NoSE: Efficient Maintenance and Initialization of Wireless Sensor Networks

Andreas Meier a.meier@tik.ee.ethz.ch

joint work with

Matthias Woehrle, Mischa Weise, Jan Beutel, Lothar Thiele

Computer Engineering and Networks Laboratory, ETH Zurich

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

NCCR MICS
National Competence Center in Research
Mobile Information and Communication Systems

FNSNF
Fonds National Suisse
Schweizerischer Nationalfonds
Fondo Nazionale Svizzero
Swiss National Science Foundation

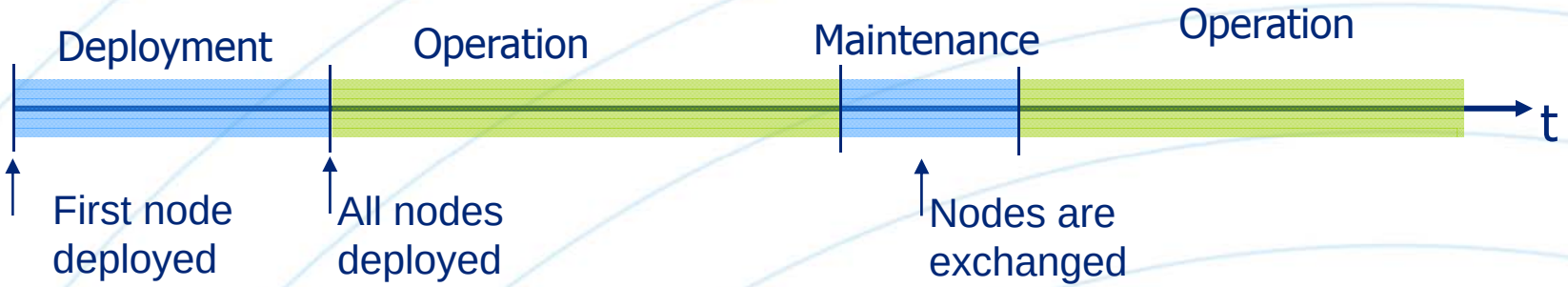
Deployment and maintenance of WSNs

- Deploying sensor nodes in a harsh environment
  - It takes a day to deploy a single sensor

- Large-scale deployments
  - Deploying dozens of nodes takes days
  - Sensors are replaced or added during operation

Motivation – WSN lifecycle

- The operation is discontinued by maintenance phases
  - Initial deployment can require extended time
  - Replacement of nodes during operation

