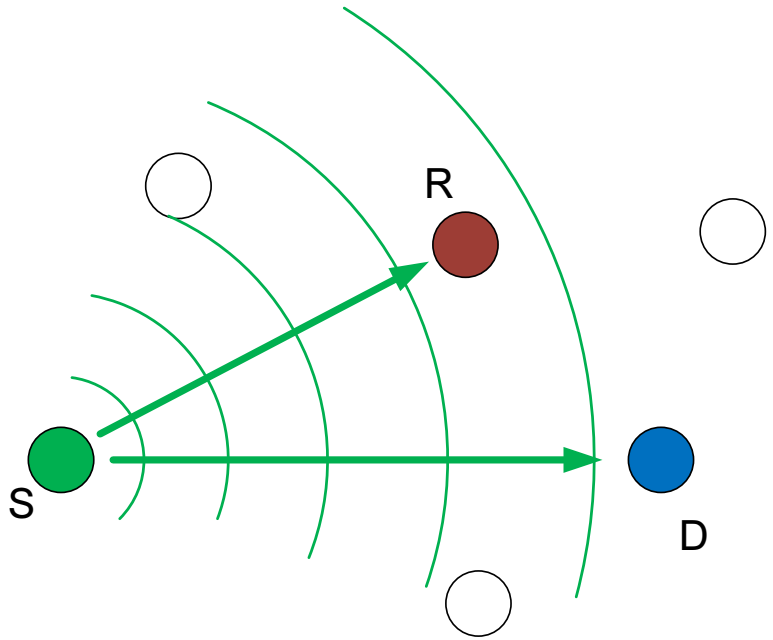
An Experimental Evaluation of Selective Cooperative Relaying for Industrial Wireless Sensor Networks

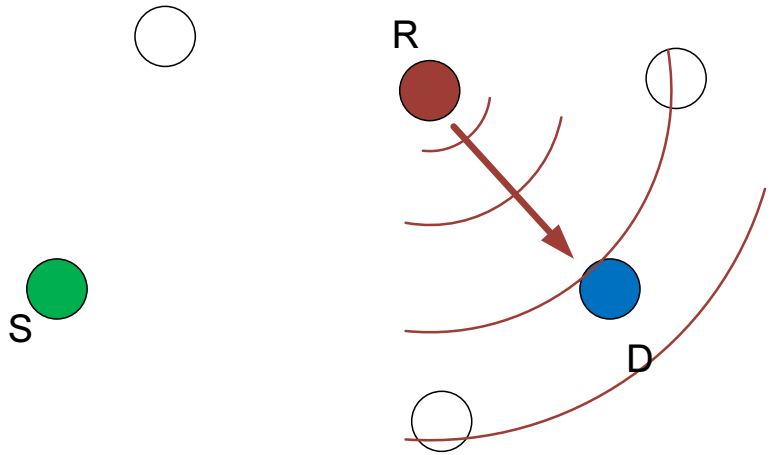
Nikolaj Marchenko, Torsten Andre, Günter Brandner,
Wasif Masood, and Christian Bettstetter

Institute of Networked and Embedded Systems
University of Klagenfurt, Austria

Quick Intro



Quick Intro



Quick Intro

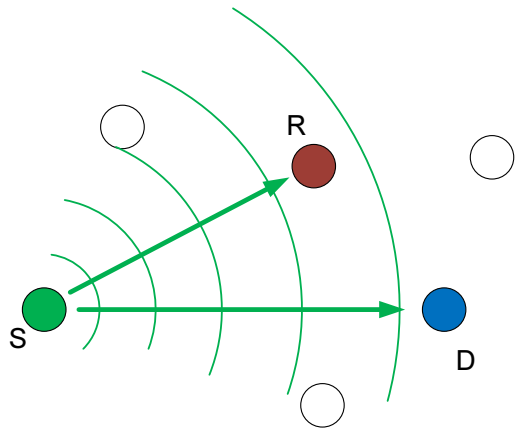
- Lots of theoretical work on cooperative relaying
- Some experimental studies (40+ articles):
  1. Software-Defined Radios: Mostly PHY Layer, few nodes
  2. Wireless Sensor Nodes: MAC/Network layer, many nodes

Application in Industrial WSN

- Monitoring and control of production processes
- Harsh environment for wireless signal propagation
- Very strict requirements on link reliability and delay
- Standards: WirelessHART, ISA100.11a, Zigbee IA Profile

Relay Selection

1. Which metrics to use for relay selection?
   - Channel quality info, residual battery life, etc.
2. How selection is coordindated?
   - Signaling messages, contention mechanism, etc.
3. How often a relay is updated?
   - Update requirements and policy.



