Performance of Energy-Efficient TDMA Schemes in Data-Gathering Scenarios with Periodic Sources

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International Conference on Networked Sensing Systems
18th June, 2010

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Introduction

Scenario

Data-Gathering Application

- Large-scale sensor network
- Equally equipped nodes
- Periodic data collection
- Single sink
- Multi-hop environment
- Routing tree

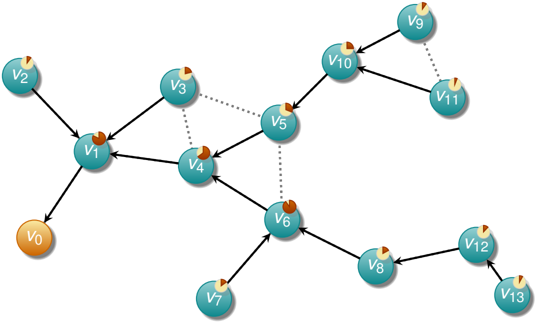
Application Cornerstones

Goals

- Reliable transportation
- Energy-efficiency
- Maximal net throughput

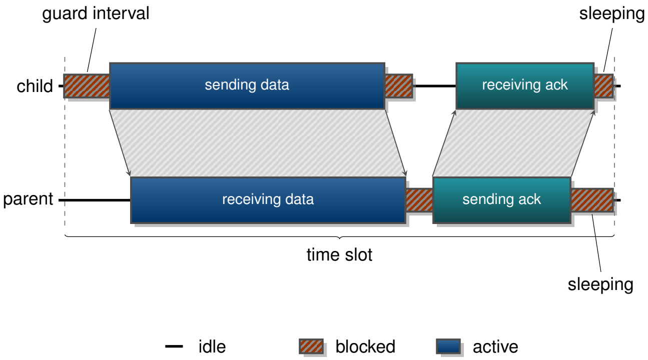
Strategies

- Hop-to-hop acknowledgments
- Flow control
- Exploit inherent tree pattern



Medium Access Control: TDMA

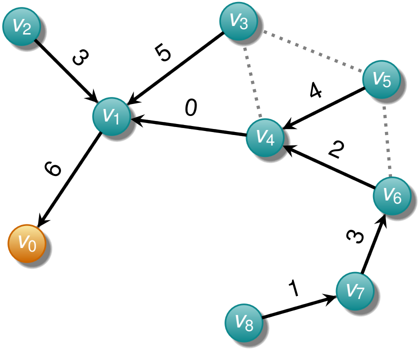
- Exclude packet collisions
- Enable high throughput
- Focus on energy-efficient send-receive scheduling
- Allow for reliable data delivery



Traditional Slot Assignment

Color Constraint Heuristic (CCH)

- One slot per node
- Minimize number of slots
- k-hop graph coloring
- Heuristic for quick slot assignment
- Decentralized approach available, but
  - complex slot assignment
  - prone to collisions
  - not optimized for tree routing



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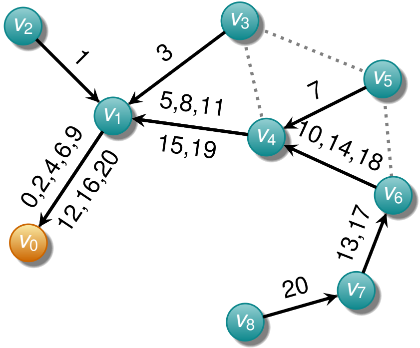
Spatial Path-based Reuse

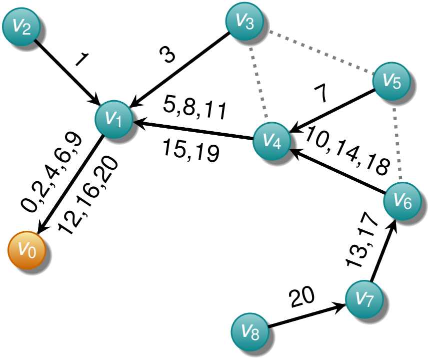
Traffic-Aware Slot Assignment

Spatial Path-Based Reuse (SPR$^+$)

- One slot per node and path
- Reuse on path after κ hops
- Staggering to avoid buffer congestion
- Ascending order of slots
- Slot assignment via double DFS



SPR$^+$ Assignment Example ($\kappa = 4$)



$$\mathcal{S}_i = \Big\{ s \;\Big|\; 1 \le k \le \kappa,\; 0 \le d < \mathbf{d}_i[k] : \\ s = \mathbf{o}_i[k] + k\,d + (-h_i) \bmod k \Big\}$$

▷ Math

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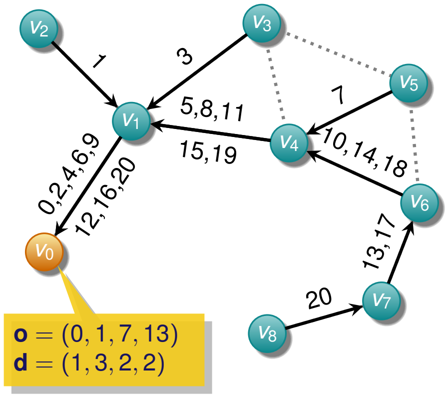