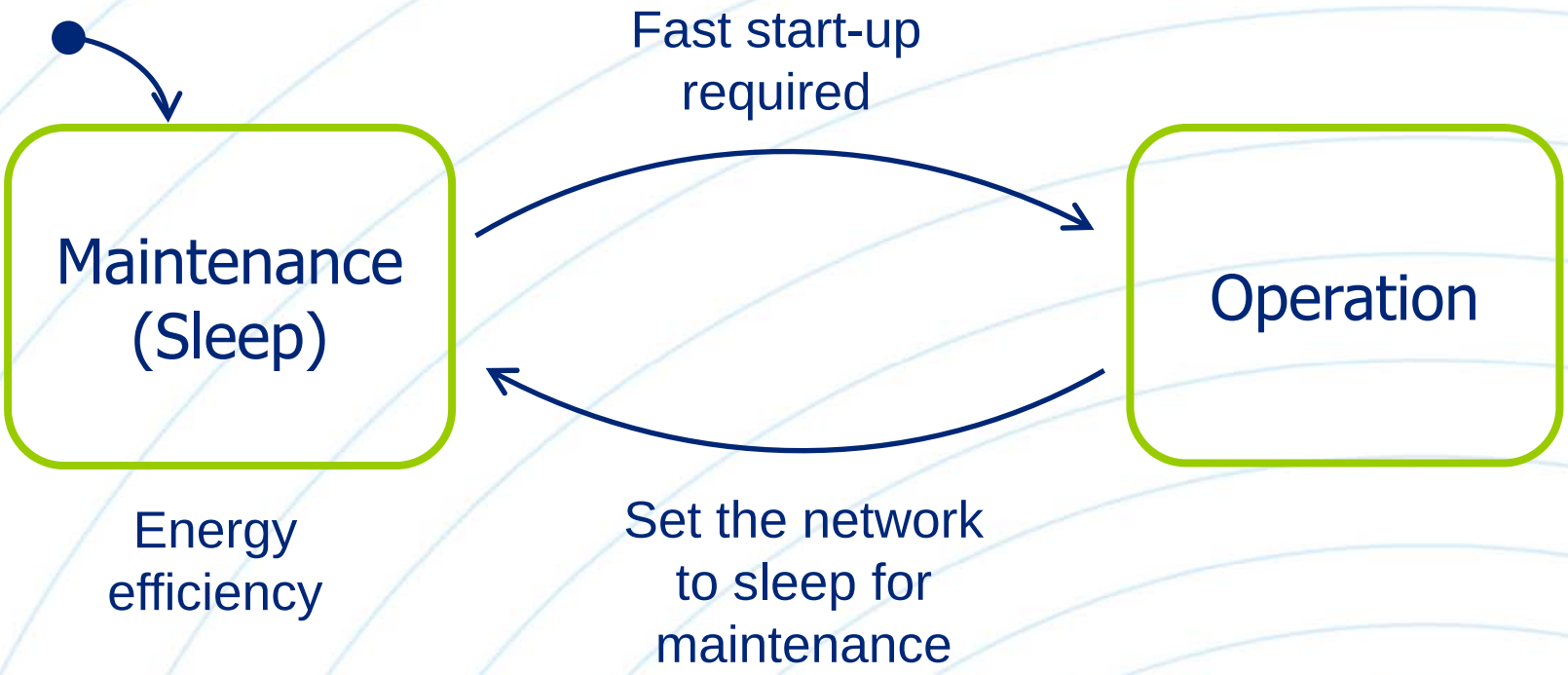


- During maintenance, the topology is likely to change
  - Nodes are removed, the sink might be temporarily switched off

- Protocols are optimized for the operation
  - Resources are wasted during maintenance tasks

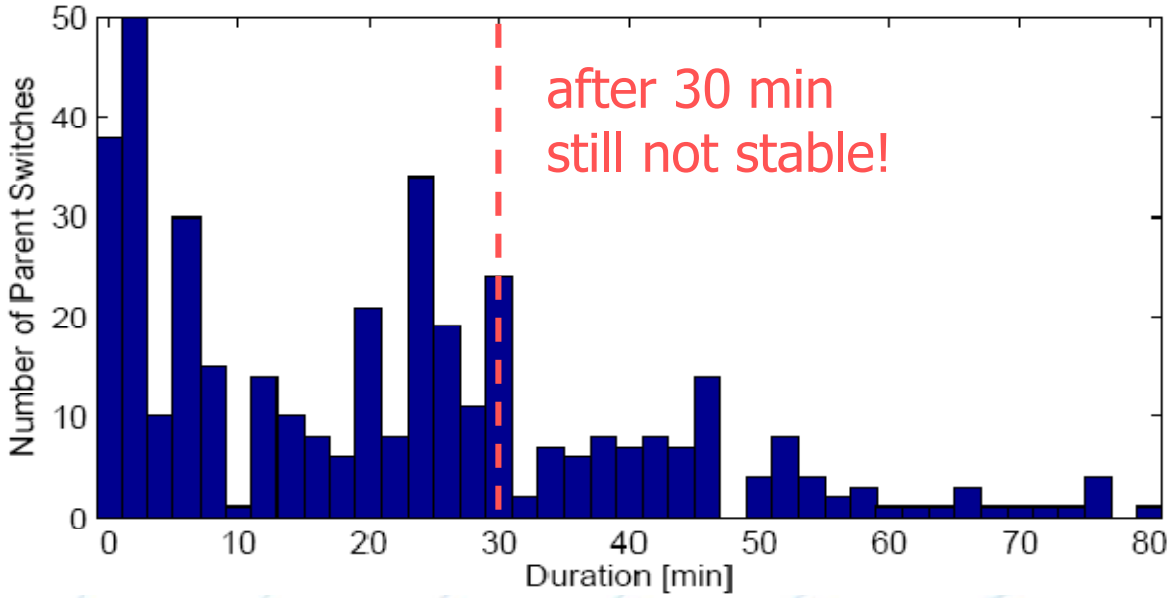
NoSE protocol stack for maintenance and initialization

- Switch between operational and maintenance mode



Initialization is crucial after maintenance/deployment

- Check for network validity after maintenance task
  - Fast start-up and stabilization of topology preferred



CTP* on a
25-node testbed

- No statistical information on the link quality available at the beginning

CTP*: Low-power implementation of CTP protocol [Lim et. al, EWSN'09]