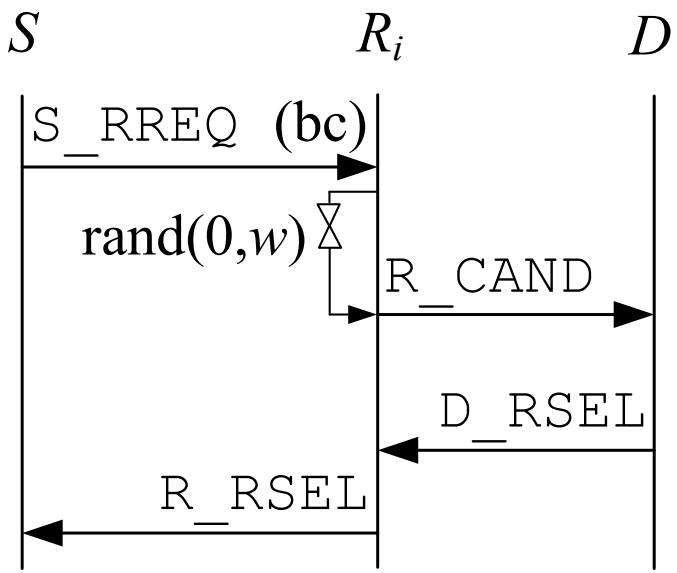
Relay Selection

I. Periodic Relay Selection

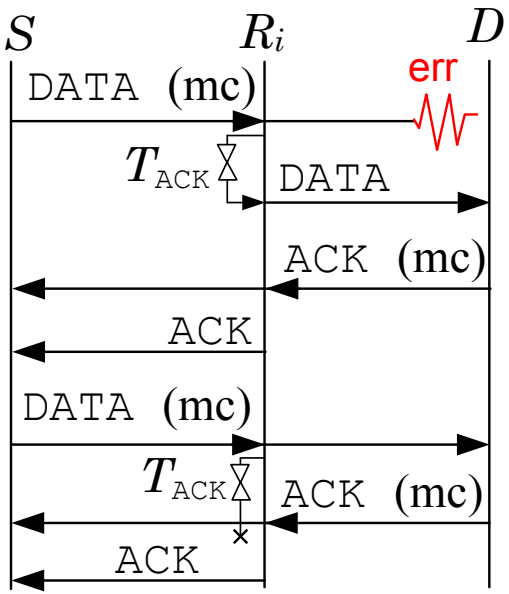
A relay is selected strictly at periodic time intervals T_{sel}

- random contention of candidates in window w.
- based on current Link Quality Indicators $S - R$ and $R - D$.

selection



retransmission



Relay Selection

II. Adaptive Selection

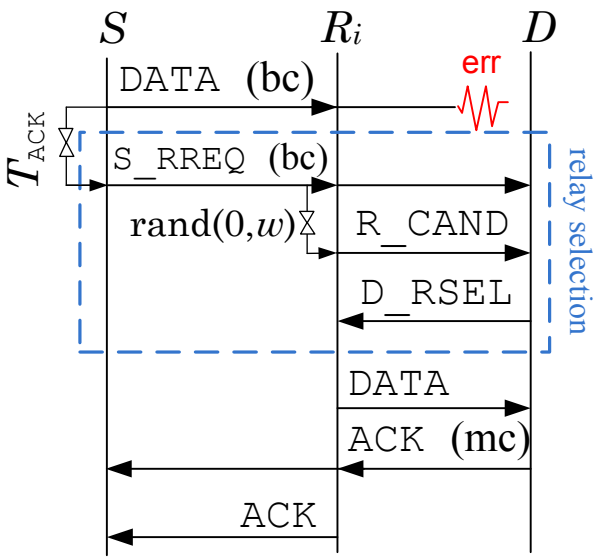
- A new relay selection when in a window W_a more than ε_a ACKs are lost.
- Selection and retransmission procedure same as periodic

III. Reactive Selection

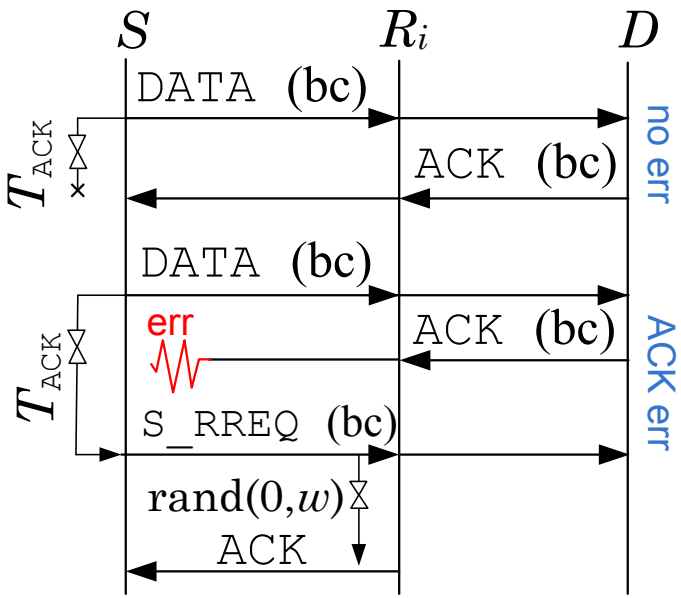
Selection is performed after each missing ACK for direct *S*-*D* transmissions among nodes that

