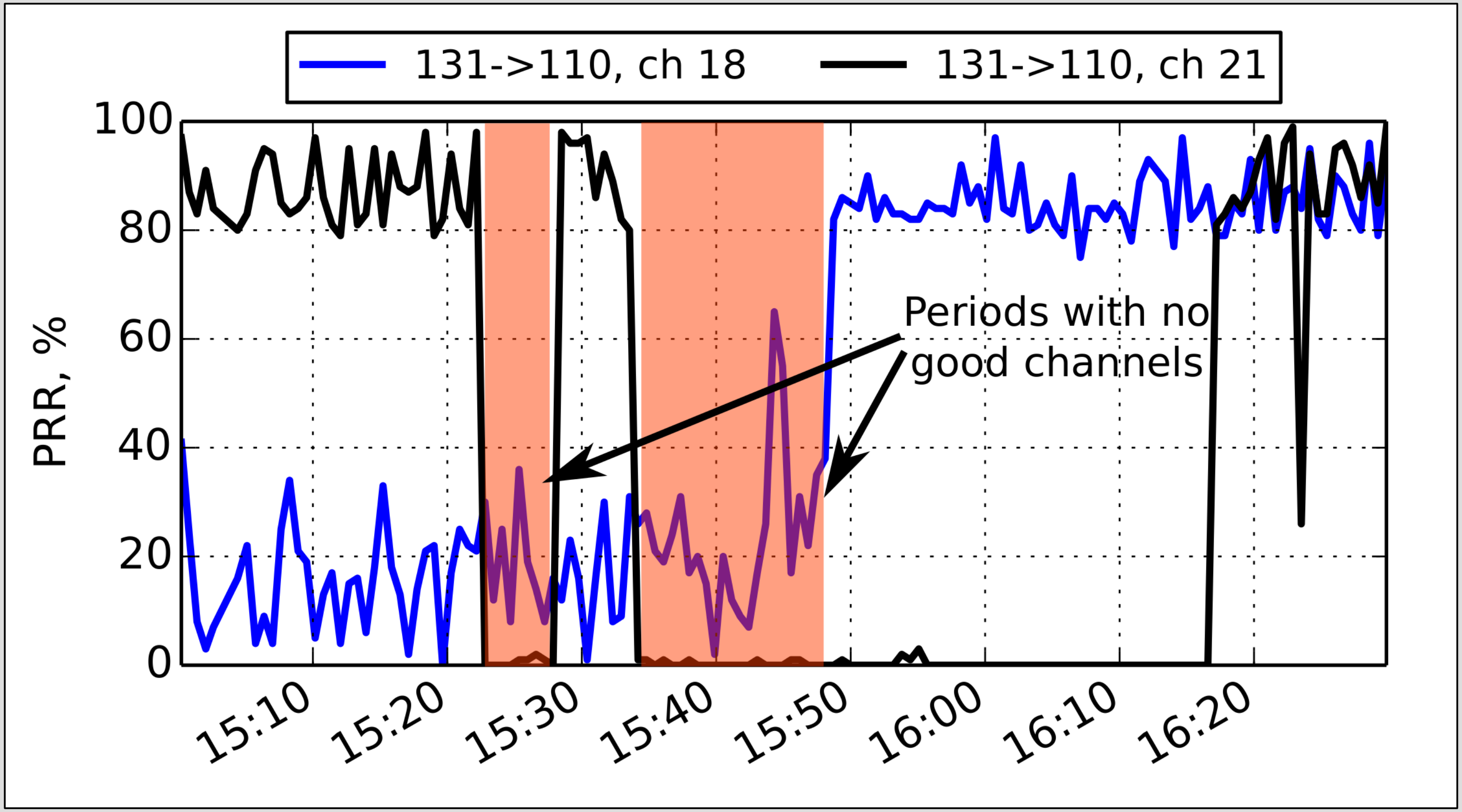
SWEDISH ICT SICS

Multichannel is not enough



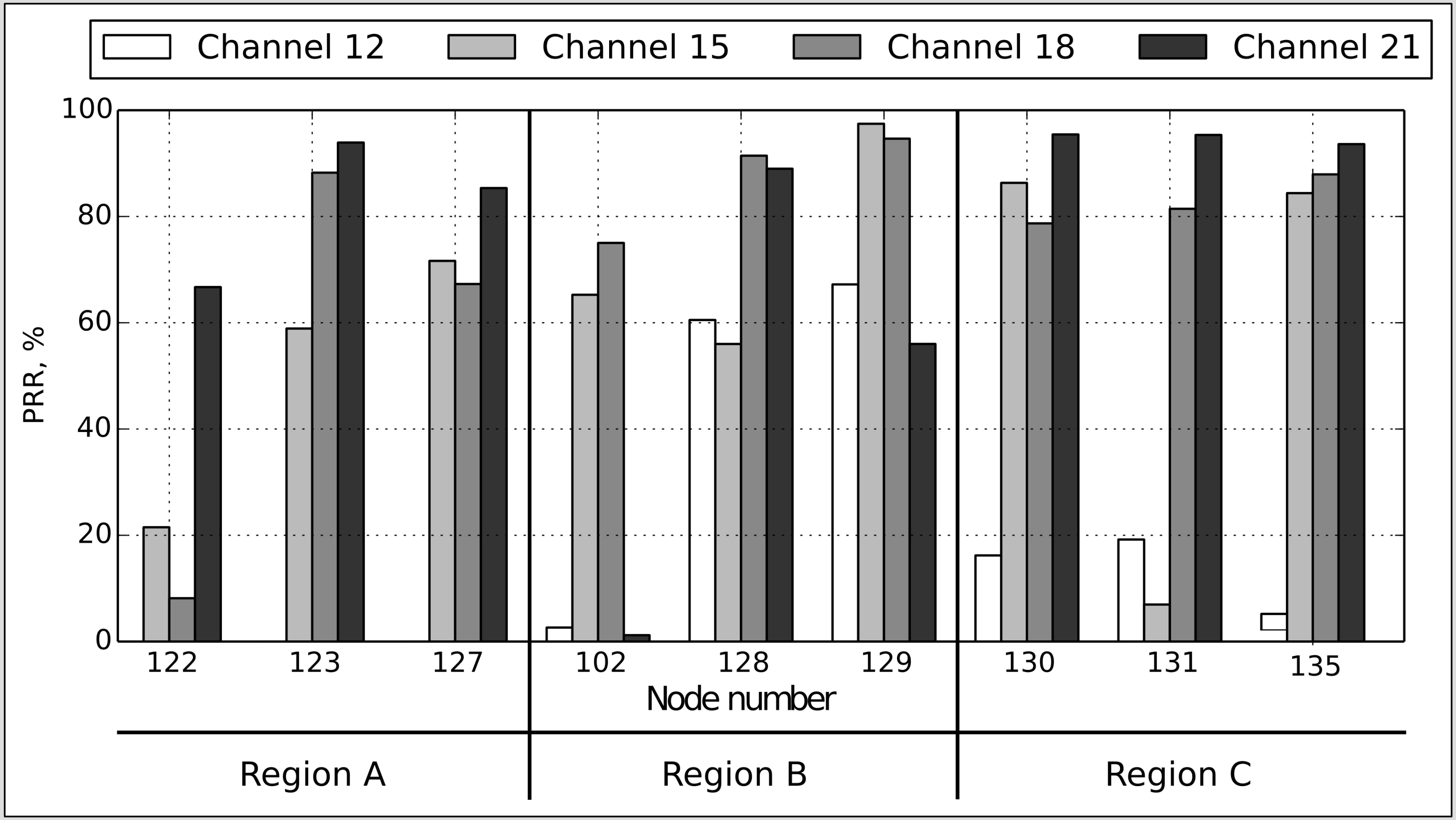
SWEDISH ICT SICS

Multichannel is not enough



SWEDISH ICT SICS

Node performance is diverse



- No channels are good on all nodes
- All nodes have some good channels (long term)

The target application

- Building climate monitoring/control with distributed temperature sensing
- Assumptions:
  - redundant source nodes
  - correlated measurements
  - link and node failures are probable
- *Time with no recent information* as the metric to minimize
  - Operational decisions should be based on recent information
  - Derived from *age of information* metric on receiver nodes:

    “*Age of information* at time *t* on node *n* is the difference between *t* and the origination time of the message with most recent origination time among the source node messages received on the node *n*.”

SWEDISH ICT SICS

Design ideas

- Adaptively activate the minimal number of required source nodes

- Adapt:
  - using (possibly) distributed decision making
  - reactively
- Always keep the system within a safety margin
- Include hopping over multiple radio channels
- Don't introduce additional traffic for link quality measurements

Ranking source nodes