Requirements for a maintenance and initialization protocol

1. Energy efficiency vs. responsiveness
   - Nodes can look aggressively for new neighbors (waste energy)
   - Reduced signaling scheme decreases responsiveness
2. Neighbor discovery and link assessment
   - No statistical information on the link quality available when selecting a new neighbor
3. Integration into protocol stack

Related work – Focus on initialization

- Birthday Protocol
  M. J. McGlynn and S. A. Borbash, **Birthday protocols for low energy deployment and flexible neighbor discovery in ad hoc wireless networks**, MobiHoc 2001.
  - Energy efficient sleep phase, exhaustive neighbor search
  - Requires 2nd protocol stack, no link assessment

- Clustered approaches
  F. Kuhn, T. Moscibroda, and R. Wattenhofer, **Initializing newly deployed ad hoc and sensor networks,** MobiCom 2004.
  T. Moscibroda, P. von Rickenbach, and R. Wattenhofer, **Analyzing the energy-latency trade-off during the deployment of sensor networks,** Infocom 2006.
  - Set up cluster for an optimized initialization process
  - Rather complex, require 2nd protocol stack

Related work – Focus on initialization

- Birthday Protocol

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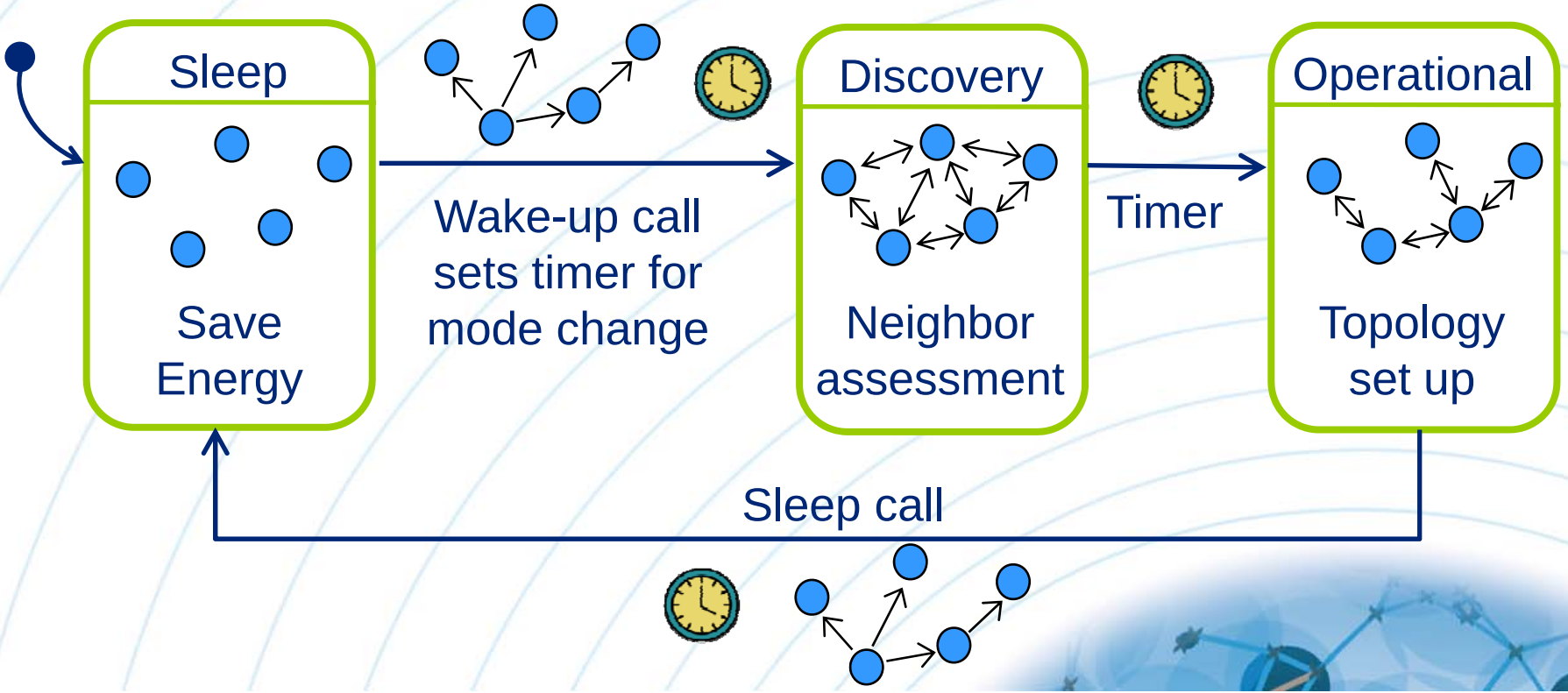
NoSE protocol enhancement:

- Energy efficiency during maintenance
- Exhaustive neighbor search and link assessment for a fast start up of the network
- Integrates well into protocol stack

NoSE in detail: Switch between sleep and operation

- Sleep: Listening only for saving energy
- Discovery: Exhaustive neighbor search & link assessment
- Operational: Set up topology and run application



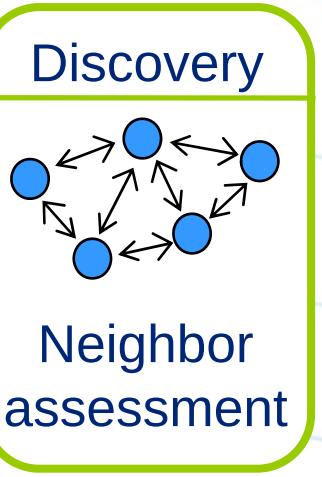
Discovery: Find all neighbors and assess link qualities

- Discovery has a fixed duration T_D

- Neighbor search
  - All nodes broadcast N messages
  - Count received broadcasts from each neighbor
  - Packet reception rate: known number of packets

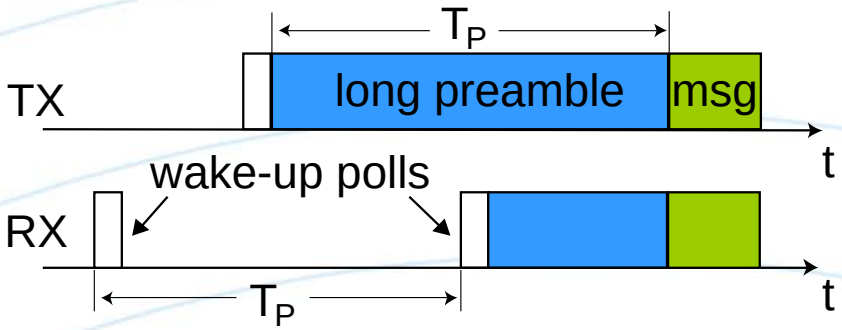
- Minimize internal interference
  - Required for valid link-quality estimation

- Provide a well assessed neighbor table for a fast startup of the network

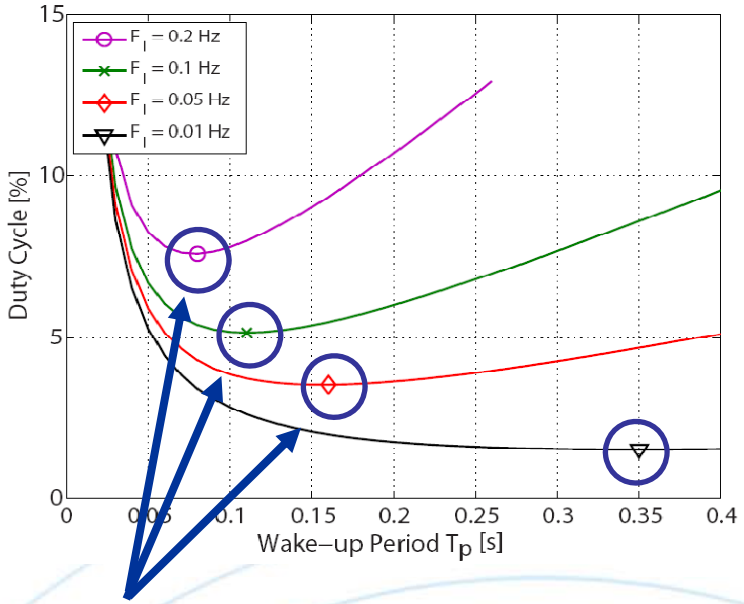


Medium Access Control (MAC) – Assume LPL-based protocol

- Low-power-listening (LPL)
  - B-MAC, WiseMAC, X-MAC
- Receiver (RX)
  - Regular channel polls every T_P
- Sender (TX)
  - Send long preamble to ensure that the receiver is listening
- Wake-up period T_P can be optimized for expected traffic