1. have received the packet correctly
2. have a good channel to the destination

DATA delivery by *S* fails



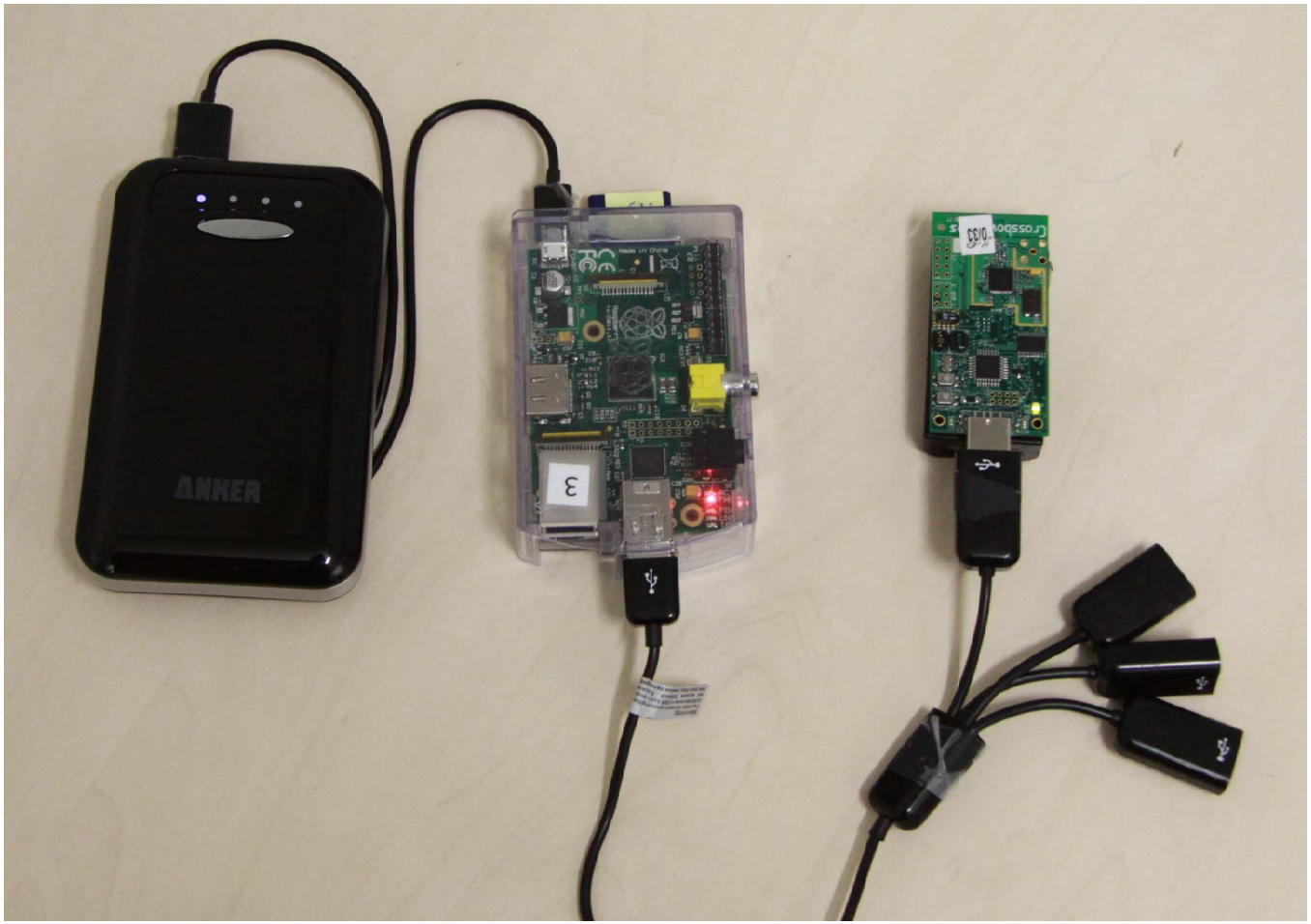
DATA is delivered by *S*



Test Environment

Test Environment

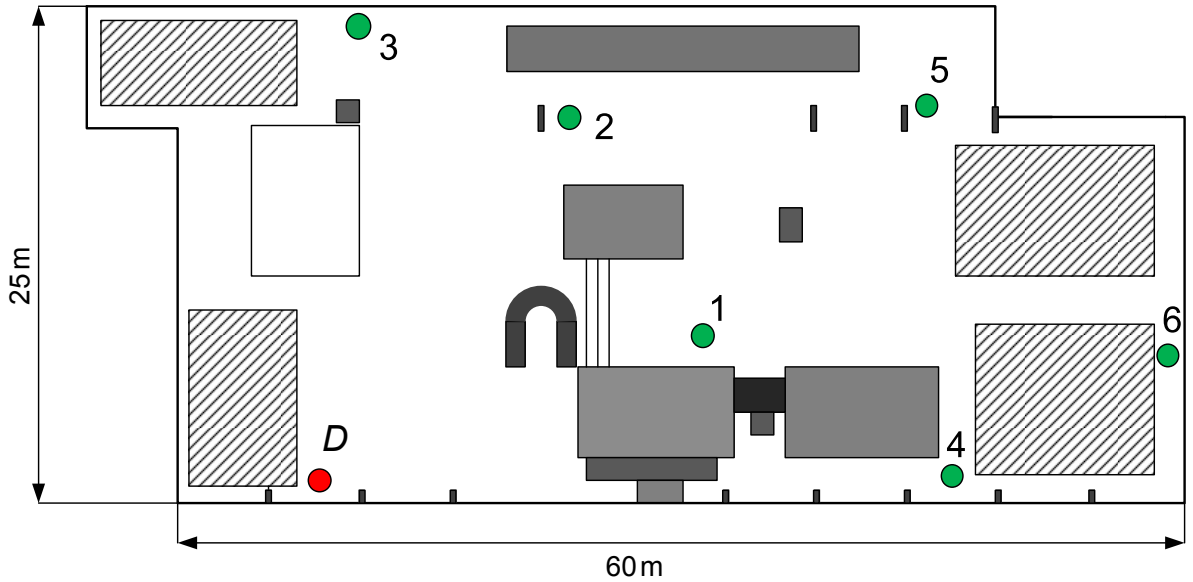
Hardware



- Crossbow TelosB
- TinyOS implementation
- Transmission: 2.4 GHz, 256 kbit/s, TxPower: -4 dBm