- Use ETX (estimated transmission count) metric
- Apply EWMA filter to incorporate history
- Apply these enhancements to ETX:
  - Hysteresis, to reduce network churn
  - Temporal decay towards the default starting value

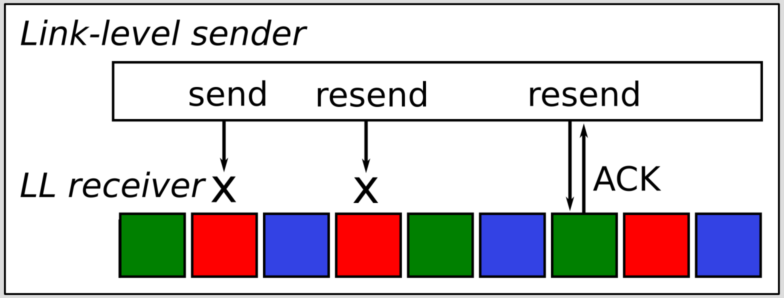
- Update ETX based on data packets:
  - Packet **received**: update ETX based on the number of retransmissions
  - Packet **expected** & **not received**: increase ETX
  - Packet **not expected** & **not received**: move ETX towards a default value

SWEDISH ICT SICS

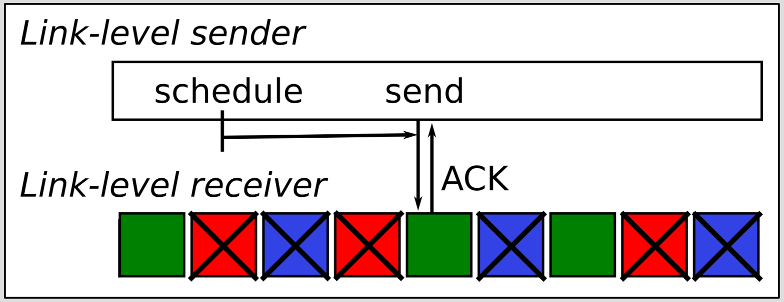
Exploiting multiple channels

- Build on ContikiMAC protocol with channel hopping (MiCMAC)
  - Hop channels pseudorandomly
  - Use network-wide channel sequence
- Add link-level blacklisting to handle regional variation
- Let the sensor stream receiver node learn the number of blacklisted channels on each source node

Without blacklisting:



With blacklisting:



SWEDISH ICT SICS

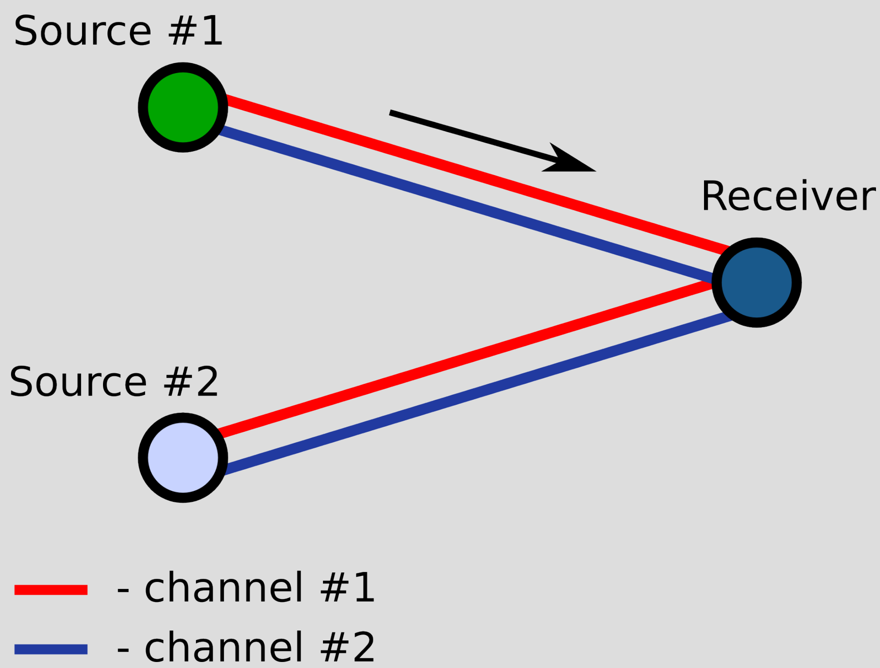
Number of active source nodes

- If the best of nodes is in a "good state", use this **single** node
  - Good state: node has low ETX & several nonblacklisted channels
- Otherwise keep at least **two** nodes active
- While the system does not deliver acceptable PDR, **keep activating** nodes