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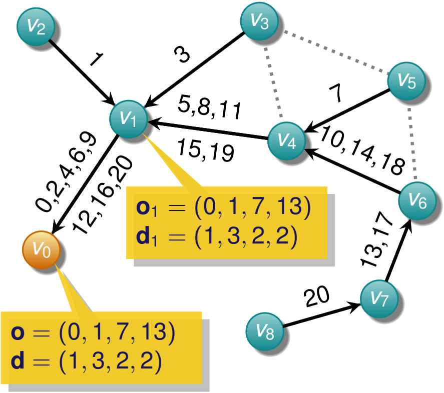

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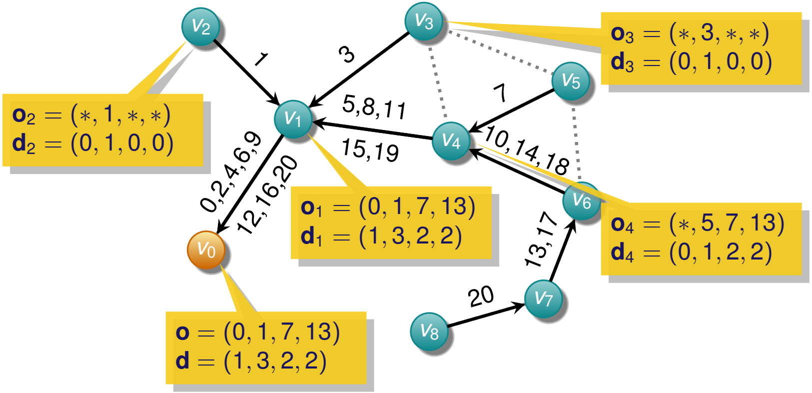

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▷ Math

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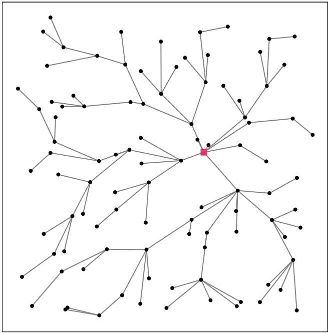
Evaluation

Evaluation Setup and Environment

Simulation Setup

- ns-2; two-ray ground
- Collisions via SINR
- Bandwidth 19.2 kbit/s
- 40 packets created per node, constant sampling rate



Environment

- Random topologies with given density
- Precalculated routing trees (BFS)
- Precalculated slot assignments

▷ Details

Data-Collection Strategies

On-demand forwarding

Nodes send data in their slots and wait to receive in the slots of their children.

Cyclic two-phase collection

Nodes perform forwarding only in periodical forwarding phases and keep the radio off otherwise.

Data-Collection Strategies

On-demand forwarding

Nodes send data in their slots and wait to receive in the slots of their children.

- ⊕ Quick data forwarding
  - responsive
  - low end-to-end delay
- ⊖ Idle listening
  - waste of energy
- ⊖ Impracticle in some scenarios

Cyclic two-phase collection

Nodes perform forwarding only in periodical forwarding phases and keep the radio off otherwise.

- ⊕ Efficient radio usage
  - switch off radio, if no data left
- ⊖ Large Latency
  - only applicable in delay-tolerant scenario
  - reduced sampling rate

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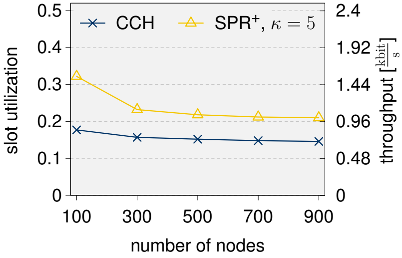
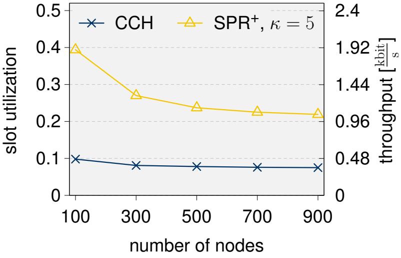
What is the achievable throughput?

