Low Power, Low Delay: Opportunistic Routing meets Duty Cycling

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Unicast Routing in Duty-Cycled WSNs

- Routing protocol: selects next hop
- MAC: wait for next hop to wakeup
  - Duty cycling: ensures lifetime
  - Assume: no synchronization: wakeups not aligned
Unicast Routing in Duty-Cycled WSNs

- Routing protocol: select next hop
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Our Approach: Opportunistic Forwarding

Forwarder: The node that
1. wakes up first,
2. successfully receives the packet,
3. provides routing progress.
Expected Benefits

Compared to traditional unicast routing

• Energy: Less transmissions ➔ less energy
• Delay: Less transmissions ➔ less delay
• Resilience
  – Not bound to single forwarder
  – Increased resilience to link dynamics / churn
Outline

• Motivation and basic concept
• System design
• Evaluation
• Conclusion
System Design

• Anycast routing metric
  – Radio-on time as metric

• Unique forwarder selection
  – Avoid duplicates

• Link estimation and neighbor discovery
  – Tailored to opportunistic routing: overhearing
Routing Metric in a DODAG

• Topology: DODAG
  – Destination Oriented Directed Acyclic Graph
  – Per packet dynamics

• Need for routing metric
  – Builds DODAG: Loop free
  – Energy as metric: key in duty-cycled settings
EDC: Expected Duty Cycled Wakeups

- Goal: Minimize energy, delay
  - Minimize “radio-on time”
  - Named EDC: Expected Duty Cycled Wakeups
EDC: Expected Duty Cycled Wakeups

• Parent / forwarder set
  – Use more neighbors
    • Reduce time until one wakes up
  – Too many neighbors
    • Harm overall progress
    • Some neighbors provide less progress than others
EDC: Expected Duty Cycled Wakeups

• Parent set of a node
  – Subset of neighbors
  – Minimal radio-on time

• EDC
  – Avg. time to forward a packet
  – Avg. EDC of the parent set
    • Weighted by link quality

• EDC: tailoring of ETX
  – To anycast
  – To radio-on time

$$EDC = \frac{1}{\sum_{i \in P} PRR_i} + \frac{\sum_{i \in P} EDC_i PRR_i}{\sum_{i \in P} PRR_i}$$

$P$: Parent Set
$PRR_i$: Packet Receive Ratio
Unique Forwarders

- Probability of duplicates
  - < 20% for 10 potential forwarders
- Allows lightweight approach
Unique Forwarders

• Avoid / detect duplicates
  – Duplicate acknowledgements
  – Detect duplicates during forwarding
    • While waiting for clear channel
  – Up stream: duplicate packet detection
    • Sequence numbers

• Evaluation:
  – Duplicate rate similar to unicast routing

Dup. data: Ack with 50%
Link Estimation

- Opportunistic routing
  - Hide failure of individual links
  - Increases resilience
    - Interference, fading, node failure, ...

- Link estimation tailoring
  - Temporally unavailable links
    - Keep in neighbor set
  - Remove after long-term failure

- Our approach: Overhearing
  - Data packet overhearing
  - Beaconing: Only when no parents
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Evaluation

• Implementation: Opportunistic Routing in WSNs (ORW)
  – TinyOS, default BoX-MAC

• Goals (compared to unicast routing, CTP)
  – Improve on energy, delay, resilience
  – Achieve similar reliability

• Scenarios
  – Two testbeds:
    • Indriya (Singapore): 120 nodes
    • Twist (Berlin): 96 nodes
  – Two TX power levels each

Today only: Indriya
0 dBm TX power
Delay and Energy

Energy: avg. -50%
  Doubles life time

Delay: -30% to -90%
  Depending on deployment

Tx: Slightly higher

Indriya:
- 3 story office building
- At National University of Singapore (NUS)
- 120 sensor nodes
Wakeup Interval

- ORW: Highest benefits at low wakeup rates
Churn and Stability

Churn: ORW stable (duty cycle, delay)

ORW: sparse networks
Outline

• Motivation and basic concept
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Summary and Conclusion

• Opportunistic routing tailored to duty cycled WSNs
  – Forwarder: First awoken neighbor
    • that provides routing progress
    • and successfully receives packet

• Insights
  – Strong improvements: energy, delay, stability
Thanks! Questions?