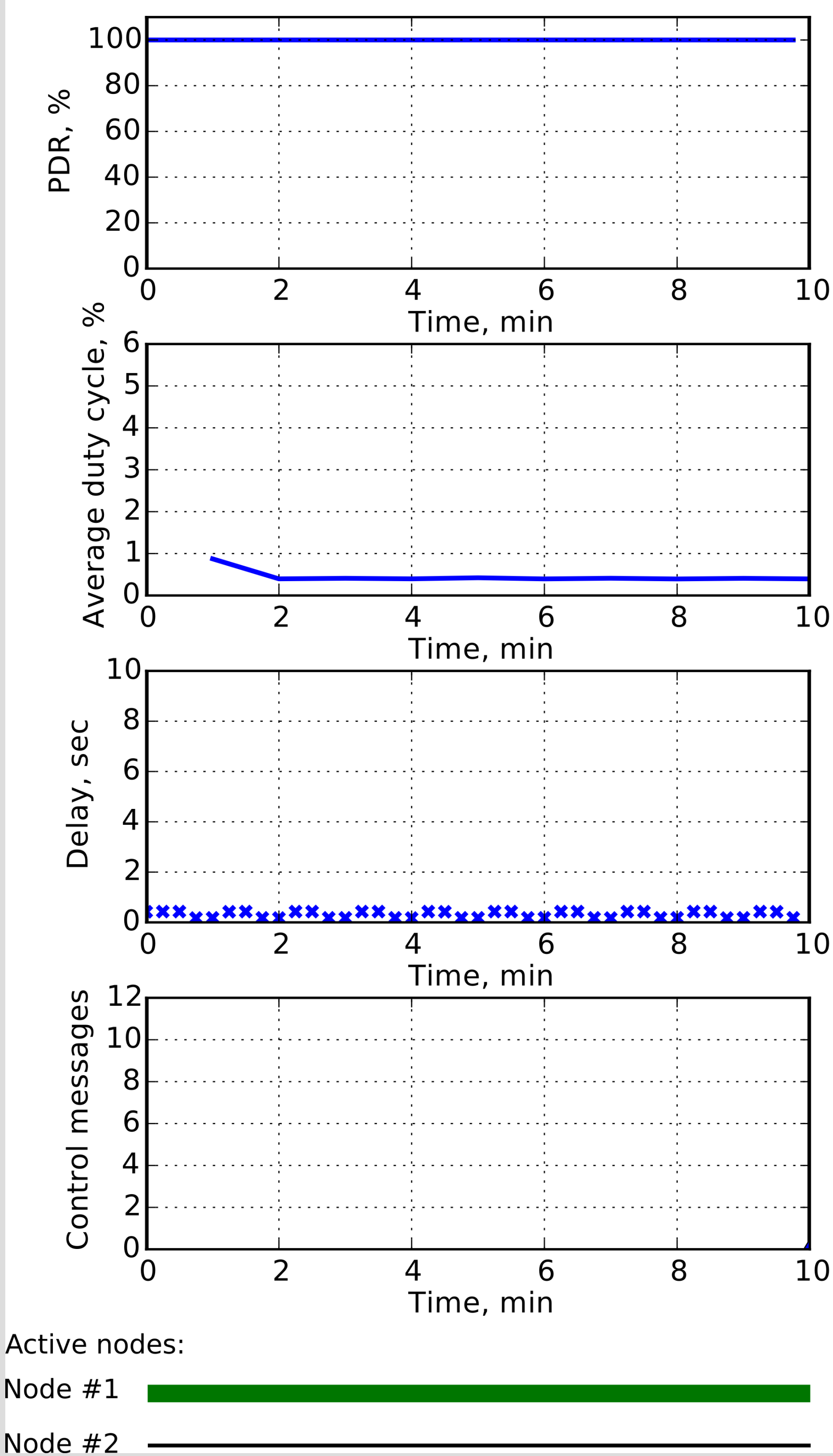
- Deactivate nodes "lazily"
  - Use only negative ACKs, not immediate deactivation messages