LPL scheme: [IEEE Micro Vol. 22]



LPL-MAC: The optimal wake-up period depends on traffic

Set MAC polling period according to current phase

Sleep

Sleep phase: save energy

- Long wake-up period (e.g., T_P = 1000 ms)

Disco-very

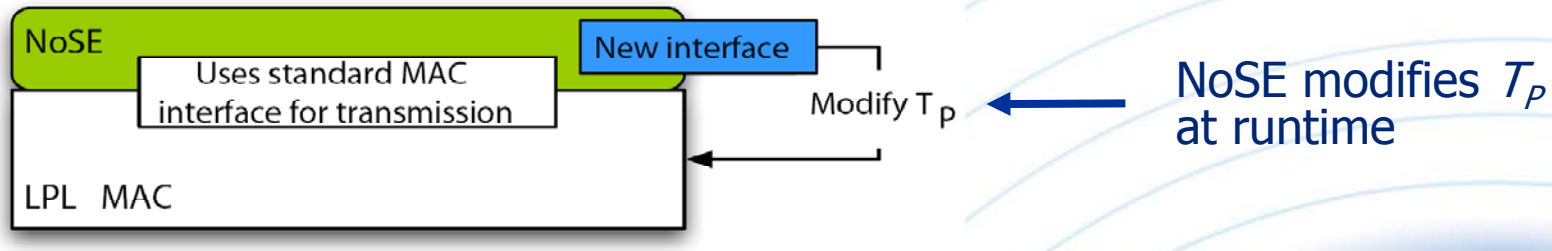
Discovery phase: speed and bandwidth

- Highly reactive (e.g., T_P = 30 ms)

Opera-tional

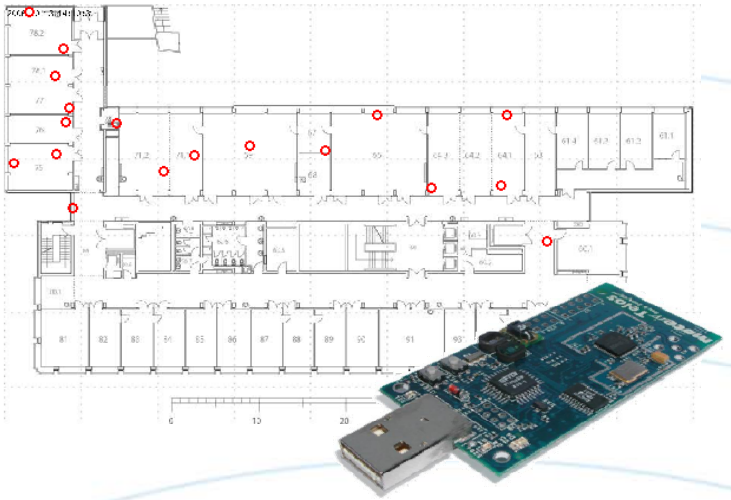
Operational phase: optimize for expected traffic

- NoSE allows to change the wake-up period at runtime (e.g., T_P = 300 ms)

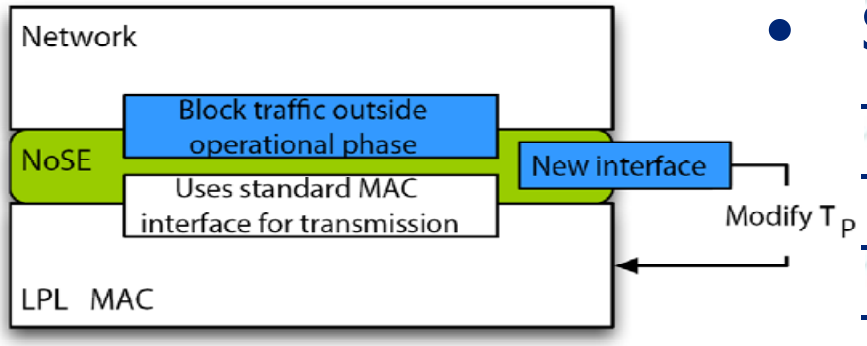


Evaluation: Testbed and simulation

- Testbed
  - Real indoor deployment (25 nodes)
  - Tmote Sky, CC2420, 2.4 GHz
  - TinyOS 2.x LPL stack [TEP126]
  - Birthday Protocol reference implementation



Protocol stack integration:



- Simulation – Castalia 1.3
  - Based on Omnet++
  - Realistic channel model [Zuniga2004]
  - Grid topology plus displacement
  - 160 nodes with varying node density

Evaluation: Testbed and simulation

- Testbed
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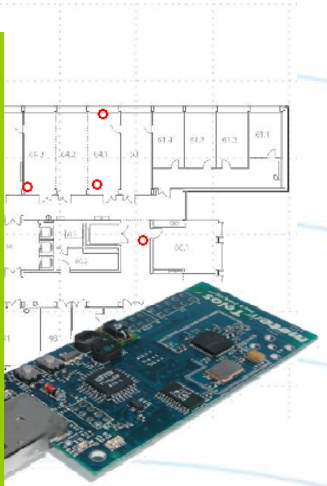
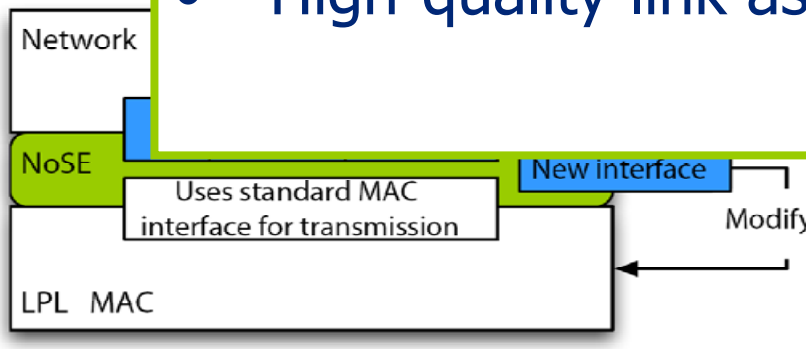


Evaluation criteria:

- Energy efficiency during maintenance
- Exhaustive neighbor search
- High-quality link assessment

Protocc



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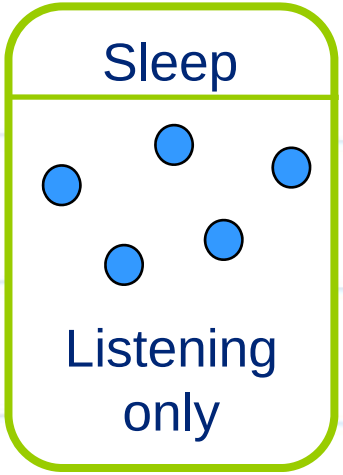
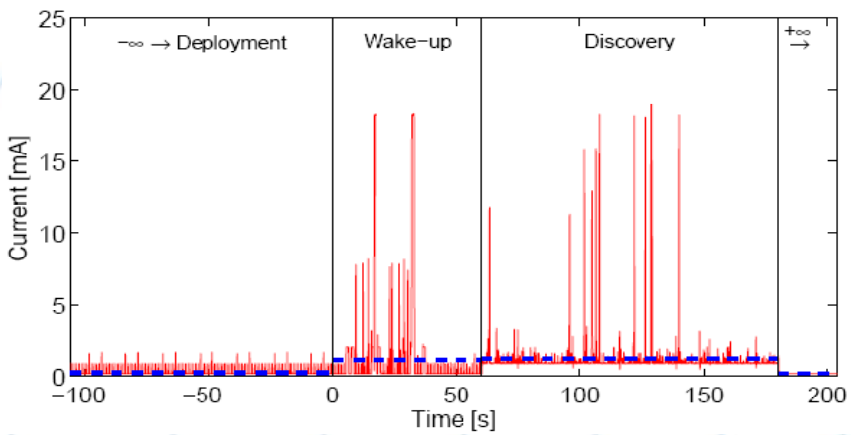
- Realistic channel model [Zuniga2004]
- Grid topology plus displacement
- 160 nodes with varying node density

Sleep phase: NoSE saves energy (30% and more savings)