Slot Utilization / Theoretical Throughput

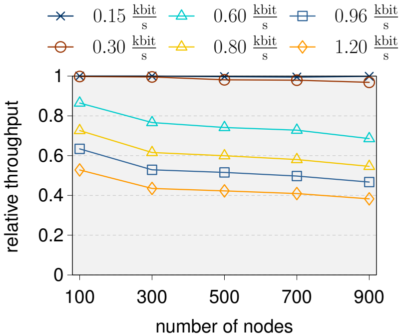


Density: 12



Density: 24

Relative On-Demand Throughput



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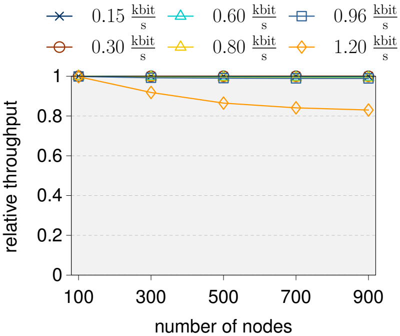
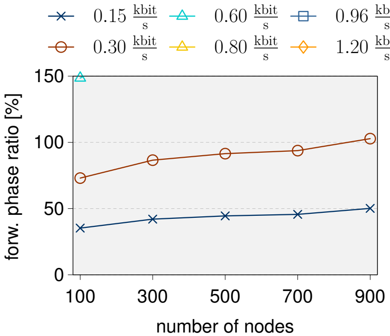
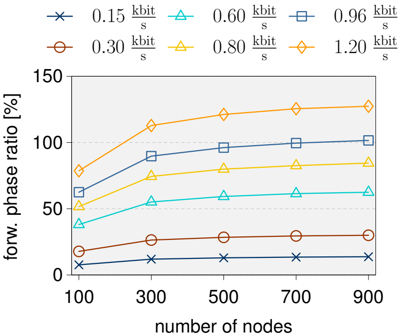


Spatial Path-based Reuse

Two-Phase Forwarding Share

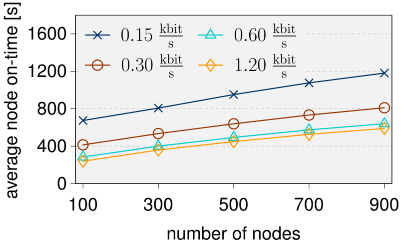


Traditional Slot Assignment

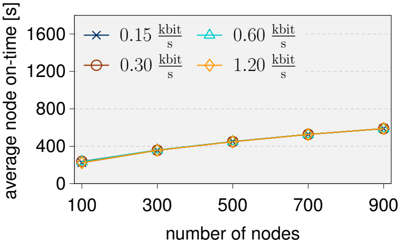


Spatial Path-based Reuse

SPR$^+$ Energy Consumption



On-Demand



Two-Phase

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Conclusion

Conclusion

- SPR^{+} combines the advantages of
  - slot reuse and
  - traffic-aware slot assignment
- SPR^{+} achieves
  - the highest net throughput among the competitors
  - while avoiding buffer congestion
  - and being highly energy efficient
- Two-Phase data collection
  - reduces energy consumption for low sampling rates
  - but introduces heavy packet delay

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SPR$^+$ Calculation

▷ Back

$$\mathcal{S}_i = \Big\{ s \;\Big|\; 1 \le k \le \kappa,\; 0 \le d < \mathbf{d}_i[k] : \\ s = \mathbf{o}_i[k] + k\,d + (-h_i) \bmod k \Big\}$$

Slots of v_4: $\mathbf{o}_4 = (*, 5, 7, 13)$, $\mathbf{d}_4 = (0, 1, 2, 2)$, $h_4 = 2$, $\kappa = 4$

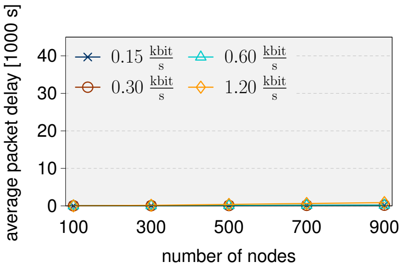
k	$\mathbf{o}_4[k]$	$+$	$k \cdot d$	$+$	$(-h_4) \bmod k$	$=$	$s \in \mathcal{S}_i$
1	$*$					$=$	$\varnothing$
2	5	$+$	$2 \cdot \{0\}$	$+$	$(-2) \bmod 2$	$=$	$\{5\}$
3	7	$+$	$3 \cdot \{0, 1\}$	$+$	$(-2) \bmod 3$	$=$	$\{8, 11\}$
4	13	$+$	$4 \cdot \{0, 1\}$	$+$	$(-2) \bmod 4$	$=$	$\{15, 19\}$

Setup Details

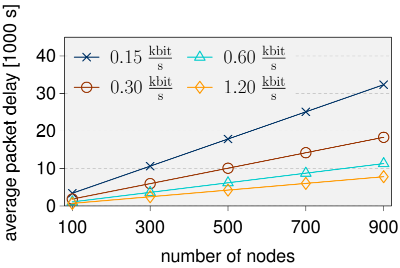
▷ Back

- 20-900 nodes
- Node densities: 6, 9, 12, 18, 24
- 50 topologies each
- Buffer size: 200 packets
- 240 bits data payload, slot length 50 ms (4.6 kbit/s net bandwidth)

SPR$^+$ Average Packet Delay



On-Demand



Two-Phase