SWEDISH ICT SICS

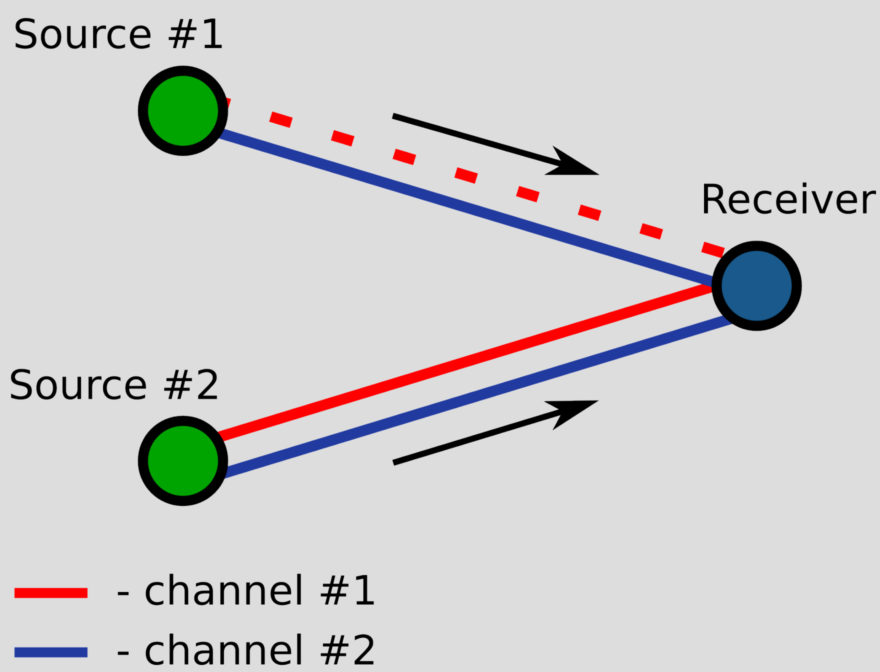
Example



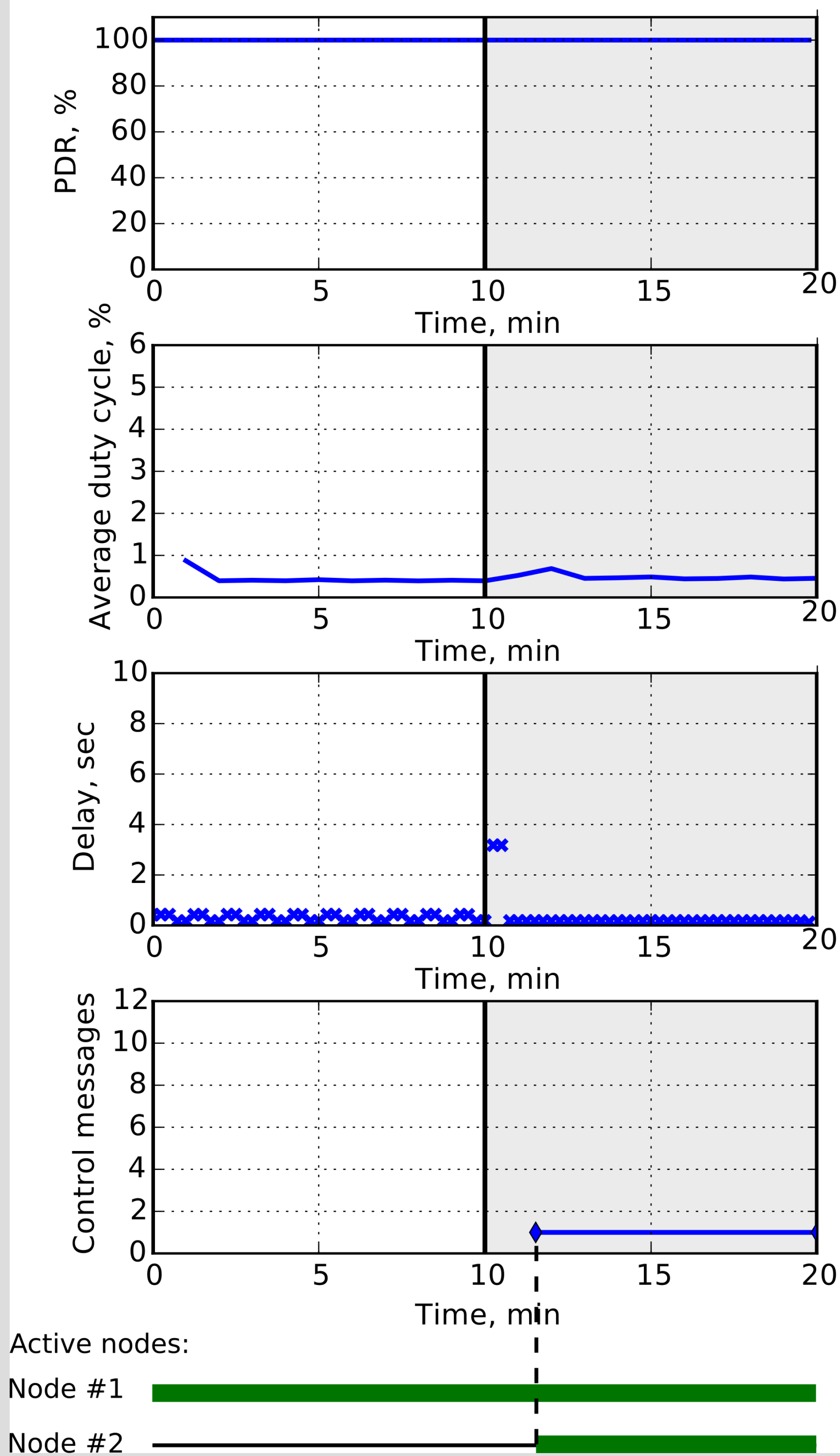
“Good” channels: 90% PRR
“Bad” channels: 10% PRR
Initially all channels are good