Layout

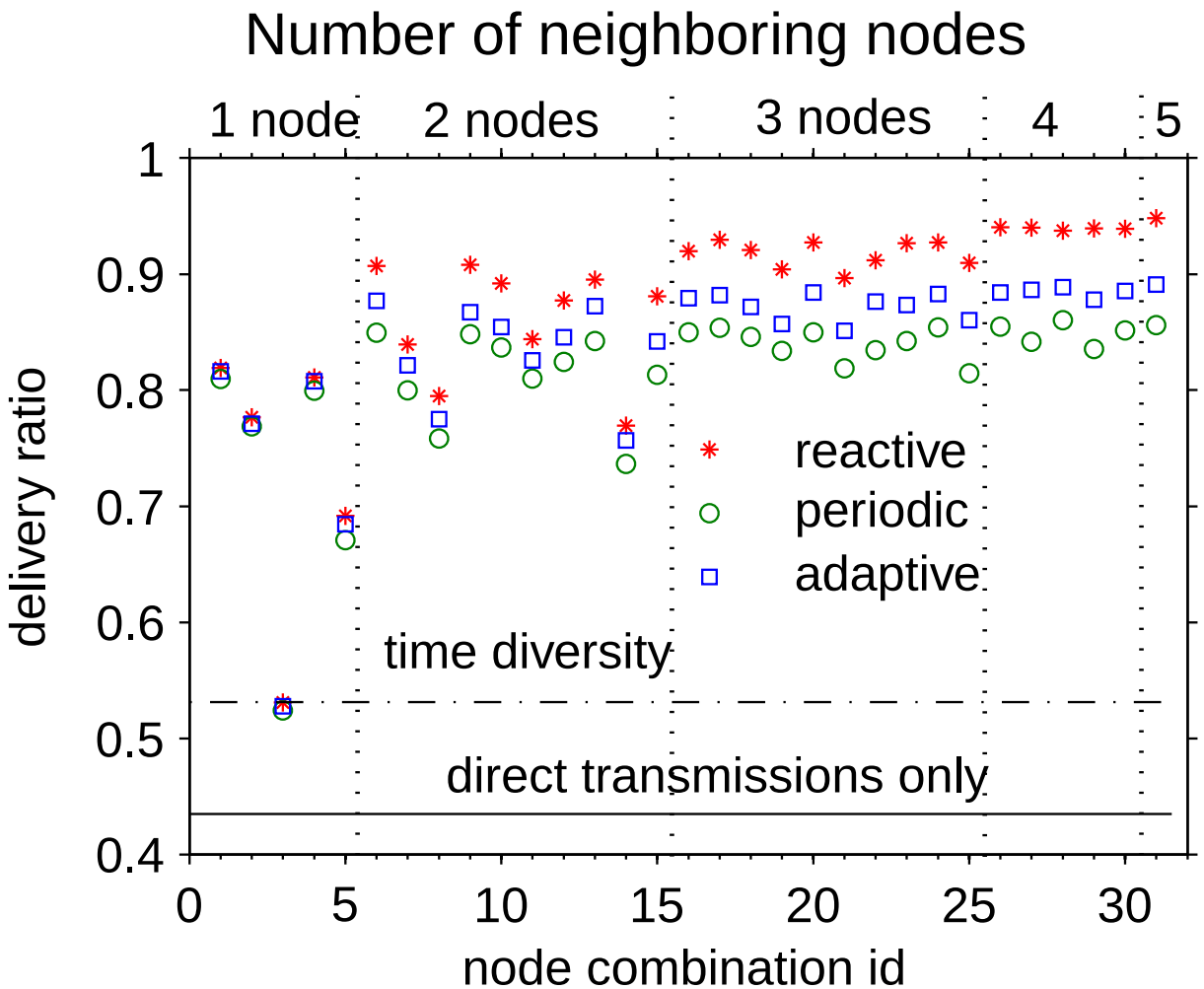
- 7 nodes, 6 tested links



- Two kind of experiments:
  1. Trace-based analysis on individual link:
     Node 6 transmits to *D* every 160 ms, other nodes retransmit
  2. Explicit experimental comparison over all links

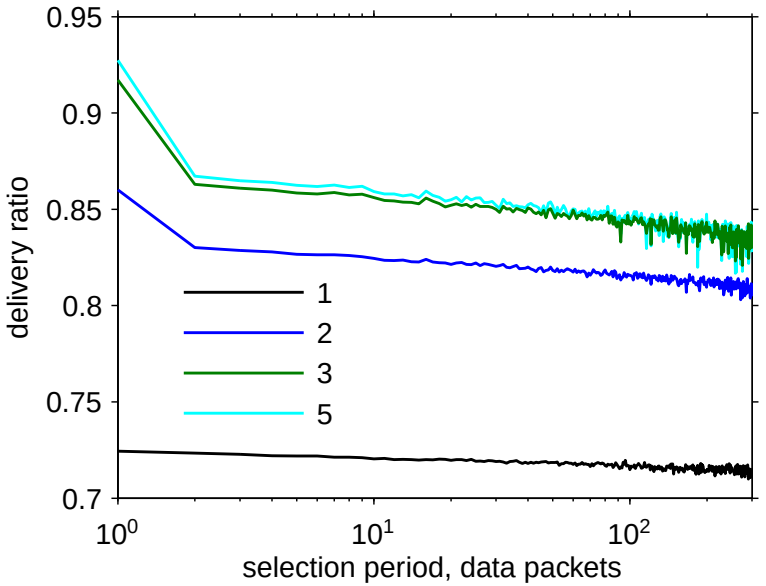
Performance Results: Trace-Based Analysis