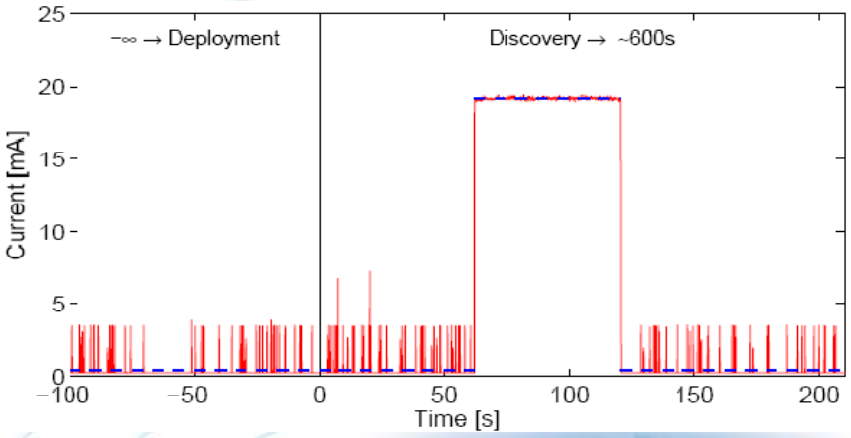
- NoSE benefits from long polling period
  - 47 mAh over 7 days
- Birthday Protocol listens into long slots
  - 69 mAh over 7 days
- CTP* sends periodic beacons
  - 115 mAh over 7 days



NoSE power trace

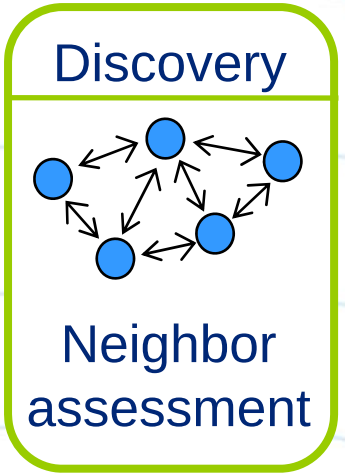


Birthday Protocol power trace



Neighbor discovery: NoSE vs. Birthday Protocol (BP)

- Protocol integration
  - NoSE: synchronous and bounded discovery time
  - BP: requires dedicated radio stack



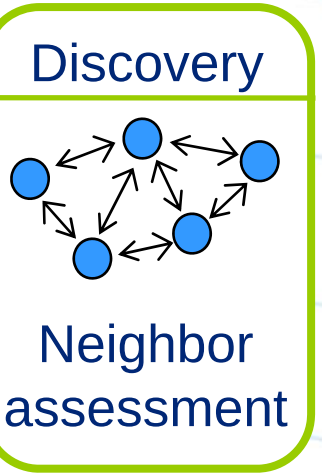
- Successful neighbor discovery
  - Both protocols find most high-quality links

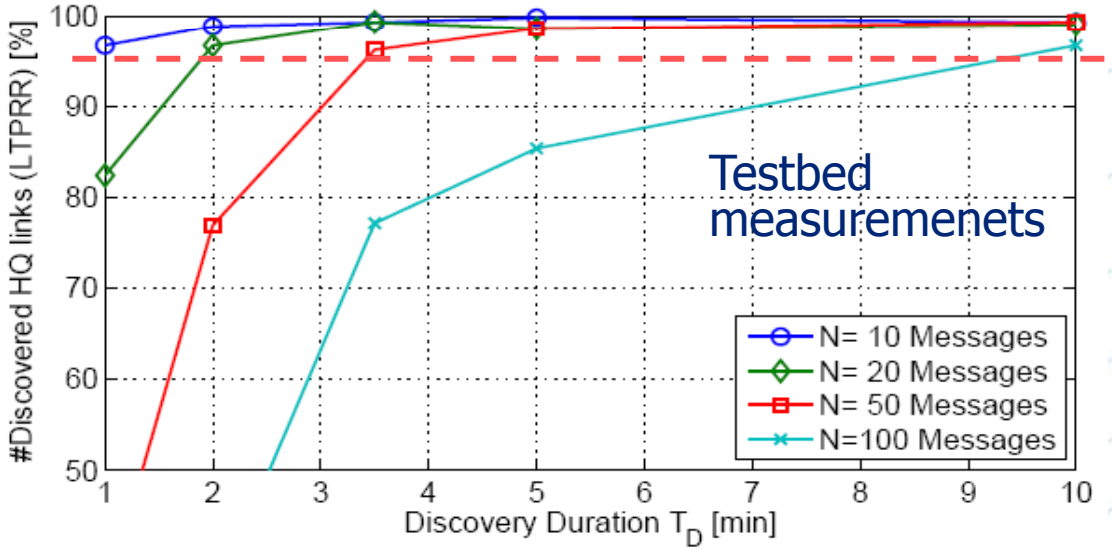
Link Quality	≥ 95%	95 - 85%	85 - 50%	≤ 50%
# links	155	45	42	75
NoSE	97.8%	88.8%	80.8%	59.3%
Birthday	97.0%	91.1%	82.5%	70.4%
	preferred		unwanted	