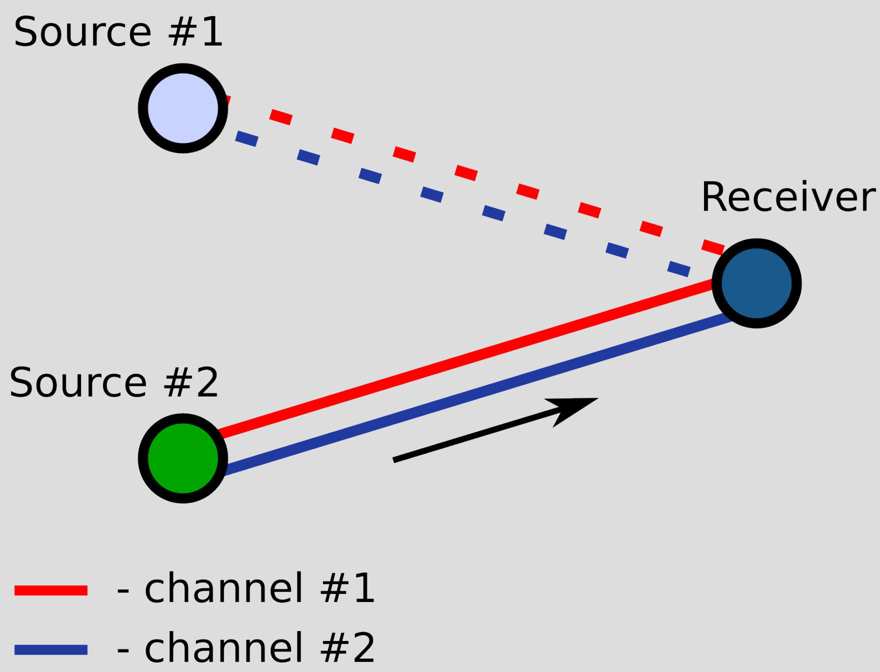
Example



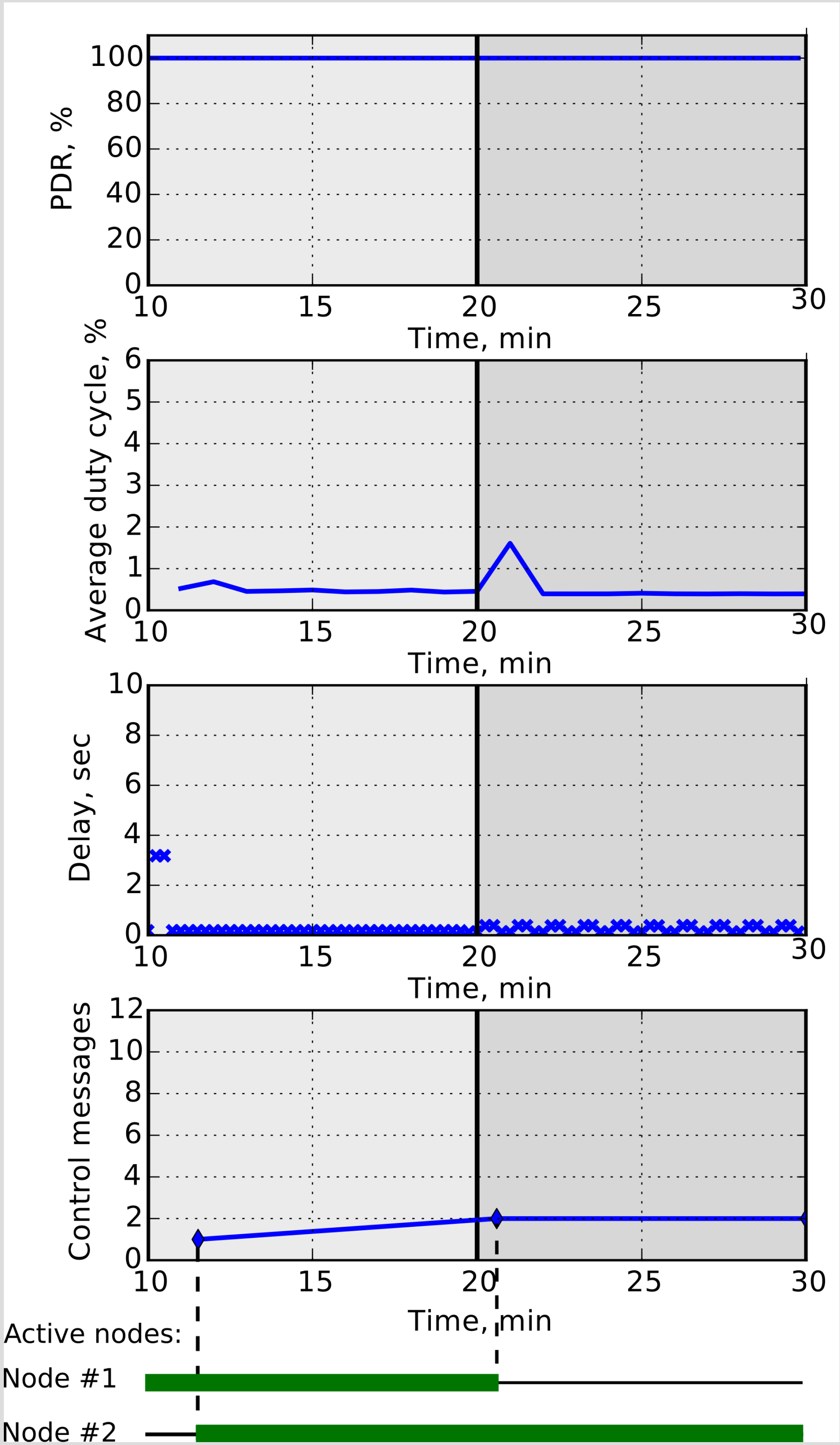
Red channel quality on *source #1* dropped to 10% PRR



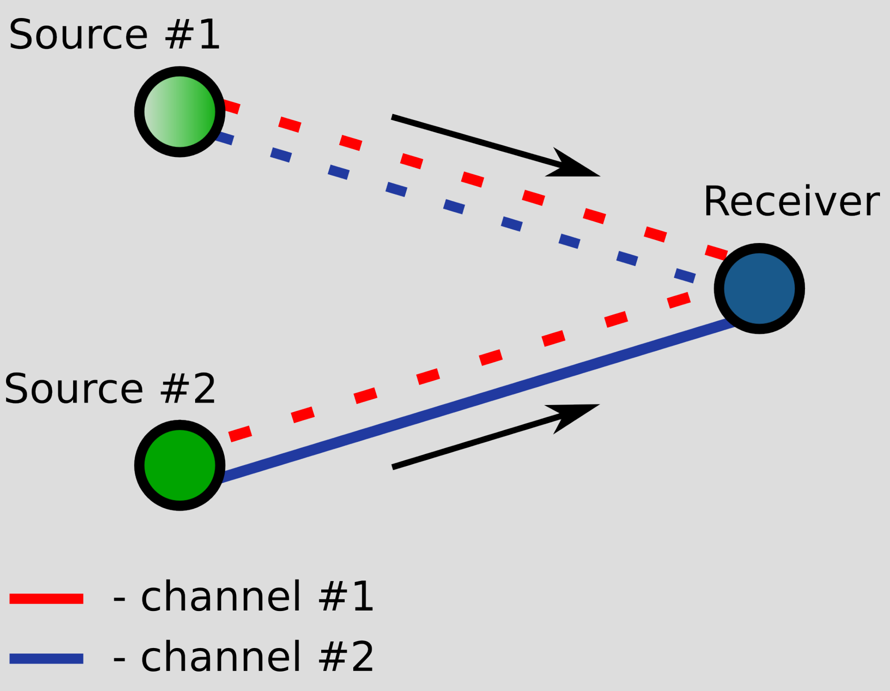
Example



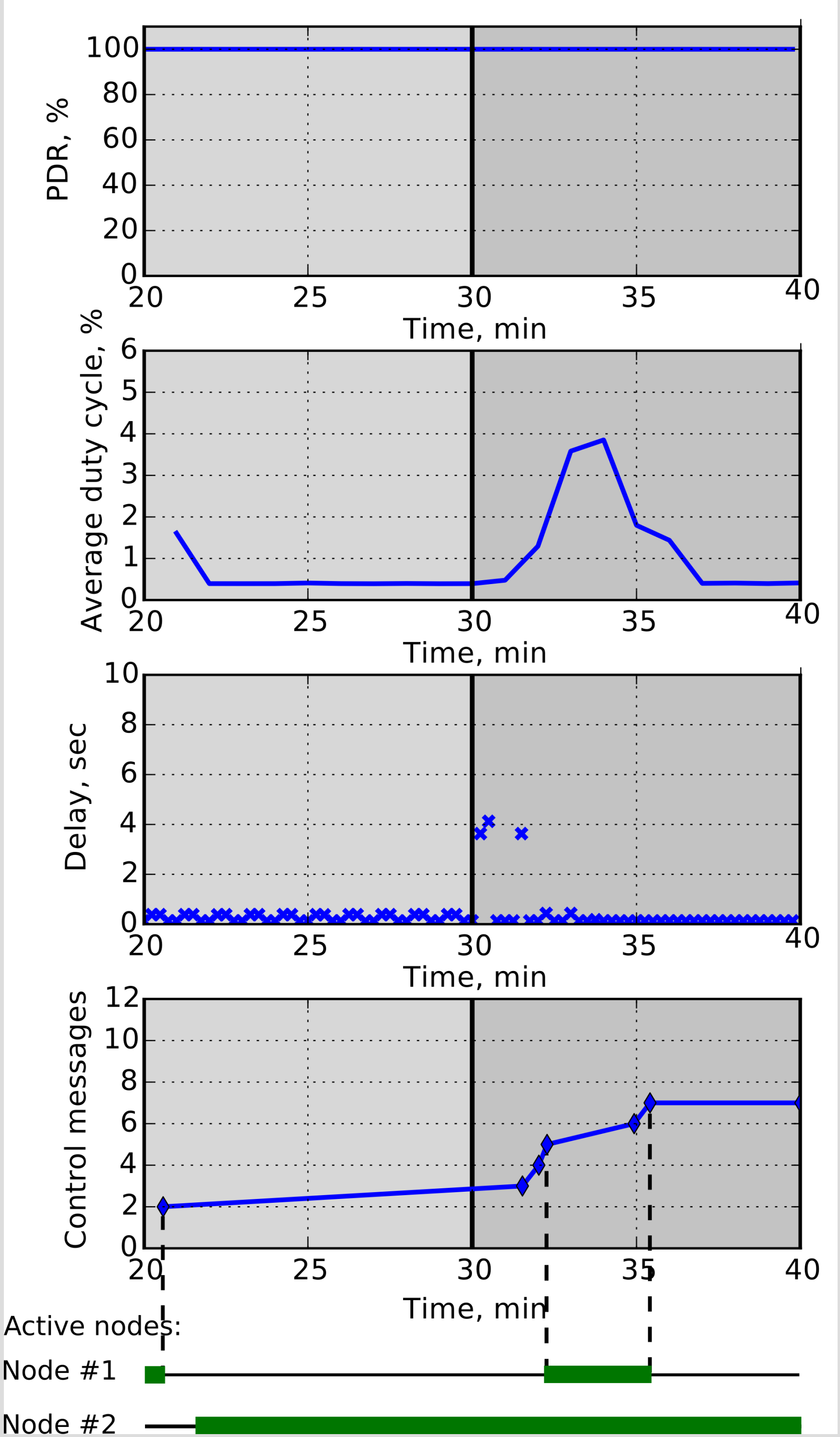
Blue channel quality on *source #1* dropped to 10% PRR