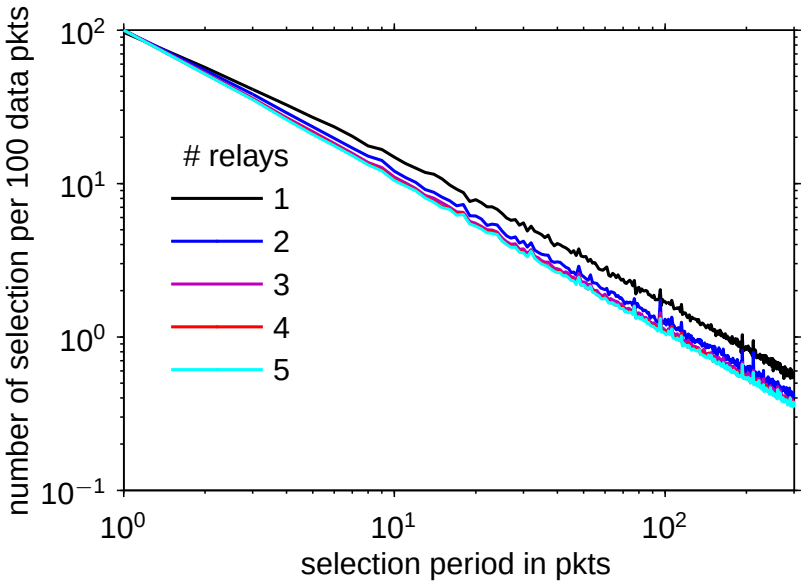
1. Periodic selection: every 200 packets
2. Adaptive selection: if error rate $>$ 10% for last 50 packets.



Performance Results: Trace-Based Analysis

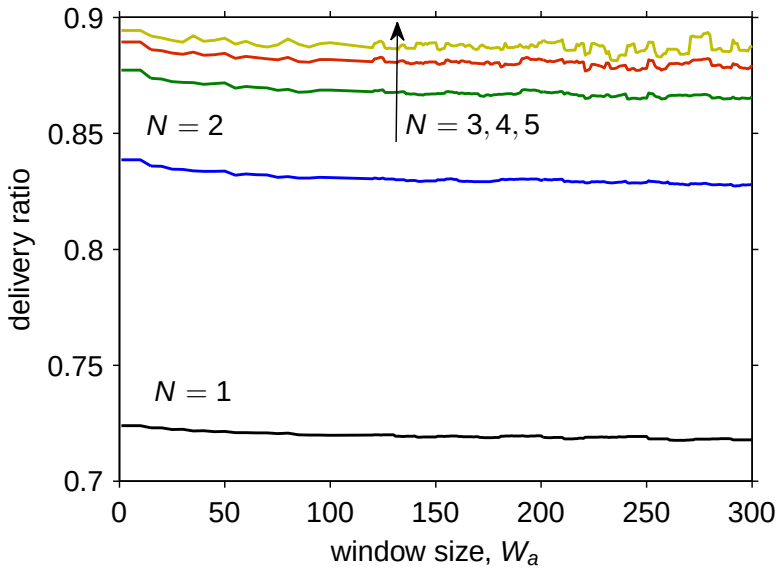
Periodic selection

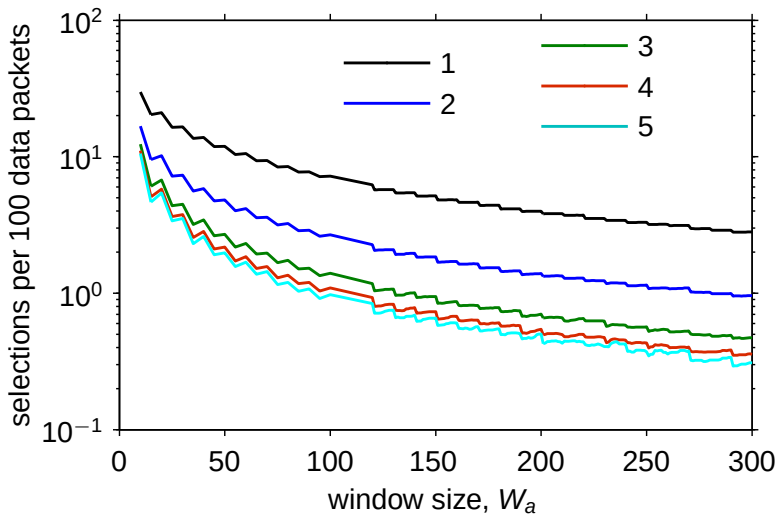




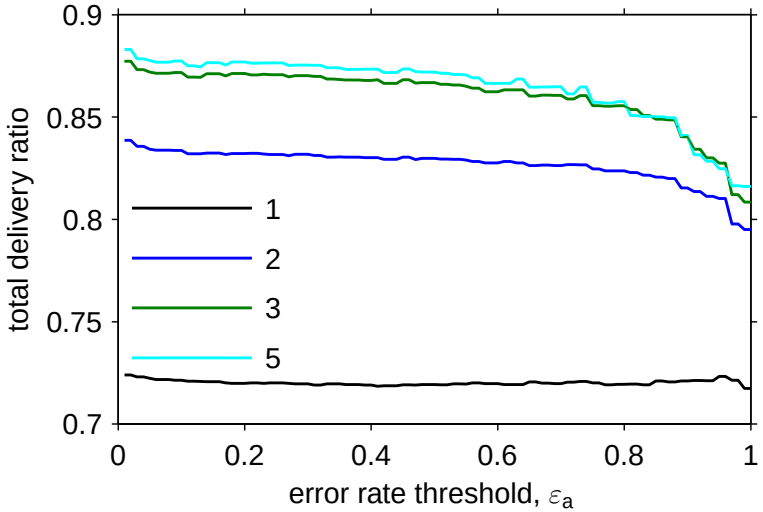
Performance Results: Trace-Based Analysis