Poorly connected neighbors motivate the link assessment of NoSE

NoSE Discovery: Link assessment quality

- Minimize internal interference
  - Clear channel assessment
  - Limit channel utilization: $C_U = N(L+1)\ T_P / T_D$
- Testbed and simulation suggest: $C_U \leq 0.2$
  - Parameterize discovery accordingly





95% of the links are assessed correctly

NoSE Discovery: Link assessment quality

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  - Clear channel assessment
  - Limit channel utilization: $C_U = N(L+1)\ T_P / T_D$
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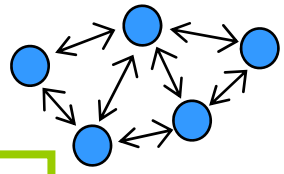
Discovery



Neighbor
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- NoSE provides a well assessed neighbor table in just 2 minutes from sleep
- The subsequent operation benefits from the well assessed neighborhood

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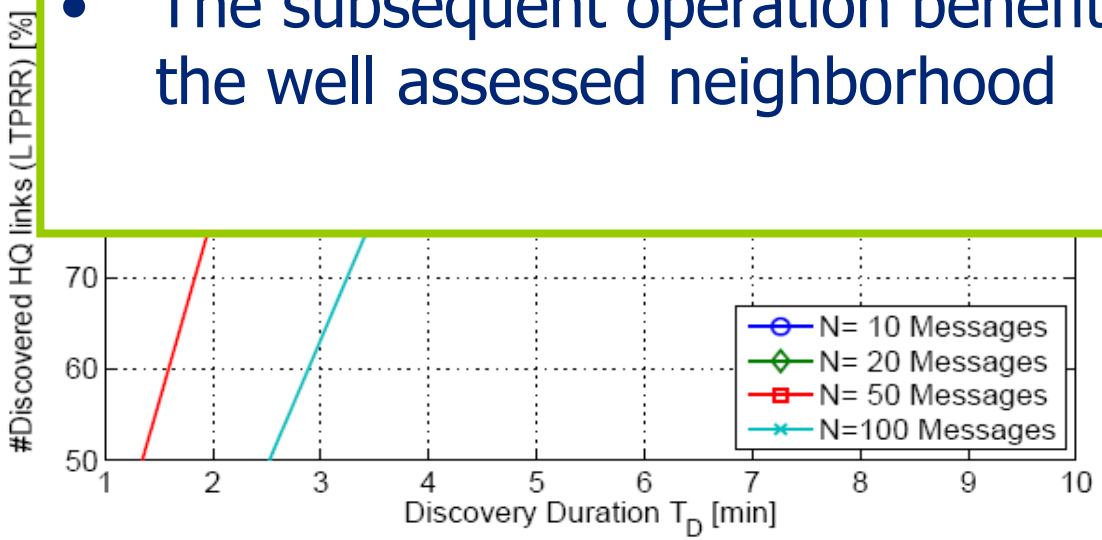
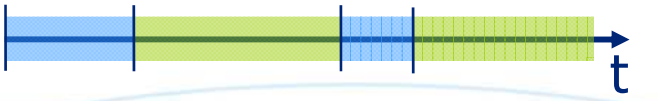


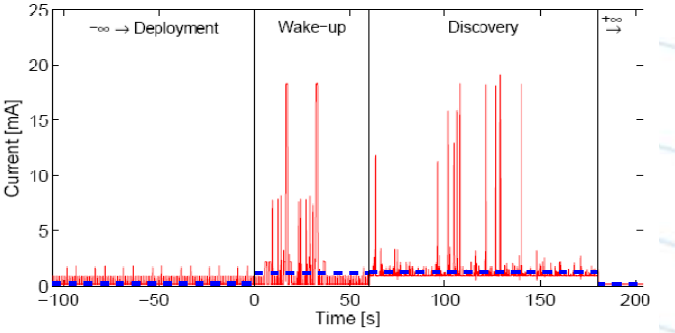
Conclusion

- Maintenance and initialization are important phases of the WSN Lifecycle



- NoSE protocol enhancement
  - Switch between sleep and operation
  - Perform neighbor assessment

- NoSE evaluation
  - Use resources when required
  - Neighbor search with link assessment provides a solid basis for the operation
  - Usable with all LPL MAC protocols



Andreas Meier: www.tik.ee.ethz.ch/~andreame/