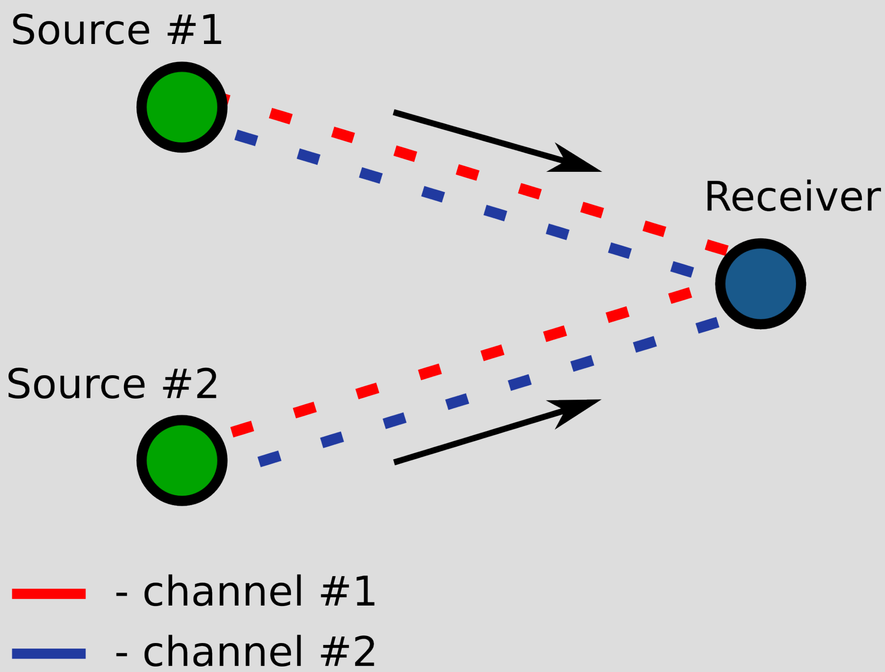
Example



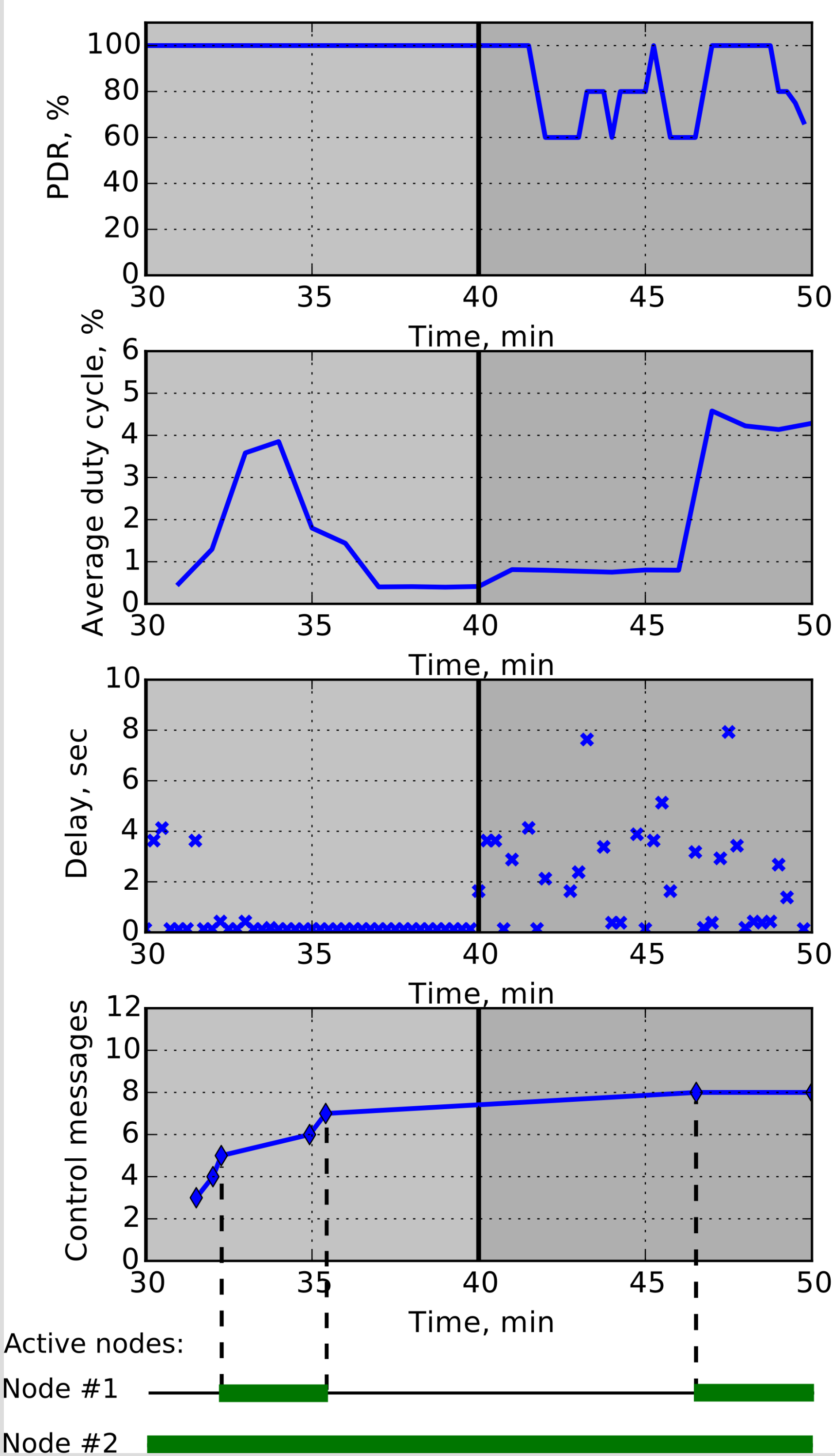
Red channel quality on *source #2* dropped to 10% PRR