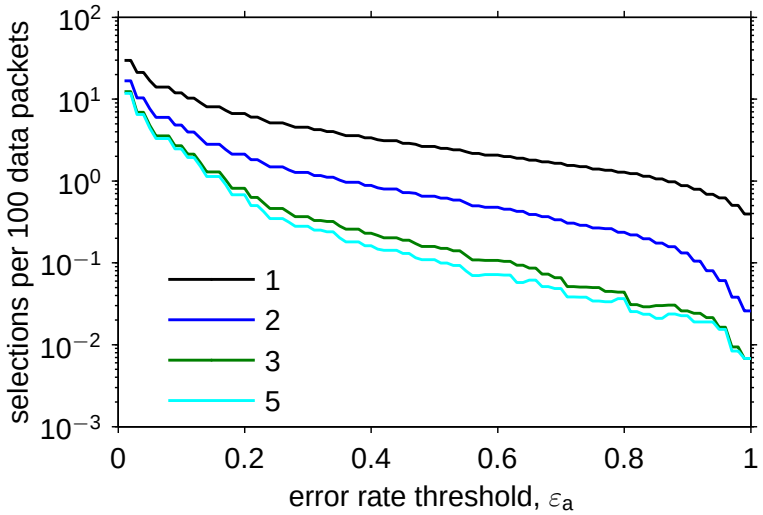
Adaptive selection: Window



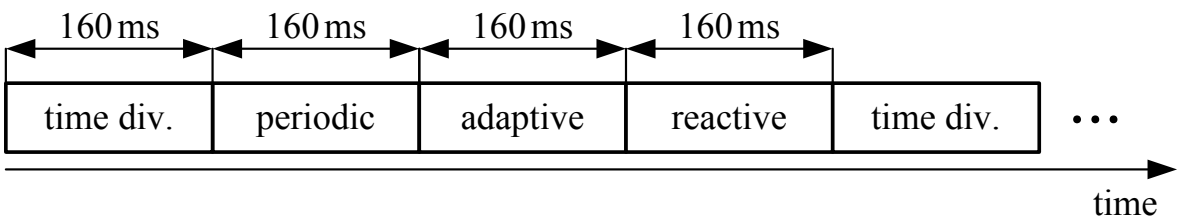


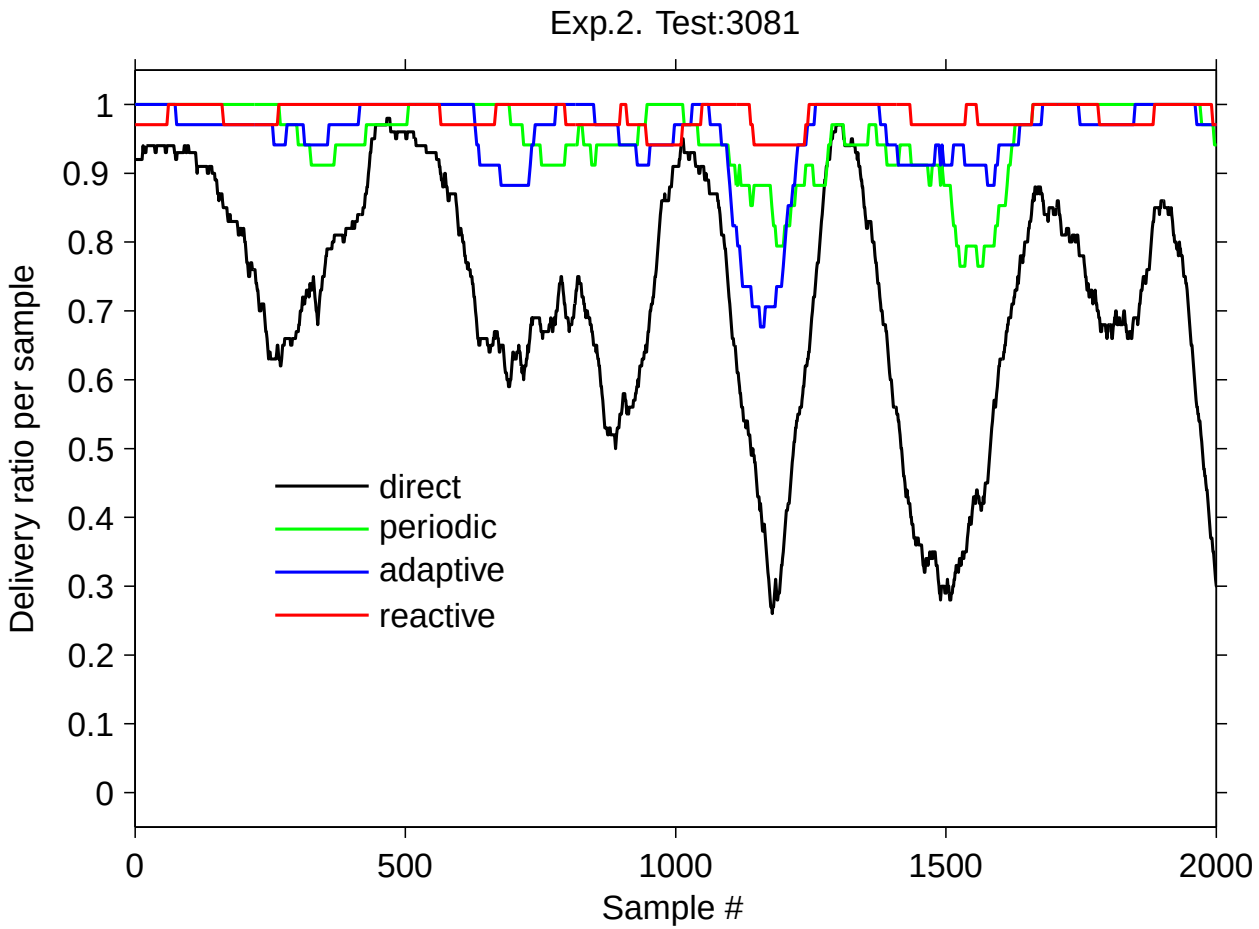
Adaptive selection: Error rate





Direct Comparison





Performance Results: Direct Comparison

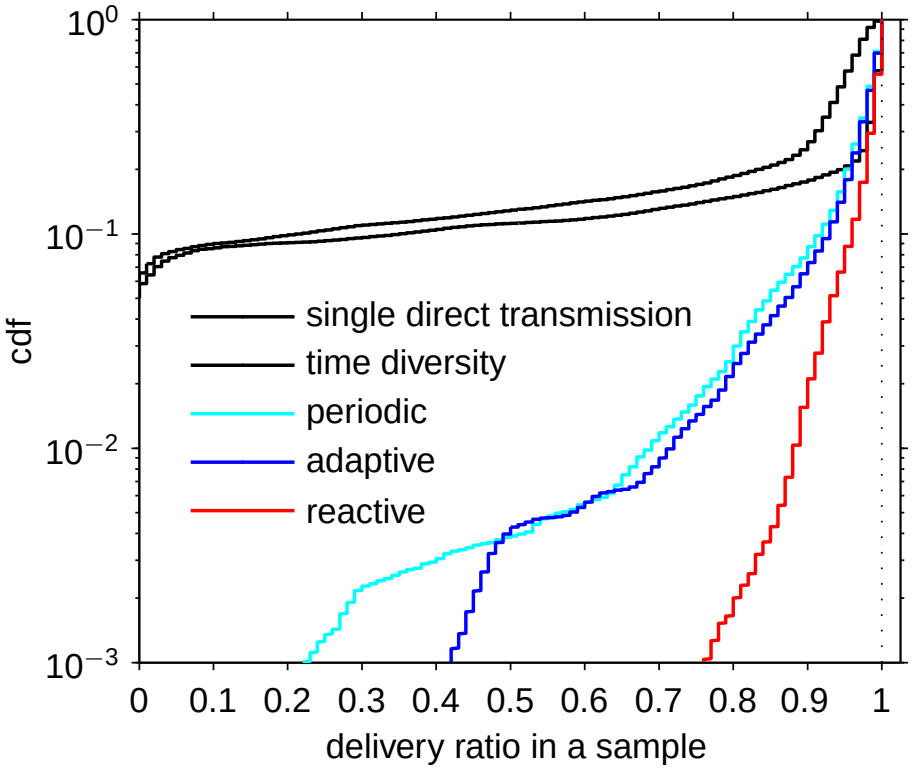
- Measurements on 3 days, each 12 hours.
- Total 810K DATA packets sent by source nodes
- 33K on each link and each scheme, over 6 hours time.
- Periodic selection: $T_{\text{sel}} = 400 \cdot 160\,ms = 64sec$
- Adaptive selection: $W_{\text{a}} = 100$, $\varepsilon_{\text{a}} = 0.1$

Table: Mean Results over the Network

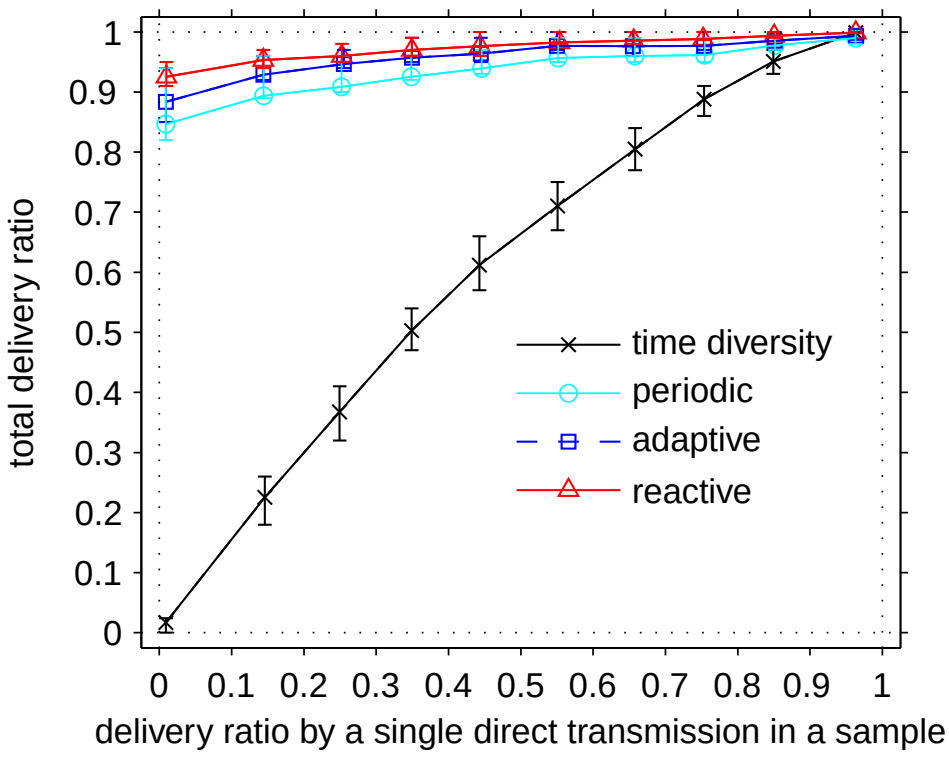
	direct	time div.	periodic	adaptive	reactive
delivery ratio, %	81.2	85.7	96.9	97.9	98.9
selections per 100 pkts	-	-	1.08	1.11	22.7
number of candidates	-	-	3.69	3.86	3.43
selection success, %	-	-	94	91	92
relaying success,%	-	-	78	82	95