Example

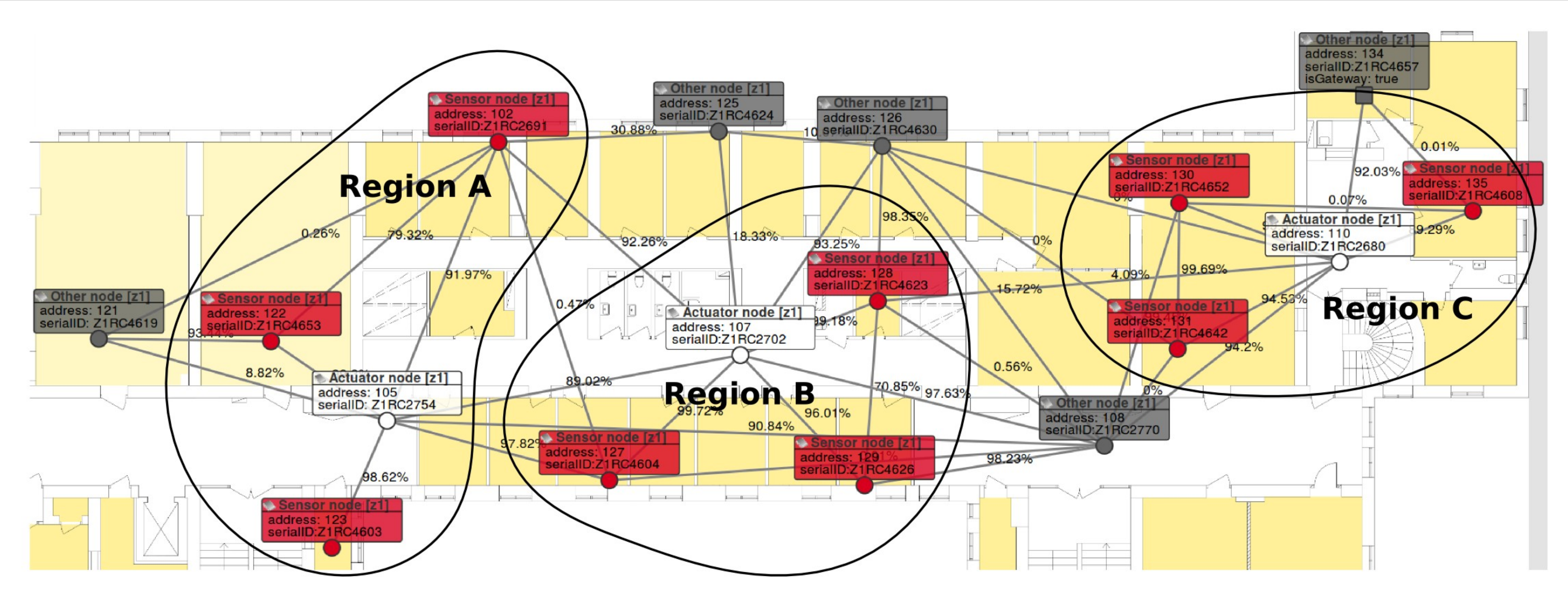


All channels at 10% PRR



Experimental setup

- Three data-sink nodes in the network
- Three data-source nodes for each sink
- Mimics a smart building network with decentralized collection/control
- Single hop: pictured; multihop: flows from regions A and B to single receiver @ region C