Performance Results: Direct Comparison

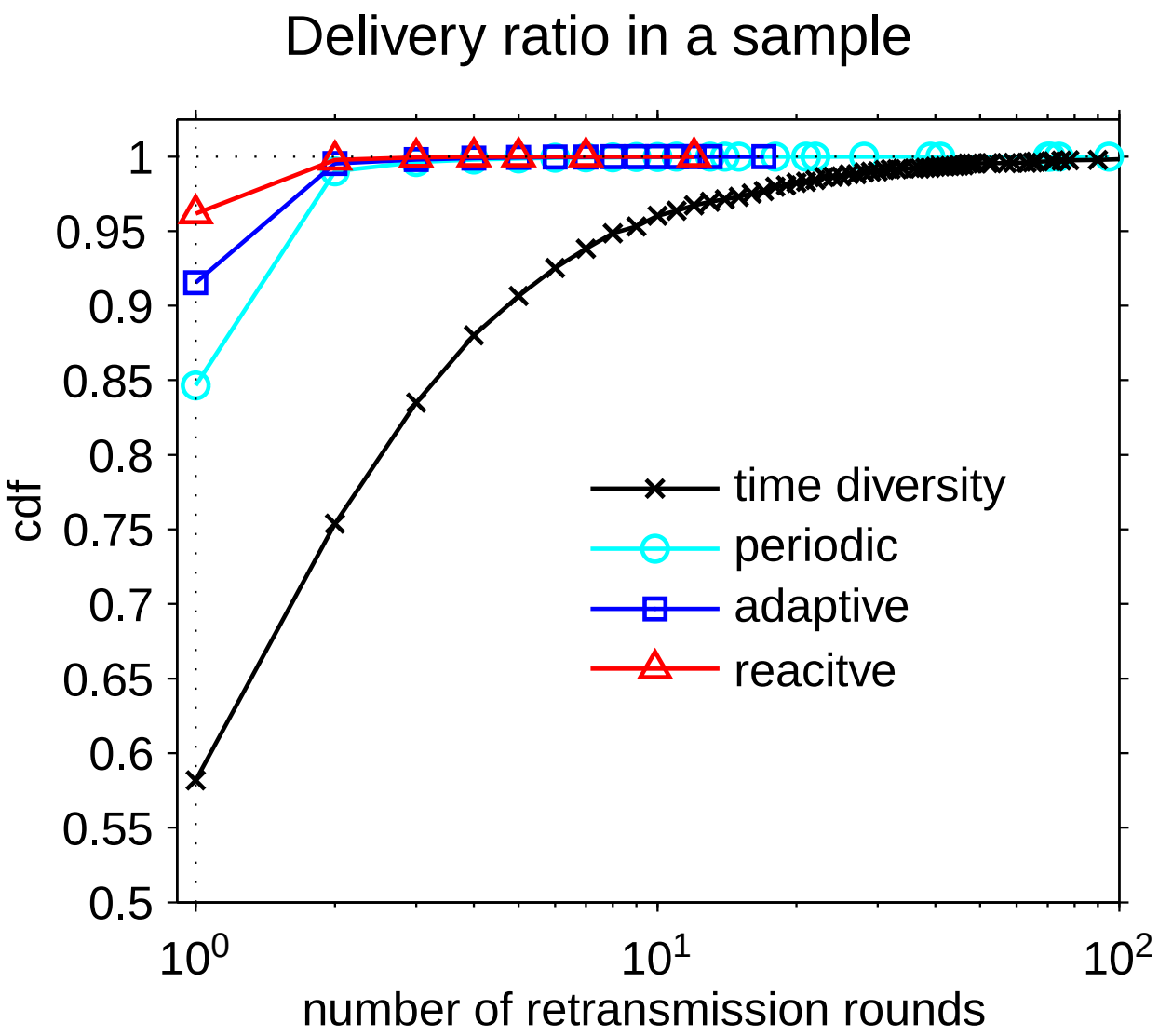
Delivery ratio in a sample



Selections in a sample



Performance Results: Direct Comparison



Conclusions

1. Cooperative relaying provides up to 99% delivery ratio
2. Short-term outages are also avoided
3. Adaptive selection provides best tradeoff between delivery ratio and selections overhead

Publications

- N. Marchenko, et al.
  An Experimental Study of Selective Cooperative Relaying in Industrial Wireless Networks. Under review in *IEEE Trans. Industrial Informatics*, 2013.
- T. Andre, et al. *WiNMee* Workshop, May 2013.
- T. Andre, et al. *GLOBECOM'12*.

Finally the Final Slide

Thank You for Your Attention!