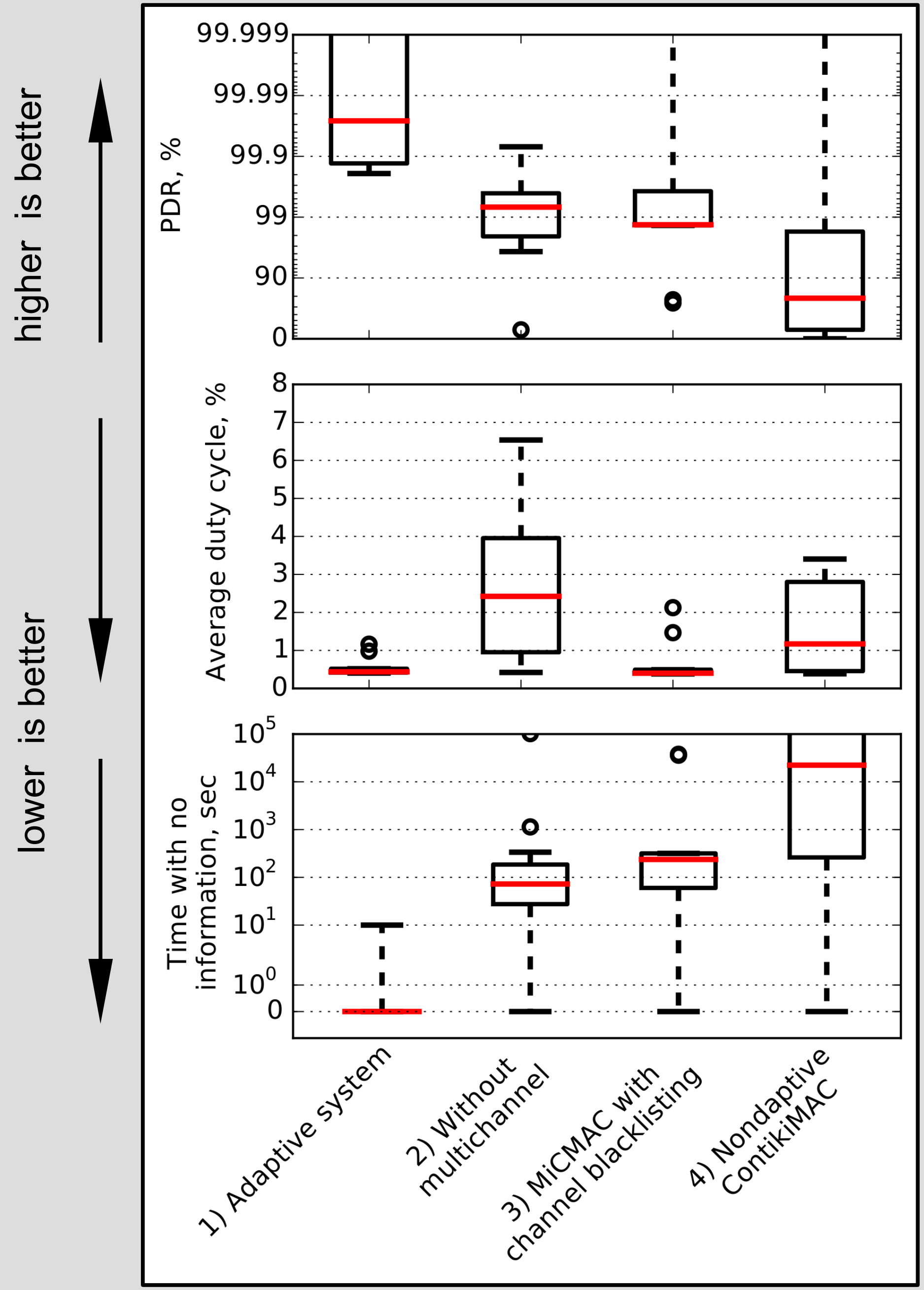
Simulation setup

- Cooja + RealSim for network simulation
- Experiments on 48 h long packet traces describing 4 channels
- 5760 h total simulation time

- Compare:
  - The complete adaptive system
  - Only source node selection (no multichannel)
  - Only multichannel
  - Default ContikiMAC

SWEDISH ICT SICS

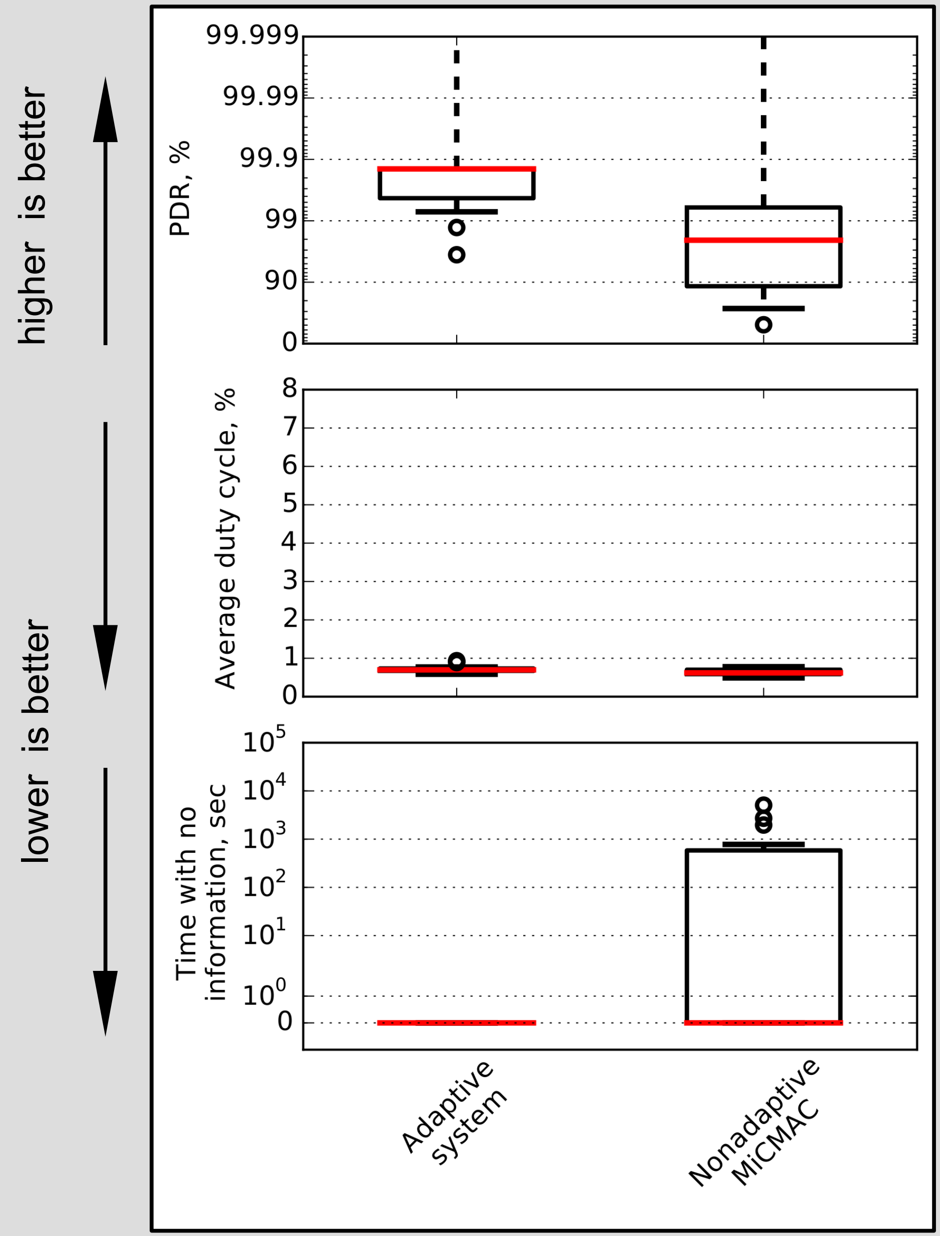
Simulation results



- Each point is a separate 48 hour experiment
- 8 – 32 experiments for each method

SWEDISH ICT SICS

Testbed results



- Each point is a separate 3 hour experiment
- 18 – 21 experiments for each method
- Methods were temporarily interleaved for fairness

Conclusion

- A simple mechanism to increase reliability
- Can handle node and link failures
- 99.86 % median PDR with < 1% radio duty cycle in the testbed

- Future work:
  - Node selection based on other metrics (e.g., remaining energy)
  - Comparison with a centralized solution (*Profun TG*)

SWEDISH ICT SICS

Questions?

Thank you!

Thanks to Uppsala University for partially funding this work, including the construction of the testbed

SWEDISH ICT SICS